

# Vessel traffic disrupts the foraging behavior of southern resident killer whales (*Orcinus spp.*)<sup>†</sup>

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**ABSTRACT:** Vessel traffic may have contributed to Southern Resident killer whales becoming endangered. To determine the importance of this threat, we measured behavior of Southern Residents in the presence and absence of vessels in 2003-2005 at two different sites along San Juan Island. We observed activity states of killer whale schools using scan sampling and collected information on the number of vessels present at various distances from each school. Transitions between activity states were significantly affected by vessel traffic, indicating a reduction in time spent foraging as was observed in Northern Resident killer whales in a previous study. If reduced foraging effort results in reduced prey capture, this would result in decreased energy acquisition. Each school was within 400m of a vessel most of the time during daylight hours from May through September. The high proportion of time Southern Resident killer whales spend in proximity to vessels raises the possibility that the short-term behavioral changes reported here can lead to biologically significant consequences.

**KEY WORDS:** whalewatching, killer whale, disturbance, behavioral disruption

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## INTRODUCTION

The Eastern North Pacific Southern Resident Stock of killer whales declined to fewer than 80 individuals in 2001, resulting in their listing as “Depleted” under the Marine Mammal Protection Act and “Endangered” under the U. S. and Washington State Endangered Species Acts, and Canada’s Species at Risk Act. The causes of this decline are uncertain, but many scientists consider a combination of reduction in prey resources, toxic chemicals, disturbance from vessel traffic, and other factors to have contributed (Bain *et al.* 2002, Wiles 2004, Krahn *et al.* 2002 and 2004, Federal Register 2004 and 2005, Killer Whale Recovery Team 2005).

Krahn *et al.* (2004) noted that the Southern Resident killer whale population increased at a normal rate in the late 1980’s (~3% / year). Growth began to slow in the early 1990’s and was followed by a decline of 20% from 1996 to 2001. This stock is composed of three social units (pods). J and K pods exhibited little change in number during this period, in contrast to the expected growth. In contrast, L Pod not only failed to grow, but it declined and this decline resulted in the decline in number of the entire population. Factors in the inshore waters of

1 Washington and British Columbia, such as declines in prey abundance, toxins and vessel traffic  
2 may be responsible for the lack of growth in all three pods. Differences in usage patterns of the  
3 inshore waters among the different pods (Bigg *et al.* 1990, Olesiuk *et al.* 1990, Osborne 1999,  
4 Hauser *et al.* 2005 and 2006) may account for some of the additional decline experienced by L  
5 Pod alone, but factors external to these waters (regional differences in prey abundance [Protected  
6 Resources Division 2004], perhaps entanglement, and exposure to oil, among others) are likely  
7 to be of similar importance to factors in inshore waters.

8 Vessel traffic may have contributed to the decline through a variety of mechanisms.  
9 Collisions between vessels and killer whales occur occasionally in residents and other killer  
10 whales and result in injury or death (Visser 1999, Ford *et al.* 2000, G. M. Ellis pers. comm.).  
11 One collision was observed in Southern Residents in 2005 that resulted in injury (K. C. Balcomb  
12 pers. comm.). Chemicals such as unburned fuel and exhaust from vessels may contribute to toxin  
13 load. The presence of noise from vessels may contribute to stress (Romano *et al.* 2004). Noise  
14 from vessel traffic may mask echolocation signals (Bain and Dahlheim 1994) reducing foraging  
15 efficiency. Behavioral responses may result in increased energy expenditure, or disrupt feeding  
16 activity, which may reduce energy acquisition (Bain 2002). Energetic mechanisms for impact  
17 are of particular concern, since Southern Resident Killer Whales may be food limited (Ford *et al.*  
18 2005).

19 Repeated disturbance of wild animals is implicated as a factor reducing the quality of life,  
20 foraging efficiency, fitness, or reproductive success of individual animals. Examples in the  
21 wildlife literature link anthropogenic disturbance to changes in foraging behavior (*e.g.*, Galicia  
22 and Baldassarre 1997), reproductive success (*e.g.*, Safina and Burger 1983), and mating system  
23 and social structure (*e.g.*, Lacy and Martins 2003). These in turn, either singly or synergistically,  
24 could influence population dynamics. Effects of vessel traffic have been studied in a range of  
25 cetacean species, including *Cephalorhynchus*: Bejder *et al.* (1999); *Delphinus*: Constantine  
26 (1997); *Eschrichtius*: Jones (1988), Duffus *et al.* (1998); *Globicephala*: Heimlich-Boran (1993),  
27 Heimlich-Boran *et al.* (1994); *Megaptera*: Corkeron (1995); *Orcinus*: Kruse (1991), Williams  
28 *et al.* (2002ab), Foote *et al.* (2004); *Physeter*: Fleming and Sarvas (1999); *Sousa*: Van Parijs and  
29 Corkeron (2001); *Stenella*: Angradi *et al.* (1993), Ritter (2003); *Tursiops*: Janik (1996), Allen  
30 and Read (2000), Nowacek *et al.* (2001), Constantine (2001), Lusseau (2003), Bejder *et al.*  
31 (2006). Effects vary within and between species, and included changes in respiration patterns,  
32 surface active behaviors, swimming velocity, vocal behavior, activity state, inter-individual  
33 spacing, wake riding, approach and avoidance, and displacement from habitat. Collisions may  
34 result in injury or death (Wells and Scott 1997, Laist *et al.* 2001). Kruse (1991) and Williams *et al.*  
35 (2002ab) demonstrated short-term behavioral changes in Northern Resident killer whales  
36 associated with vessel traffic. Kruse (1991) found Northern Residents increased swimming  
37 speed as vessel number increased. Nowacek *et al.* (2001) found *Tursiops* also increased  
38 swimming speed in the presence of vessels. Williams *et al.* (2002ab) found Northern Residents  
39 swam in less predictable paths in the presence of vessels, and *Tursiops* exhibit similar behavior  
40 (Nowacek *et al.* 2001). Williams *et al.* (2006) found Northern Residents were less likely to  
41 forage in the presence vessels, and *Tursiops* exhibit the same change in parts of their range  
42 (Allen and Read 2000). Adimey (1995) found percussive behavior of Northern Residents was  
43 inhibited in the presence of vessels, though Williams *et al.* (2002ab) found no significant  
44 differences. However, for Southern Resident killer whales in the waters of Washington and  
45 British Columbia, even subtle behavioral responses to boats have not been reported in the

1 primary literature. This is a critical area of study because the San Juan and Gulf Islands are a  
2 region with high vessel traffic.

3 In this region, the commercial whale watching day runs from about 0900-2100 in summer,  
4 and until sunset in spring and early fall. In addition to commercial whale watching vessels, other  
5 vessels are also in contact with whales throughout the day. Early in the morning (sunrise),  
6 whales are approached by recreational vessels transiting the area, scientific research vessels, and  
7 sport fishing vessels. For part of the season, seiners and gill netters are also present. In the  
8 middle of the day, these boats are joined by the commercial whale watching fleet, and a few of  
9 these commercial whale watching vessels remain with whales until near sunset. Homeland  
10 security vessels are on the water much of the day, and sometimes approach whales or vessels  
11 near whales (pers. obs.). Further, commercial freight traffic is intermittently present 24 hours a  
12 day. Due to the variety of vessels observed in the presence of whales, the term whale watching  
13 as used in this paper refers to all whale-oriented vessel traffic, regardless of whether the vessels  
14 are commercial whale watching vessels or not. Because these whales are in the presence of  
15 vessels, including those not focused on whale watching, during much of the day, the potential for  
16 cumulative effects makes it important to investigate whether the behavior of killer whales is  
17 altered in the presence of vessels (Bain *et al.* 2006). This study addresses relationships between  
18 vessel activity and Southern Resident killer whale behavior.  
19  
20

## 21 MATERIALS AND METHODS

22

23 **Study areas.** From 28 July to 30 September 2003, 1 May to 31 August 2004, and 15 May to  
24 31 July 2005, a land-based team of observers monitored behavior of whales and activity of boats  
25 from two study sites. One site (hereafter referred to as the North Site) was located at 48° 30.561'  
26 N, 123° 8.494' W at an altitude of approximately 99m above mean lower low water. The South  
27 site was located at Mt. Finlayson (48° 27.421' N, 122° 59.401' W) at a height of 72m and the  
28 view of the eastern portion of Juan de Fuca Strait was unobstructed. Whales have been reported  
29 to use this area heavily for foraging, whereas the North site appeared to be used primarily for  
30 travel and socializing (Felleman *et al.* 1991, Hoelzel 1993, Heimlich-Boran 1988). Together,  
31 these sites were chosen to maximize sample size and to allow the behavioral observations to  
32 include the entire repertoire of the population.

33 **Behavioral sampling.** During the study periods 238 days were spent on effort of which 128  
34 days were spent with whales. During that time scan sampling was conducted at 15 minute  
35 intervals to characterize subgroup size (ranging from one to the size of the school in the study  
36 area), activity state, and the number of vessels within 100, 400 and 1000 meters. The activity  
37 state sub-categories (1-9, Table 1) were combined to match the categories described by Ford *et*  
38 *al.* (2000). The resulting activity states were cumulatively inclusive and mutually exclusive. A  
39 scanned group was defined as animals within 10 body lengths of one another at the time of a  
40 scan-sample observation, using a chain rule (Connor *et al.* 2000). The identity of group members  
41 was recorded but when individuals were too far away to be identified, their identity was assigned  
42 to categories based on size (e.g., calf, juvenile, medium sized whales [large juveniles or adult  
43 females], subadult male, adult male). When group composition remained unambiguous over  
44 time, but individual identity was unknown within the group, groups were given arbitrary labels  
45 (a, b, c...) in order to track their activity over time.

1 **Vessel traffic sampling.** Vessels were counted separately depending on whether or not they  
2 were engaged in whale watching, although commercial and recreational whale watching boats  
3 were not distinguished in scan sample counts. Distances were estimated by eye, and checked  
4 against measurements with a theodolite when possible to improve observer reliability with  
5 experience (Bain et al. submitted). Sequential observation of focal groups allows *estimating* the  
6 probability of animals' switching from one activity state to another as a function of vessel traffic.

7 **Analysing scan-sampling data from focal groups.** Understanding the recurrence of activity  
8 states allows one to understand the likelihood that a state will be disrupted by, in our case, boat  
9 presence. The data were divided into a series of scan samples of a focal group which were treated  
10 as samples of activity state sequences. A sequence stopped when sampling stopped on a given  
11 day or when a focal group ceased to exist due to changes in group membership (through fission  
12 or fusion with other individuals), or because they left the study area. For the purposes of this  
13 study, we were only interested in understanding the change in the likelihood that when a group  
14 was in State A that they would be in State B 15 minutes later (i.e., at the next scan). These are  
15 called first-order transitions in activity. This sequence of discrete time samples could be treated  
16 as a Markov chain (Lusseau 2003, 2004) because it was ergodic. A time series is ergodic when  
17 transitions between all states are possible; in this study a group could transition from any state to  
18 another (there was no biological constraint preventing whales from switching between each state  
19 and the others). The other requirement for a time series to be ergodic is that there cannot be  
20 negative values for transition probabilities; since the sequence was bounded by time, sequences  
21 could only move in one way; that is forward in time, and therefore no negative values could be  
22 expected.

23 To understand the effect of boat interactions on the state transitions, the number of vessels in  
24 the field of view was counted, as these vessels may have contributed to ambient noise in the area  
25 (Bain, pers. obs.). The number of vessels within 100 m, 400m, and 1000m of subgroups were  
26 also counted. Distances were estimated visually as range rings around individuals or groups, but  
27 checked with a theodolite when possible (Bain et al. submitted). When the measured distance  
28 varied from the boundary distance (the boundaries marking the 100, 400 or 1000m range rings)  
29 by more than 10%, observers consistently placed the vessel in the correct range ring. The  
30 numbers within specific distances were used as candidate explanatory covariates, to assess  
31 whether the probability of animals switching among activity states varied as a function of boat  
32 traffic. We therefore constructed a transition matrix, representing the probabilities for whales to  
33 be observed in a State  $i$  at time  $t$  and subsequently in State  $j$  at the next sampling event ( $t + 15$   
34 minutes):

35 
$$p_{ij} = \frac{e_{ij}}{\sum_k e_{ik}}$$
 where  $e_{ij}$  is the total number of times the transition was observed and  $\sum_k e_{ik}$  is

36 the total number of time State  $i$  was observed as the starting state.

37 This transition matrix is based on an ergodic time series which means that eigenanalysis of this  
38 matrix reveals several properties of activity states. Applying the Perron-Frobenius theorem we  
39 show that the transition matrix long-term behavior, *i.e.*, the amount of time that the whales spent  
40 in each activity state can be approximated by the left eigenvector of the dominant eigenvalue of  
41 the matrix (Lusseau 2003). Ultimately, this approach can be used to calculate stable, unbiased  
42 time-activity budgets. Further, reliance on transitions rather than individual scans helped control  
43 for possible effects of whale behavior on vessel behavior.



1 Due to small sample size the full interaction of the three independent variables could not be  
2 quantified (Table 2). This analysis reveals that three models provided more information on the  
3 data's variance (Figure 1). The null model (i.e. no effects from independent variables (PS,  
4 BYLP), the model considering a site effect (LPS, BYLP), and the model considering a boat  
5 effect (BPS, BYLP) all had lower Akaike Information Criteria (AIC) than the other models  
6 (Table 3) indicating that the null, site effect, and boat effect models were each plausible. In  
7 addition, adding a boat and site effect to the model provided significantly more explanation of  
8 the data variance (significant effects represented by stars on Figure 1, and see Table 3); the site  
9 effect being still significant after the year effect was taken into consideration. The significance of  
10 the terms being derived from the maximum likelihood estimates derived as described in the  
11 methods. From this analysis, we can conclude both that boat presence within 100m from the  
12 focal whales affected their behavioral transitions and that the whales behaved differently  
13 between the two sites, in contrast to the null model which was not rejected when considering the  
14 AIC value alone. The introduction of a boat effect explains significantly more variation in the  
15 dataset than the null model alone (as shown by the red star in Figure 1). We can therefore  
16 conclude that while intrinsic behavioral processes and data structure (the null model) as well as  
17 site are explaining some of the variation in the dataset, a boat effect cannot be excluded (because  
18 of the AIC weights) and should be included as well (because this parameter is providing  
19 significantly more information than the null model alone).

20 We calculated the activity budgets of the whales at both sites, as well as in the presence and  
21 absence of boats. Whales tended to spend significantly more time traveling and less time  
22 foraging when boats were present within 100m than when they were absent within 100m (Figure  
23 2a, all data pooled with site effect ignored). The difference in activity budgets between both sites  
24 only involved socializing (Figure 2b, all data pooled with boat effect ignored). Whales spent  
25 significantly more time socializing at the north site.

### 26 27 **The influence of pod identity** 28

29 The southern resident community of killer whales is composed of three pods (J, K, and L),  
30 which do not spend the same amount of time within Puget Sound (Ford et al. 2000). This may  
31 result in differences in the cumulative exposure of each pod to whale watching and therefore  
32 may lead to variation in the way these pods respond to boat presence. We therefore assessed  
33 whether the identity of the focal whales affected the behavioral response observed in relation  
34 with boat presence. To do so, we conducted a log-linear analysis including pod identity and boat  
35 presence within 100m as independent variables. Sample size restricted the analysis because we  
36 only considered focal schools composed of members of only one pod (see Table 4 for sample  
37 size). So we coarse grained the analysis and only considered two states (foraging and not  
38 foraging). The log-linear analysis showed that there does not appear to be any variation in the  
39 way that whales responded to boat presence depending on their pod (Table 5) because there was  
40 no interaction between the pod and boat effect (Table 5). The analysis shows that while the best  
41 model was the null model, both pod effect and boat effect could not be discounted (Table 5,  
42  $\Delta AIC < 2$ ). This highlights that potentially the site effect we observed in the previous analysis  
43 (Figure 1) may just be a reflection of the difference in use of the two sites by the three pods  
44 (Figures 3 & 4). J pod seemed to be the pod most likely to be foraging and interestingly they  
45 seemed to be more likely to be foraging at the south site while K and L were equally likely to  
46 forage at both sites (Figure 4).

1  
2 **The influence of the distance between the focal school and boats**  
3

4 While an effect of boat presence was apparent when boats were within 100m of the focal  
5 schools, we wanted to assess whether more distant boats also influenced the activity states of the  
6 schools. Control samples are more difficult to obtain when considering boat presence at  
7 distances of 400m and 1000m, because boat traffic around the two sampling sites is consistently  
8 high. For this reason the current samples available did not allow us to assess the site effect in  
9 relation to boat presence within 400m of the whales. Similarly, we could not assess the effects  
10 of boats within 1000m of the whales because of the lack of a minimum amount of control  
11 samples. Therefore, we present only the results of the log-linear analysis assessing the effects of  
12 boat presence within 400m of the whales without considering the other potential effects (*i.e.*,  
13 merging samples obtained during all years and at both sites). Given that the site effect (or  
14 potentially the pod effect) was found to affect the activity budget in previous analyses, the  
15 following results need to be interpreted with caution. As in previous models, we compared the  
16 model, obtained from log-linear analyses, containing all two-way interactions (**Boat presence** by  
17 **Preceding behavior**, **Boat presence** by **Succeeding behavior**, **Preceding behavior** by **Succeeding**  
18 **behavior**) to the fully saturated model (**Boat presence** x **Preceding behavior** x **Succeeding**  
19 **behavior**) to assess the effect of boat presence on behavioral transitions (Lusseau 2003). This  
20 comparison, based on the difference in maximum likelihood estimates of both models using  $G^2$   
21 statistics, did not reveal an effect of boat presence within 400m on behavioral transitions ( $\Delta G^2$   
22 =11.0,  $\Delta df= 9$ ,  $p= 0.28$ ). However, trends in behavioral budgets depending on boat presence  
23 within 400m were in the same direction as those when boats were within 100m (Figure 2a and  
24 Figure 5), with whales spending significantly more time traveling and significantly less time  
25 foraging.

26 We then assessed the effect of boat presence within 100, 400 and 1000m on the probability  
27 to stay foraging when foraging. The effect size of boat presence, *i.e.* the difference in the  
28 likelihood to stay foraging when foraging between control and impact situation (vessels present  
29 within the specified distance), decreased with the distance to boat present increasing (Figure 6a).  
30 The effect of boat presence appeared to be only significant when boats were within 100m and  
31 400m (Figure 6a, note the star and the confidence intervals), yet sample size might be preventing  
32 the detection of smaller effect size for the other treatment (Figure 6a, 1000m). In addition, the  
33 likelihood to stay foraging when foraging increased as the distance between the focal group and  
34 boats present in the study area increased but not significantly (Figure 6b).

35  
36 **DISCUSSION**  
37

38 Behavioral sequences varied significantly between locations, as expected. They also  
39 differed significantly with the presence of vessels. It is possible that the observed differences  
40 between locations is actually related to pods using the two sites with different intensity and some  
41 differences in behavioral sequences existing between pods. J pod was more likely to be observed  
42 at the North site while L pod was more likely to be at the South site. Similarly, schools  
43 composed of members of all three pods were more likely to be observed at the North site.  
44 However, Boats interacting within close vicinity of the whales (within 100m) also affected their  
45 activity budget in a similar fashion at both sites. Whales were significantly less likely to be  
46 foraging and significantly more likely to be traveling when boats were around. This finding is in

1 agreement with previous studies undertaken with the northern resident population (Williams *et*  
2 *al.* 2006). This effect raises concerns about the implications of this short-term displacement for  
3 the ability of individuals to acquire prey and the potential for long-term repercussions at the level  
4 of the population; especially in the light of the level of whale-watching activities carried out with  
5 Southern Residents. Vessel activity is also believed to reduce foraging success in other species  
6 (*Tursiops*, Allen and Read 2000). After controlling for effects of site and boats, there was no  
7 significant difference in the data between years. Additional years of study will be needed to  
8 determine whether the three years happened to be similar in factors that vary on an annual time  
9 scale (e.g., prey abundance), or if our results will be robust across a range of conditions. This  
10 study shows whales are displaced short distances by the presence of vessels. Thus whales may  
11 be displaced from optimal foraging routes. Further, Bain and Dahlheim (1994) suggested noise  
12 would mask echolocation signals and reduce foraging efficiency. These data are also consistent  
13 with observations of Northern Residents (Williams 2003; Williams *et al.* 2006.). Thus we would  
14 encourage further study to determine how noise and proximity interact to reduce foraging effort.

### 15 16 **The influence of pod identity**

17  
18 Boat interactions appear to have the same effect on all three pods, yet more sampling is  
19 required to fully understand the interaction between the composition of focal groups and the  
20 influence of boats on their activity state. Since pods appear to use certain areas preferentially  
21 (Hauser *et al.* 2005, 2006), and whales use both study sites differently, it was not surprising to  
22 see that the site effect observed earlier may actually relate to a pod effect. J pod, which spends  
23 the most time in the Sound, was more likely to be observed foraging than the two other pods.  
24 That pod was also significantly more likely to be foraging at the south site than at the north site,  
25 while the two other pods were equivocally foraging at both sites. This may relate to a better  
26 knowledge of the area.

### 27 28 **The influence of the distance between the focal school and boats**

29  
30 Boats within 100m clearly have a significant effect on whale behavior. Boats between 100m  
31 and 400m also have a significant effect, although we cannot say whether boats throughout this  
32 range cause effects, or the significance is due to effects of vessels just over 100m away. More  
33 spatial resolution in the data collection protocol would have been needed to address this issue.  
34 Similar but smaller differences were observed when the closest vessels were between 400m and  
35 1000m away. However, the sample is such that the results in the 400-1000 ring differ  
36 significantly neither from the larger effects when boats were closer than 400m, nor from no  
37 effect at all. That is, a larger sample would be needed to determine whether effects extend  
38 beyond 400m. These results suggest the zone of influence of vessels in this area exceeds the  
39 100m radius in current guidelines, and that more extensive guidelines such as those developed by  
40 the Whale Watch Operators Association NorthWest (2003), or those proposed by Orca Relief  
41 Citizens Alliance (2005) will be necessary to completely prevent behavioral changes caused by  
42 vessels, and more data will be needed to determine appropriate guidelines.

43 One potential explanation for these results is that noise impairs the ability to forage using  
44 echolocation (Soto *et al.* 2006). Previous studies have shown that the active acoustic foraging  
45 range of killer whales can be reduced or masked by boat noise (Erbe 2002; Bain and Dahlheim  
46 1994). Since received noise levels typically decline with distance, the closer the boats are, the

1 more echolocation range is reduced (Williams *et al.* 2002a), potentially leading to foraging  
2 disruption, as suspected here. To test this hypothesis, acoustic monitoring would be required, as  
3 noise produced varies with engine type, and the speed at which boats operate. These data were  
4 beyond the scope of this study. The changes in deviation and directness indices observed here  
5 and reported by Williams *et al.* (2002ab) reflect increases in non-directional movement that  
6 would make behavior tend to more closely resemble foraging, indicating movements to avoid  
7 vessels cannot account for a *decrease* in foraging.

## 8 9 **Conclusions**

10  
11 This study found evidence consistent with changes in behavior in the presence of vessels.  
12 These effects support the development and enforcement of regulations for whale watchers, both  
13 recreational and commercial. Future research could address whether different approaches to  
14 whale watching have different degrees of impact (as paralleling and leap-frogging were  
15 compared by Williams *et al.* 2002ab). However, since it has proven difficult to demonstrate  
16 significant differences in behavioral responses to currently accepted practices and no  
17 disturbance, it could be expected to take carefully controlled experiments or many years of  
18 observation to compare the implications of proposed guidelines to current guidelines. Future  
19 research could also attempt further elucidation of age, sex, pod, and individual differences in  
20 responses to vessels. Strong behavioral responses of animals to disturbance do not always  
21 indicate population-level effects. Indeed, inter-specific variability in site fidelity and availability  
22 of alternative suitable habitat make it difficult to infer population-level consequences from inter-  
23 specific variability in sensitivity to disturbance (Gill *et al.* 2001). Thus it will be important to  
24 develop the link between short-term behavioral effects and population dynamics (see Bain *et al.*  
25 2001).

26 This study echoes findings with northern resident killer whales: the presence of vessels  
27 inhibited the foraging behavior of fish-eating killer whales. This may lead to a reduction in  
28 energy acquisition, and a priority research area would be to address directly through field studies  
29 whether prey capture actually is affected by vessel presence. In addition, modeling exercises  
30 should be carried out to identify potential mechanisms and the biological significance of any  
31 effects found.

32  
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1 **List of Tables**

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4

**Table 1.** Definition of activity states used in this study

Activity state	Sub-category	Definition
<b>Rest</b>		characterized by prolonged surfacing in contrast to the rolling motion typically observed during travel
	1	Deep rest, hanging, logging: whales do not progress through the water
	2	Resting travel, slow travel: whales progress through the water, although they may not make forward progress over the ground.
<b>Travel</b>		Characterized by a rolling motion at the surface, progress through the water, and membership in a subgroup of more than four individuals
	3	Moderate travel, medium travel: travel in which whales do not porpoise
	4	Fast travel: travel which includes porpoising
<b>Forage</b>		characterized by progress through the water by lone individuals or while a member of a subgroup of four or fewer individuals
	5	Dispersed travel: foraging in a directional manner
	6	Milling, feeding, pursuit of prey: foraging involving changes in direction
<b>Socialise</b>		interaction with other whales, or other species in a non predator-prey context
	7	Tactile interactions: socializing that involves touching another whale, such as petting or nudging
	8	Display: socializing that does not involve touching, but may include behaviors such as spy hops, tail slaps and breaches
<b>Object play</b>		tactile interaction with an object such as kelp, wood or fish (in a manner not related to feeding)
	9	Kelping, object play: (when kelping also involved tactile interaction, it was counted as tactile interaction rather than object play.)

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**Table 2.** The number of activity state transitions observed in the presence/absence of boats within 100m.

Site	2003		2004		2005	
	No boat	Boat	No boat	Boat	No boat	Boat
North site	49	30	121	30	111	52
South site	45	11	46	20	40	48

10

1 **Table 3.** Information theoretic approach used to select models, from Figure 1, providing the  
 2 most parsimonious explanation for the variation in the scan-sample dataset. The selection is  
 3 based on the Akaike Information criterion. The models are described in Figure 1. The difference  
 4 between the best fitting model and the other models,  $\Delta AIC$ , helps defining models that are less  
 5 plausible (usually  $\Delta AIC > 4$  to 8). The likelihood of the model given the data can be approximated  
 6 using an exponential transformation of  $\Delta AIC$ :  $\ell(\text{model}_i | \text{data}) = e^{(-0.5\Delta AIC_i)}$ . The weight of  
 7 evidence provided by each model can be obtained by normalizing these likelihoods so that they  
 8 sum to 1.  
 9

Model	AIC	$\Delta AIC$	weight
Null model	-109.8	0	0.507
Boat	-109	0.8	0.340
Site	-107.4	2.4	0.153
Year	-93.5	16.3	0.0001
Boat + site	-97.5	12.3	0.001
Site + year	-93.1	16.7	<0.0001
Boat + year	-82.2	27.6	<0.0001
Boat + year + site	-81.4	28.4	<0.0001
Boat x site	-86.8	23	<0.0001
Boat x year	-65.6	44.2	<0.0001
Year x site	-69.1	40.7	<0.0001
Year + (boat x site)	-76.3	33.5	<0.0001
Site + (boat x year)	-66.9	42.9	<0.0001
Boat + (year x site)	-55.9	53.9	<0.0001

10  
 11  
 12 **Table 4.** Number of activity state transitions observed with and without boats present within  
 13 100m of subgroups for each pod for both sites in all years (considering only schools composed  
 14 solely of members of one pod).  
 15

Pod	No boat present	Boat present
J	158	35
K	21	21
L	99	47

16

1 **Table 5.** Information theoretic approach used to select models, from the log-linear analysis  
 2 considering pod identity, site, and boat presence, providing the most parsimonious explanation  
 3 for the variation in the scan-sample dataset. The difference between the best fitting model and  
 4 the other models,  $\Delta\text{AIC}$ , helps defining models that are less plausible (usually  $\Delta\text{AIC}>4$  to 8).  
 5 The likelihood of the model given the data can be approximated using an exponential  
 6 transformation of  $\Delta\text{AIC}$ :  $\ell(\text{model}_i|\text{data}) = e^{(-0.5\Delta\text{AIC}_i)}$ . The weight of evidence provided by each  
 7 model can be obtained by normalizing these likelihoods so that they sum to 1.  
 8  
 9

<b>Model</b>	<b>mle</b>	<b>Df</b>	<b>AIC</b>	<b><math>\Delta\text{AIC}</math></b>	<b>Weight</b>
Null	21.43	22	-22.57	0	0.378
Pod	14.43	18	-21.57	1	0.229
Boat	19.22	20	-20.78	1.79	0.154
Site	20.97	20	-19.03	3.54	0.064
Boat + site	18.89	18	-17.11	5.46	0.025
Boat + pod	13.42	16	-18.58	3.99	0.051
Site + pod	12.44	16	-19.56	3.01	0.084
Site x pod	8.66	12	-15.34	7.23	0.010
Site x boat	18.21	16	-13.79	8.78	0.005
Boat x pod	48.79	12	24.79	47.36	<0.0001
Boat x pod x site	0	0	0	22.57	<0.001

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 12

## 1 List of figures

2  
3 **Figure 1.** Tests of boat presence within 100m (*B*), site (*L* for location to avoid confusion in  
4 abbreviations), and year of sampling (*Y*) effects on behavior transitions (*PS*) using log-linear  
5 analyses. Models and their respective goodness-of-fit  $G^2$  statistics, degrees of freedom, and AIC  
6 values are shown in the boxes (adapted from Caswell 2001). Terms added are color-coded. Blue  
7 arrows represent the addition of a site effect (LS, LPS terms added to the previous model), red  
8 arrows represent the addition of a boat effect (BS, BPS), and green arrows represent the addition  
9 of a year effect (YS, YPS). To those terms correspond an increment in  $G^2$  and degrees of  
10 freedom, which are used to test for the significance of the term addition. Arrows are marked  
11 with a star when the term addition is significant ( $p < 0.05$ ). The top left star indicates a significant  
12 boat effect, and the center and right stars indicate significant site effects. Year effects were non-  
13 significant.

14  
15 **Figure 2.** The proportion of time focal killer whales spent in each activity state (their activity  
16 budget) depending (a) on the presence of boat within 100m of them and (b) the site sampled.  
17 Data from all three pods at both study sites are combined. Error bars are 95% confidence  
18 intervals. Black stars indicate differences that are significant at the 0.05 level.

19  
20 **Figure 3.** The proportion of time focal killer whales spent in each activity state (their activity  
21 budget) depending on the pod membership of the focal school. Data from both sites are  
22 combined. Error bars are 95% confidence intervals. Black stars indicate differences that are  
23 significant at the 0.05 level.

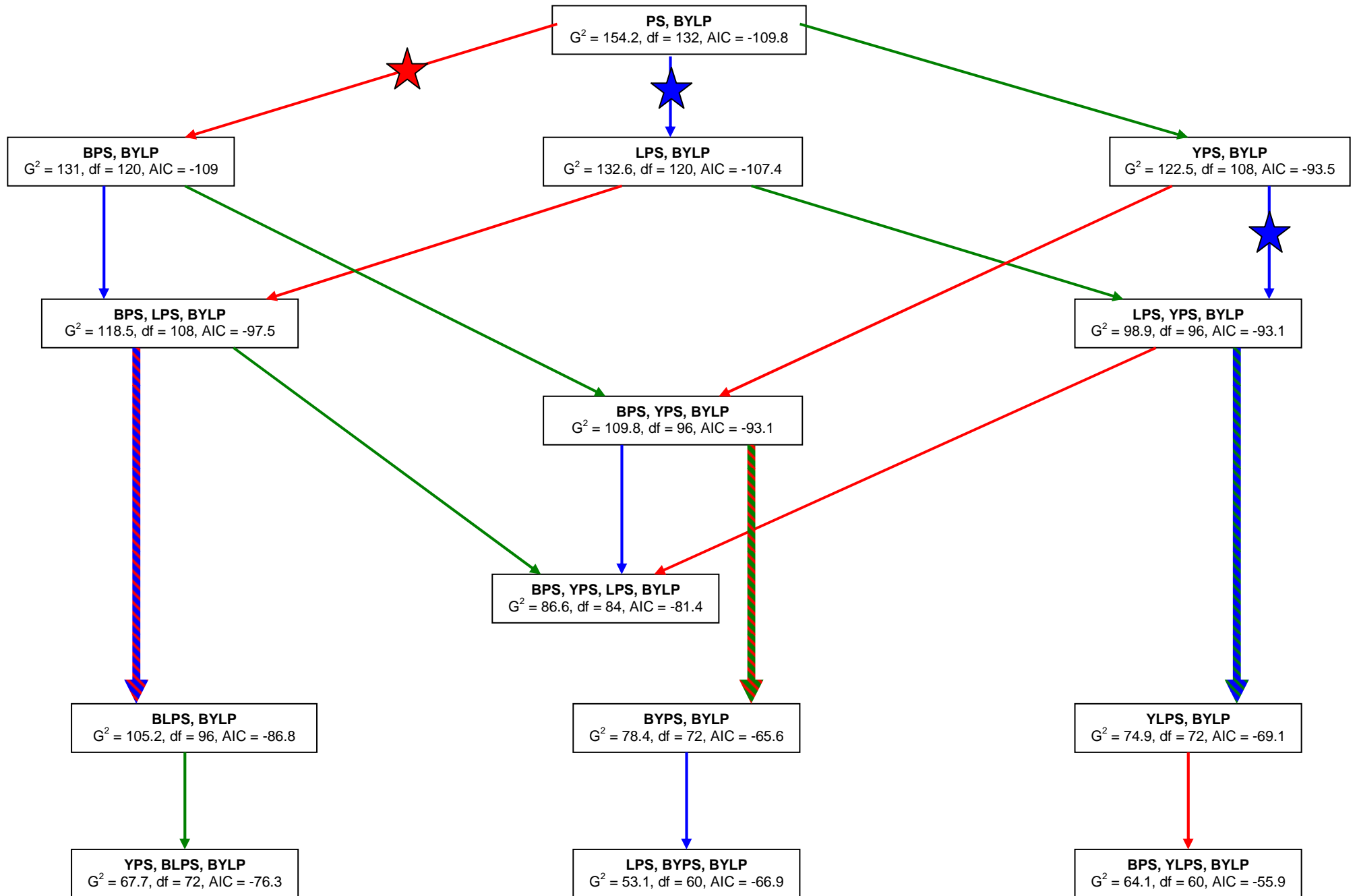
24  
25 **Figure 4.** The proportion of time focal killer whales spent foraging depending on the pod  
26 membership of the focal school and the site at which they were observed. Error bars are 95%  
27 confidence intervals. Black star indicates difference that is significant at the 0.05 level.

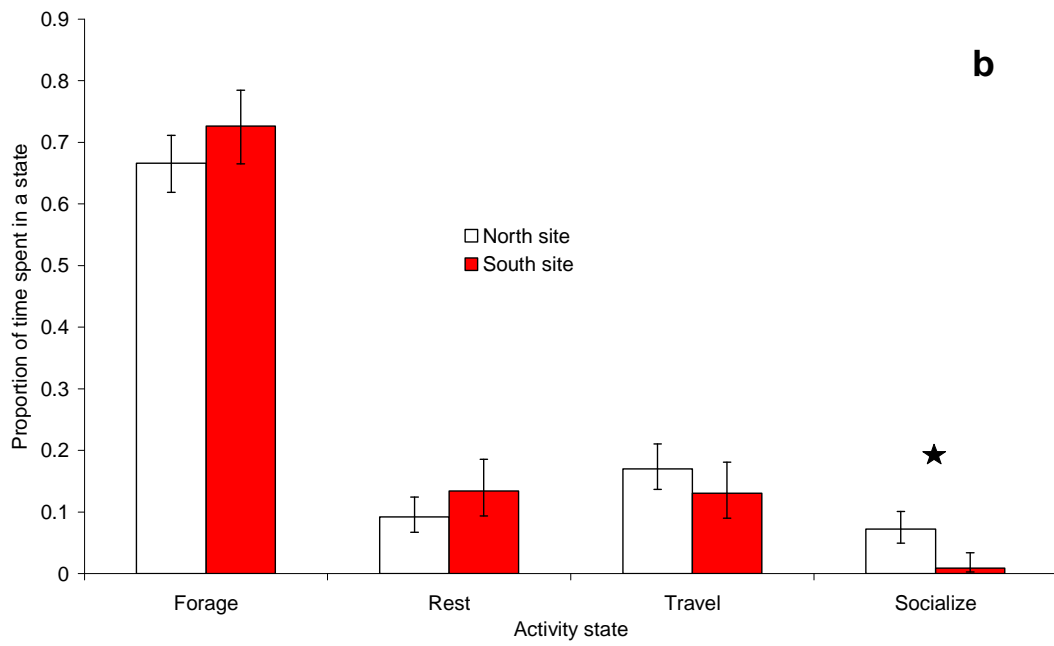
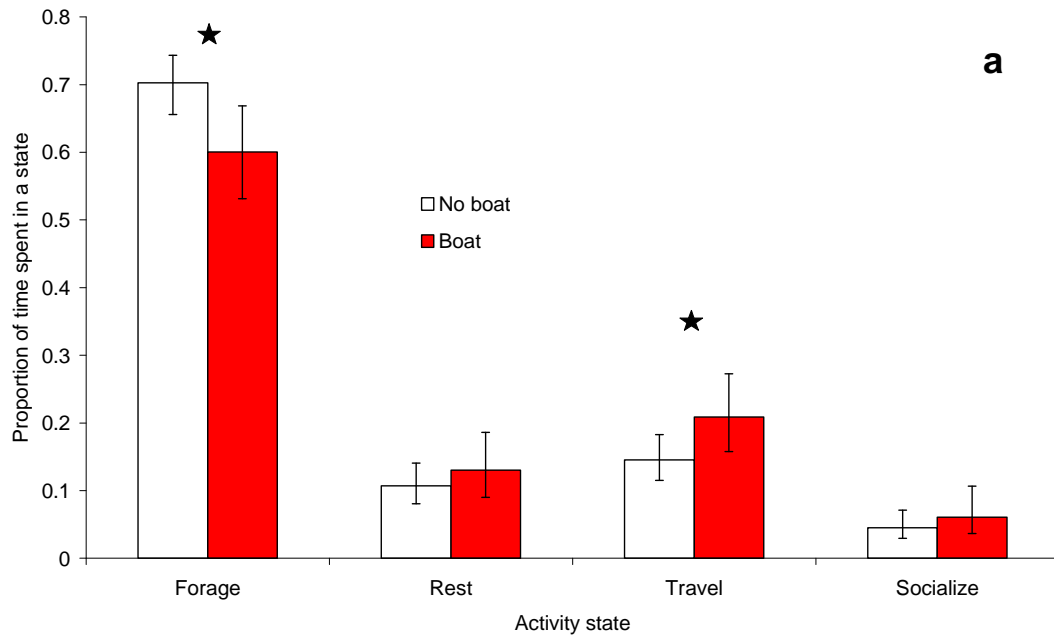
28  
29 **Figure 5.** The proportion of time focal killer whales spent in each activity state (activity budget)  
30 depending on the presence of boat within 400m of them, pooling across years and sites. Error  
31 bars are 95% confidence intervals. Black stars indicate differences that are significant at the 0.05  
32 level.

33  
34 **Figure 6.** Difference in the likelihood to stay foraging when foraging ( $p_{F \rightarrow F}$ ) between control and  
35 impact situations ( $p_{\text{control}} - p_{\text{impact}}$ ), i.e. effect size, (a) depending whether some boats were present  
36 within 100m, 400m, or 1000m of the focal whales and (b) when there is no boat present within  
37 100m, 400m, or 1000m of the focal school. The diagram describes these three treatments in  
38 which the focal group is at the centre of the concentric doughnuts (100m, 400m, and 1000m  
39 radii) and the boat exposure is represented in black. In order to test the effect of distance to  
40 boats, this analysis only takes into consideration samples when there were boats present only at  
41 the given distance. Error bars are 95% confidence intervals for the difference. If the interval  
42 includes 0, the difference is not significant at the conventional ( $p < 0.05$ ) level (indicated by a  
43 star). The number of transitions observed is given above each bar ( $n_{\text{control}}$ ,  $n_{\text{impact}}$ ).

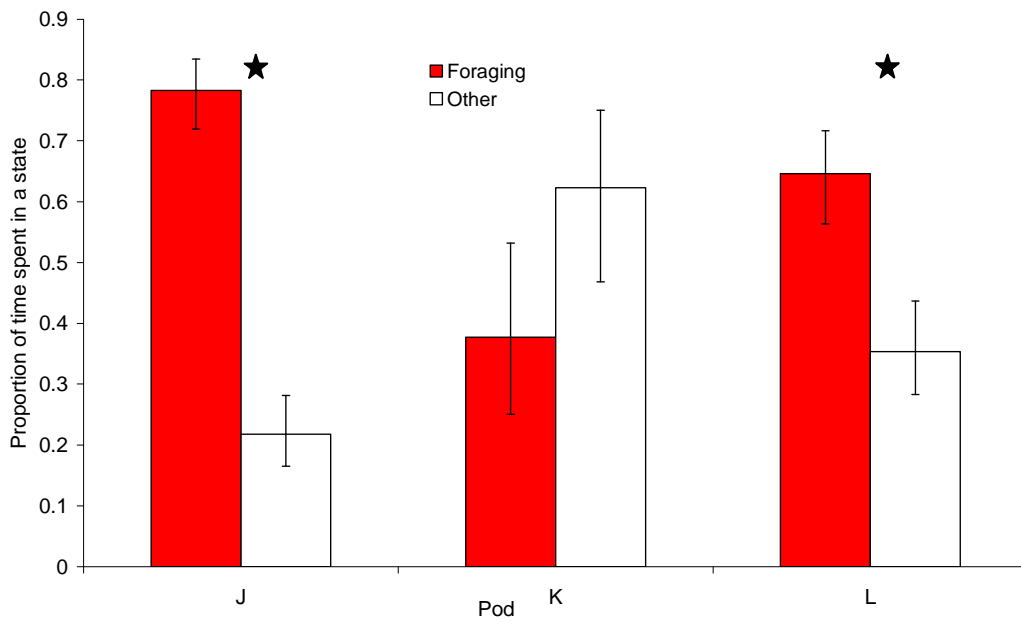


Figure 1.

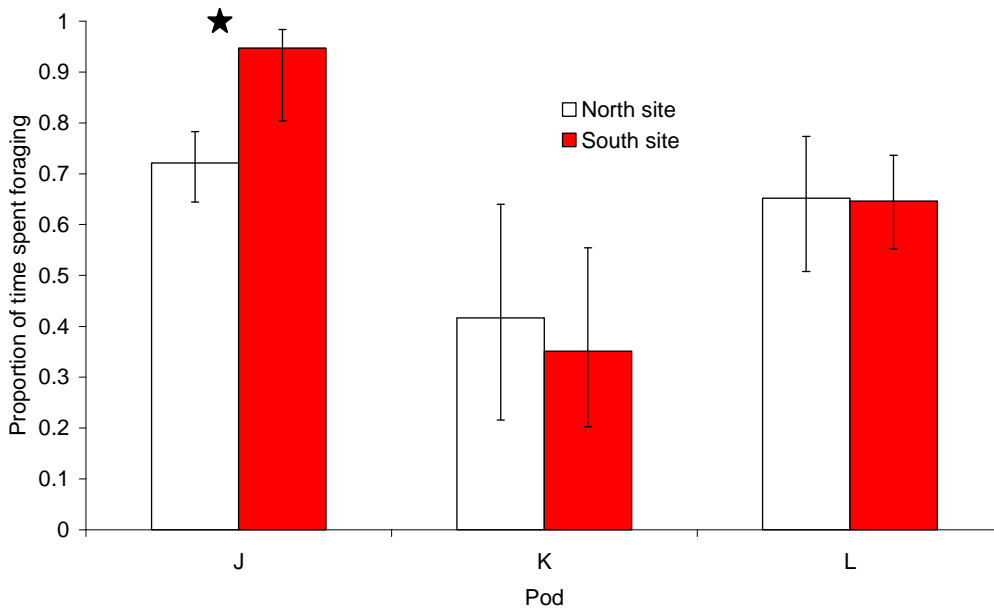




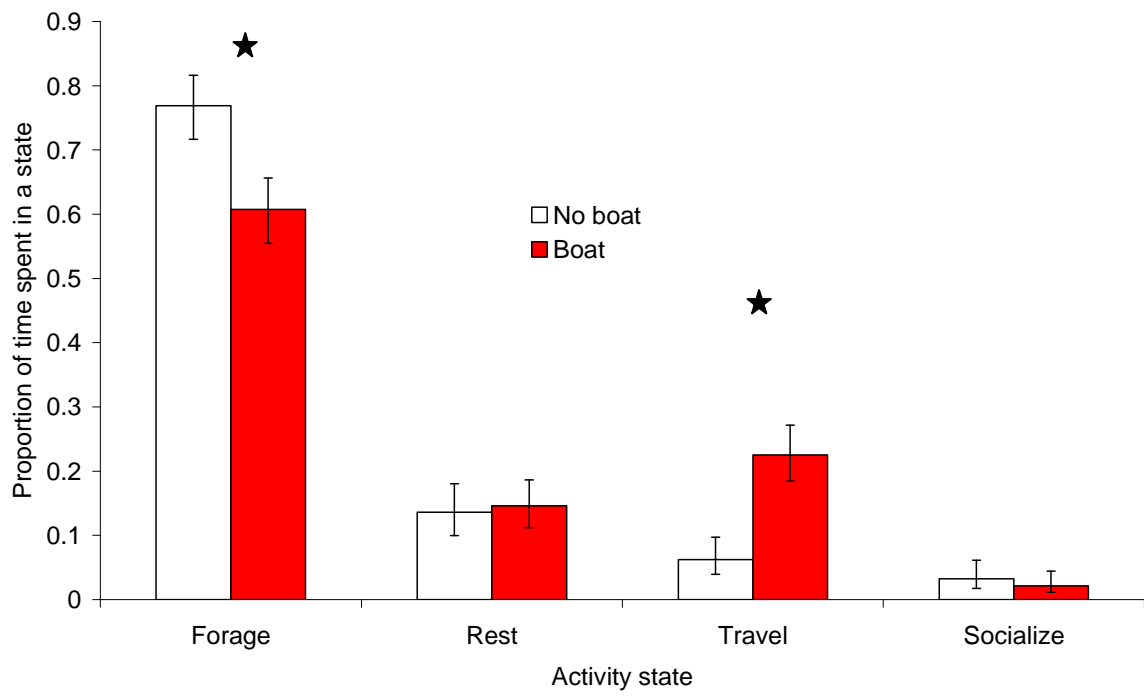
**Figure 2.**



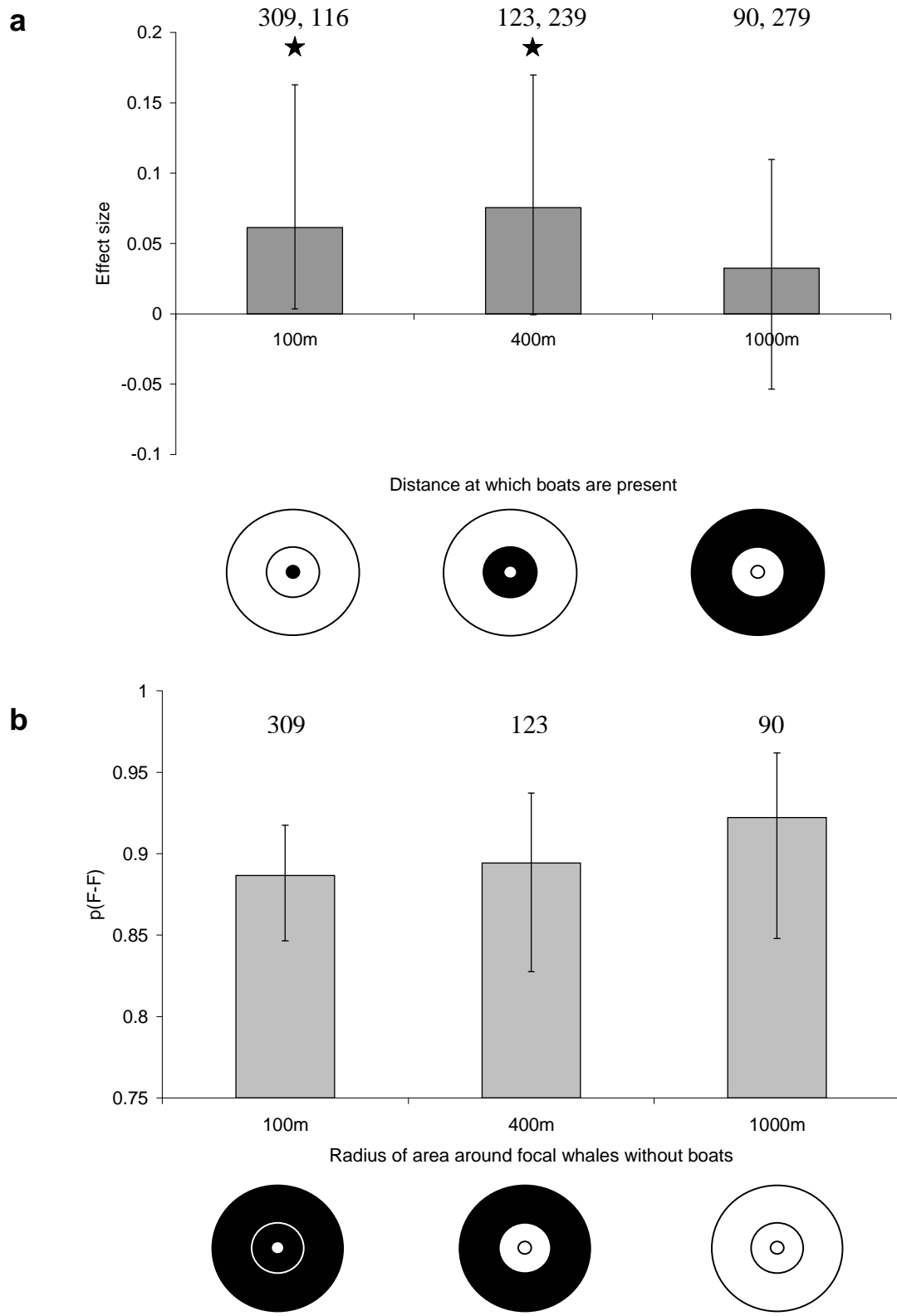
**Figure 3.**



**Figure 4.**



**Figure 5.**



**Figure 6.**