Vol. 295: 265–272, 2005

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published June 23

Residency pattern of bottlenose dolphins *Tursiops* spp. in Milford Sound, New Zealand, is related to boat traffic

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ABSTRACT: A population of bottlenose dolphins inhabits 7 of the 14 fjords that compose Fiordland, New Zealand. One of these fjords, Milford Sound, supports a large tourism industry that results in intense boat traffic. Bottlenose dolphins regularly visited Milford Sound and tour boats interacted with them during these visits. I studied the factors affecting the frequency of visits to Milford Sound by relating the residency pattern of dolphins in this fjord to oceanographic parameters and variations in boat traffic between December 1999 and February 2002. Boat traffic was the only variable that could explain the frequency of dolphin visits to Milford Sound. Dolphins spent less time in Milford Sound during seasons of intense boat traffic. Moreover, when dolphins visited this fjord, they spent more time at the entrance of the fjord when boat traffic was intense, out of the reach of tour boats. It seems that dolphins avoid Milford Sound when traffic is heavy. This avoidance could have long-term implications for the demography of the population.

KEY WORDS: Bottlenose dolphin · *Tursiops* · Tourism impact · Area avoidance · Habitat use

INTRODUCTION

The movement of many marine animals is associated with changes in water temperature and productivity (Quinn & Brodeur 1991). Top predators such as bottlenose dolphins are also affected by these oceanographic parameters as they can alter the distribution of their prey. For example, the distribution and residency of bottlenose dolphins in many locations have been related to temperature (Kenney 1990, Shane 1990, Wells et al. 1990, Barco et al. 1999, Bristow & Rees 2001). Bottlenose dolphins are also more often encountered close to shore during summer months, and often use coastal bays and estuaries as nursery areas (Wursig & Wursig 1979, Kenney 1990, Scott et al. 1990, Berrow et al. 1996, Wilson et al. 1997, Barco et al. 1999, Bristow & Rees 2001).

Anthropogenic impacts on the coastal environment are increasing. Human activities can affect the distribution and movement of whales and dolphins (cetaceans). Gray whales *Eschrichtius robustus* have been displaced from areas heavily used by humans (Withrow 1983, Bryant et al. 1984), as have Indo-Pacific humpback dolphins *Sousa chinensis* (Jefferson 2000). Humpback whales *Megaptera novaeangliae* might also have been displaced by boat traffic on summering grounds (Baker & Herman 1989) and from their migration routes (Nishiwaki & Sasao 1977). Boat traffic also affected the habitat use of the cetacean community in the NW Atlantic Ocean (Sorensen et al. 1984). These long-term displacements may be related to short-term avoidance strategies (Lusseau 2004). Short-term displacement is a common response of cetaceans to interactions with boats (Edds & MacFarlane 1987, Bejder et al. 1999, Constantine 2001, Nowacek et al. 2001,

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Williams et al. 2002, Lusseau 2003a, 2004). Cetaceans move away from boats when interactions become intrusive or too lengthy (Bejder et al. 1999, Williams et al. 2002, Lusseau 2003b). Why they do so is seldom known exactly, but there are many probable causes, ranging from acoustic disturbance to risk of physical injuries.

We still have little understanding of how these short-term displacements are used and selected by the animals for varying boat traffic intensity. What happens if the probability of encountering another boat is so high that a short-term displacement only results in another boat interaction? Would dolphins start to avoid the area because the boat traffic in this area is too intense? To answer these questions, I assessed the relationship between the presence of bottlenose dolphins in Milford Sound, New Zealand, and boat traffic. Boat traffic is intense in Milford Sound and based on tourism (scenic cruise tour operators). More than 8000 trips were undertaken in 2002. These tours operate year-round and seek to interact with dolphins when the animals visit the fjord. These interactions affect the behavioural state of these dolphins in the fjord, which tend to engage in a short-term horizontal avoidance strategy when interacting with boats (Lusseau 2004). Wide ranging photo-ID surveys (C. D. Rundgren unpubl. data) and incidental sightings show that the home range of the affected population of bottlenose dolphins spans over 7 fjords, from Lake McKerrow to Charles Sound (Fig. 1). Of these, only Milford Sound supports daily boat traffic. These fjords are relatively small (Fig. 1); Milford Sound is 15.7 km long and 1.6 km wide on average (Stanton & Pickard 1981). It is, therefore, easy to determine whether dolphins are present in the fjord or not on a daily basis.

Four individuals out of between 45 and 55 dolphins in this population bear propeller scars resulting from collisions with boats (Lusseau et al. 2002). Of these 4 individuals, 2 were hit during the present study in Milford Sound and one of them, a 2 wk old calf, disappeared after being hit. Boat interactions are, therefore, risky for bottlenose dolphins in this location. Associating a risk with an area can lead to its avoidance (Whittaker & Knight 1998, Gibeau et al. 2002). I examined the residency pattern of the bottlenose dolphins in Milford Sound and assessed whether they were avoiding this fjord when boat traffic was intense on a seasonal and daily basis. I also looked at the effects of a range of oceanographic parameters on their residency pattern. The habitat of this population is composed of several estuary-type zones separated by a coastal environment (Lusseau et al. 2002). The dolphins may have a cycle of occupancy of these fjords (for example they may visit all of them every week). I, therefore, also looked for any temporal cycle in the residency pattern of the dolphins in Milford Sound.

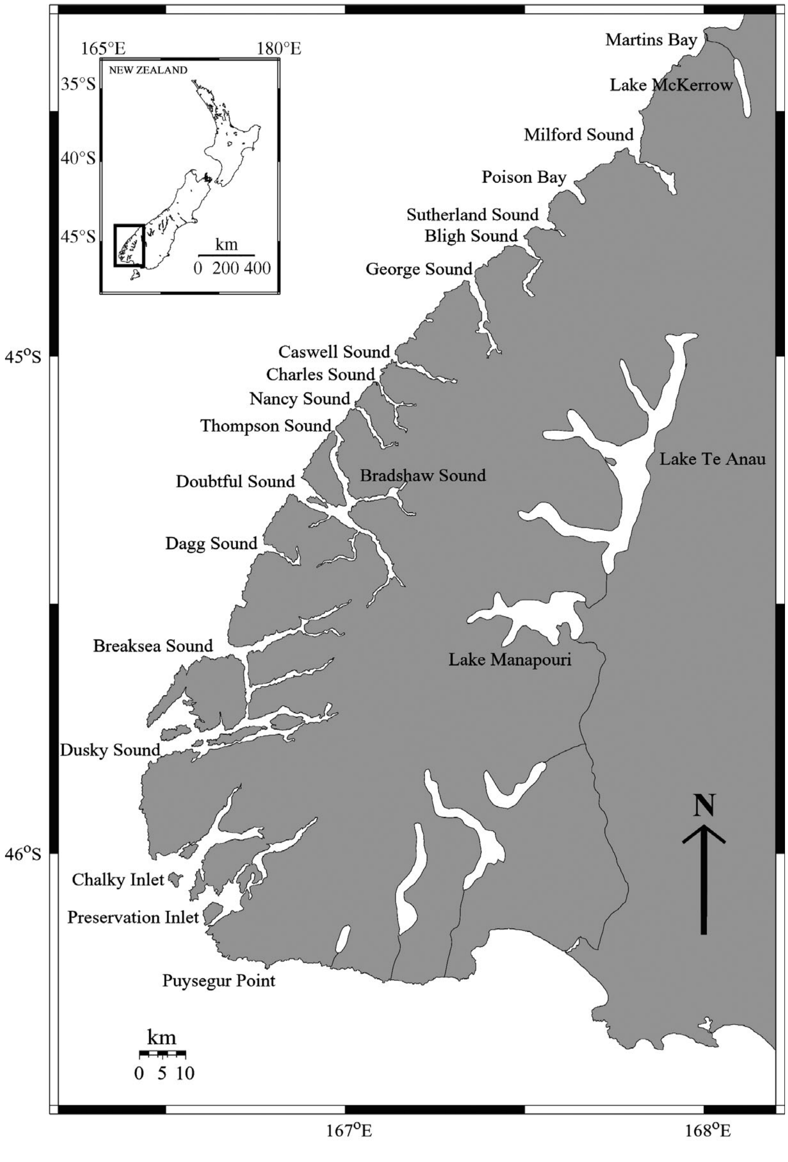

Fig. 1. Map of the area where bottlenose dolphins visiting Milford Sound have been observed. Their home range spans from Lake McKerrow to Charles Sound. This home range is deduced from photo-identification of dolphins in all 7 fjords (University of Otago Marine Mammal Research Group unpubl. data)

MATERIALS AND METHODS

Dolphin sightings. From December 1999 to February 2002, I conducted systematic surveys in Milford Sound using a 4.8 m aluminium boat, powered with a 50 hp 4-stroke outboard engine. The same survey route was followed every day until a group of dolphins was encountered. The route allowed for a complete survey of the fjord and ensured uniform temporal and spatial effort. I then stayed with that group until it was lost or until weather conditions deteriorated. A code of conduct was established to minimise the effect of the observing vessel (Schneider 1999, Lusseau 2003b). Previous studies showed that this code of conduct was successful (Lusseau 2003b).

In addition, tour operators provided dolphin sighting information from February 1996 to April 1999, along with their sighting effort (Lusseau & Slooten 2002). It was, therefore, possible to determine days with and without dolphins in the fjord during this period.

Boat traffic. Tour operating companies provided information on the number of trips that they undertook between December 1999 and February 2002. Private boat traffic is restricted in the area because of the remoteness of the fjord. It represents a small fraction of the daily boat traffic and occurs year-round; therefore, the information gathered on boat traffic in Milford Sound is conservative but represents a true sample of the real boat traffic.

Oceanographic parameters. The Milford Underwater Observatory provided information on physical parameters for the period June 1996 to February 2001. These were compared to the sighting data from tour operators (Lusseau & Slooten 2002). Rainfall, surface temperature, depth of the freshwater layer, and oceanic layer temperature were recorded every day from June 1996 to February 2001 (the period covering the sightings available).

Statistical analyses. A discriminant analysis (Quinn & Keough 2002) was carried out to assess the effect that each of these oceanographic parameters had on the presence of dolphins in the fjord. The same analyses were conducted for the period December 1999 to February 2001 using the sighting information from my systematic surveys. In addition, using this latter dataset (1999 to 2001), seasonal averages were obtained for each parameter and compared to a seasonal residency index (number of days dolphins were sighted in a season divided by the number of days of effort) using Spearman rank correlations.

A similar correlation analysis was conducted to detect any effect of boat traffic on the residency index of dolphins at a seasonal level. The northern shore of the fjord's entrance can be considered as a 'no boat zone' (Fig. 2) because tour boats do not visit it. I assessed the likelihood of the dolphins using this zone depending on the time of the day. Information was available on departures and lengths of scenic cruises during the day and was compared to the likelihood of encountering dolphins inside the fjords. For each hour (from 06:00 to 20:00 h, New Zealand Summer Time), I calculated the amount of time dolphins spent in the 'boat zone' compared to the amount of time I observed them during that hour. In addition, I calculated the typical number of boats present in the fjord (calculated from tour operators' timetables) for each hour. I calculated the Spearman rank correlation coefficient between these 2 variables and its significance.

Boat traffic and oceanographic parameters. From December 1999 to February 2001, both oceanographic parameters and boat traffic information were available. I, therefore, looked at the influence of each of these variables separately and together, at a seasonal level, using multiple regression analyses. Seasonal residency indices were normalised via arcsine transformation. To find the best-fitting model, I calculated an Akaike Information Criterion (AIC) for each model. AIC estimates the amount of information a model explains from its residual sums of squares (RSS, related to the amount of the variance left unexplained) and penalises models for the number of parameters used (Burnham & Anderson 1998).

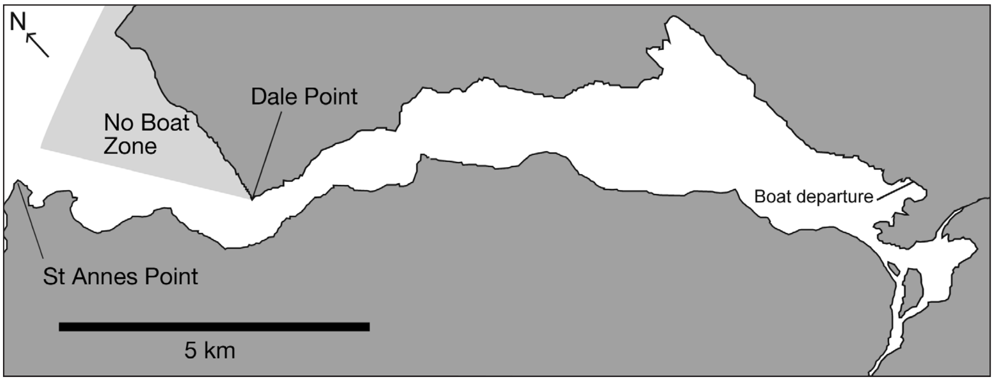

Fig. 2. Area used by tour boats in Milford Sound. This 'no boat zone' is present because the northern shoreline of the fjord's entrance is exposed to prevailing winds and swells. It is not a managed protected area. Tour boats depart from the inner fjord and go up to St. Anne Point. A typical cruise lasts 1¾ h

Temporal cycle. A discrete time Markov chain model was fitted to the time series of dolphin presence/absence to determine whether the presence of dolphins on a given day influenced the presence of dolphins on following days (Guttorp 1995). From the data available, it was possible to compute 4 types of Markov chains. These 4 orders of chains looked at whether the presence of dolphins on a given day depended on their presence 0 to 3 d beforehand.

An information theory approach was used to choose which Markovian model best fitted the data. Bayes Information Criteria (BIC) were calculated for each model. Like AIC, BIC quantifies the amount of the data variation explained by the model and penalises models for the number of parameters they use. BIC was used instead of AIC because it provides a better estimation of information content for Markov chains (Guttorp 1995). BIC uses the maximised likelihood estimate as a measure of information content. A model was accepted if it maximised BIC and had a BIC difference of more than 9.2 (Guttorp 1995) with the other models.

RESULTS

During the study period, I spent 112 d (505.5 h) on the water. Dolphins were observed on 53 d (296.1 h). The survey effort was equally spread across seasons (summer: 110.5 h, autumn: 120 h, winter: 140 h, and spring: 135 h). From the tour operator information, we were able to reliably determine the presence and absence of bottlenose dolphins in Milford Sound for 760 d (out of 839 d during which records were made).

Oceanographic parameters

Oceanographic variables were not a good predictor of dolphin presence. The discriminant function did not significantly separate days with dolphins from days without them (Wilk's lambda = 0.990, df = 4, p = 0.097, $n_{\text{dolphin days}} = 217$, $n_{\text{no dolphin days}} = 543$) and 100 % of days with dolphins present were misclassified after cross-validation.

Sea surface temperature tended to be colder when dolphins were present in Milford Sound between December 1999 and February 2001 ($F_{1,81} = 8.70$, p = 0.004, using the systematic survey data). During this time, the sea surface temperature varied from 6 to 18°C. However, dolphins were more likely to be present in the fjord during the colder seasons (Fig. 3). To tease apart seasonal effect (dolphins being present during the colder seasons) from the effect of temperature (dolphins being present on colder days of every season), I blocked dolphin sightings by season. After blocking, sea surface temperatures did not vary with the presence of dolphins in the fjord ($F_{1,81} = 0.146$, p = 0.70); therefore, it did not appear that there was any difference in sea surface temperature between days with and days without dolphins.

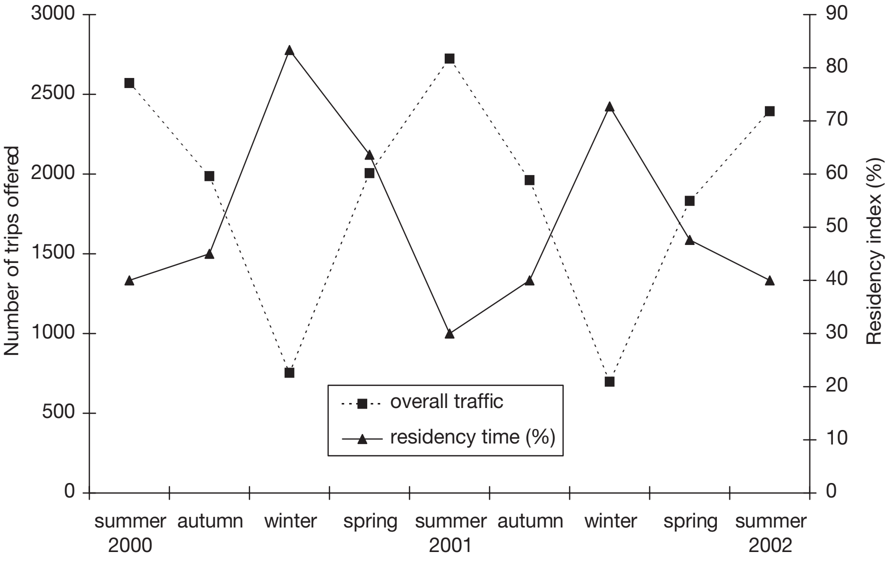

Fig. 3. *Tursiops* spp. Relationship between the number of boat trips offered each season and the seasonal residency index of bottlenose dolphins in Milford Sound between December 1999 and February 2002. The residency index is the number of days when dolphins were present in the fjord related to the number of days spent looking for them each season

Boat traffic

Seasonal residency index, derived from the systematic survey data, was negatively related to the total number of trips offered in every season (Fig. 3, Spearman rank correlation: r = –0.814, Z = –2.30, p = 0.021). Correlation does not prove causation, yet the same trend can be detected at a different temporal scale. When dolphins visited Milford Sound, they seemed to spend less time inside the fjord when it was most used by boats, and therefore were more likely to be found in the no boat zone (Fig. 4, Spearman rank correlation: r = –0.888, Z = –3.20, p = 0.0018, corrected for ties).

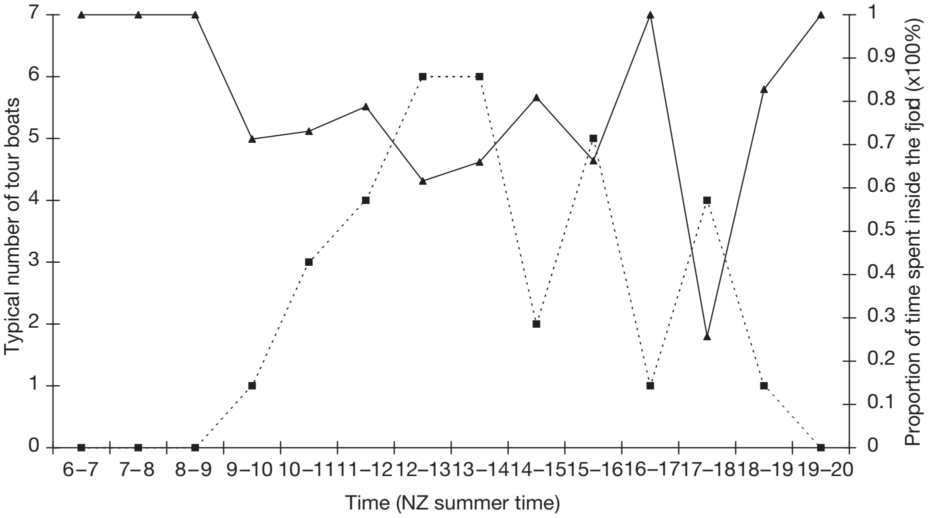

Fig. 4. *Tursiops* spp. Relationship between the typical number of vessels present in Milford Sound every hour and the use of the fjord by bottlenose dolphins between 06:00 and 20:00 h. Habitat use is described as the proportion of time spent inside the fjord (Fig. 2) to the total observation time for each hour class. Hours are given in New Zealand summer time. Solid line: the proportion of time dolphins spent inside the fjord; broken line: the typical number of boats present at any given hour

Effects of boat traffic and temperature

Since boat traffic and surface temperature have a significant effect on the residency index, they were the 2 variables considered for this analysis. Both univariate regression analyses were significant (boat traffic: $R^2 = 0.91$, $p = 0.01$ and surface temperature: $R^2 = 0.79$, $p = 0.04$, respectively). When both parameters were considered simultaneously in multiple regression, the regression was not significant ($R^2 = 0.92$, $p = 0.08$).

The AIC, however, indicated that boat traffic alone predicted the best residency pattern (Table 1). There was an AIC difference of 4.08 between the boat traffic model and the surface temperature model. Consequently, the seasonal variation in residency pattern seems to be mainly explained by the seasonal variation in boat traffic rather than by the variation in sea surface temperature.

Temporal cycle

None of the Markov chains could be discerned from one another (Table 2). In other words, higher-order Markov chains did not contain more information than the zero-order chain. It is, therefore, not possible to predict the presence of dolphins in the fjord on the basis of when they were last there. Thus, there does not appear to be a discernible temporal cycle in the presence of dolphins in Milford Sound.

DISCUSSION

Bottlenose dolphins visited Milford Sound more often in winter. This temporal variation in habitat use was not directly related to temperature. Dolphins spent more days in the fjord during the colder seasons, not on colder days. This counter-intuitive finding could be the result of seasonal prey distribution. No information was available on seasonal variation in the abundance and distribution of fish communities. This parameter must play an important role in the presence of dolphins in the fjord and bottlenose dolphins may rely on a series of species predominantly present in Milford Sound during winter. These prey items may also become distributed closer to the coast during winter. Similarly, prey abundance may vary seasonally among the 7 fjords over which the population spans. These

Table 1. Estimates of the information contained in each linear regression model using AIC. Models tested the dependence of the seasonal residency index (over 5 seasons, n = 5) on seasonal average surface temperature, the number of trips offered in each season, and both variables at the same time. Each model contained a constant and therefore *k* parameters

Model	RSS	n	*k*	AIC
Surface temperature	0.061	5	2	−18.03
Boat traffic	0.027	5	2	−22.11
Temperature and boat traffic	0.023	5	4	−18.91

Table 2. Estimates of the information contained in each Markov chain using BIC. The number of parameters (*k*) for each chain was given in Guttorp (1995). The sample size (n) is the number of transitions. A difference of 9.2 between the best model and the other models is necessary (Guttorp 1995)

Chain order	*k*	n	$l(\theta \mid data)$	BIC
0	1	133	−39.67	−84.23
1	2	108	−35.11	−79.58
2	4	86	−29.95	−77.71
3	8	66	−26.04	−85.60

hypotheses are contrary to what is known of the general movement pattern and spawning behaviour of fishes in the area (Lasker 1981, Nybakken 1993). In addition, recent stable isotope analyses of bottlenose dolphin diet in another Fiordland population (Lusseau 2003c) showed that they relied on food items residing inside the fjord. This diet does not appear to vary with season and it is, therefore, unlikely that prey distribution would affect the residency pattern in Milford Sound. The relationship between boat traffic and residency pattern provided a more parsimonious explanation for the use of Milford Sound by bottlenose dolphins. It is interesting to note that Gaskin (1972), from ship surveys from 1968 to 1970, had described bottlenose dolphins as regular visitors in Milford Sound during the summer, and that the species appeared to have been rarely encountered during winter. He also noted that bottlenose dolphins seemed to use the fjord as a nursery area in summer. This anecdotal evidence may well support a shift in habitat use related to an increasing modern tourism industry which started in the fjord in the late 1980s.

Interestingly, there was no temporal cycle in the dolphin's usage of Milford Sound. It can be hypothesised that these dolphins have a way to collect information about the status of different parts of their home range which does not require them attending each fjord regularly. If this were the case, they would not have to visit each fjord regularly, which would explain the lack of a temporal trend.

Boat traffic restricts the use of Milford Sound by bottlenose dolphins

Boat traffic seemed to play an important role in the use of Milford Sound by bottlenose dolphins. It is apparent that the more boat traffic increased on both a seasonal and a daily basis, the less time dolphins spent in the fjord (Figs. 3 & 4). This finding is in agreement with the predictions made from the observations of short-term horizontal avoidance strategy (Lusseau 2004). Once the likelihood of interacting with a boat when in Milford Sound becomes too high, it is no longer advantageous to try eluding boats in the short-term because it will only result in interacting with another boat. The energetic cost of boat avoidance becomes too expensive and the results indicate that dolphins prefer to avoid the area altogether. The relationship between boat traffic and the dolphin residency index seemed quite linear. If the relationship remained linear with boat traffic increasing beyond present values, a 40 to 60% increase in current summer traffic would result in dolphins completely abandoning the fjord (residency index = 0%). Such an extrapolated outcome is remote as other avoidance techniques may be available to the dolphins. These would permit them to still visit Milford Sound without increasing the intensity of interactions. The data collected only reflects diurnal use of the fjord. In theory, dolphins could compensate for increasing boat traffic by shifting their use of Milford Sound to the night. In any case, this impact from tourism activities is clear and potentially serious. Several long-term implications can be hypothesised.

The carrying capacity of a population is directly related to the productivity and quality of its home range (Macdonald & Rushton 2003, Mitchell & Powell 2004). If the size of the home range is decreased, or restricted during certain periods, it will decrease the productivity available to the population. It could, therefore, decrease the population-carrying capacity (Singer et al. 2001, Mitchell & Powell 2004). To remain stable, the population would have to increase its home range in order to make up for lost resources, or alternatively the population size could decrease. This population is already small, being estimated at 45 to 55 individuals (D. Lusseau et al. unpubl. data), and any decrease in population size would raise demographic concerns.

Another implication of area avoidance is a potential increase in predation pressure on the population. When in Milford Sound, dolphins spend more time at the entrance (Fig. 4), where the water is largely oceanic and lacks a low-salinity layer characteristic of the inner fjord (Gibbs et al. 2000). Low salinity restricts access of large sharks to the inner fjord, and hence creates a low-predation zone for the dolphins (Stanton & Pickard 1981). By spending less time inside the fjord, dolphins may be more exposed to predation.

Finally, if dolphins avoid Milford Sound when boat traffic is intense, it means that the benefits of being in this fjord are largely overcome by the costs of interacting with boats. The home range of the population spans over 7 fjords. Regardless of the nature of the costs, it means that these cannot be covered efficiently by using 1/7 of the population's home range (1 fjord out of the 7). This avoidance strategy indicates that the tourism industry in Milford Sound has a biologically significant impact on the bottlenose dolphin population. More importantly, this avoidance strategy may lead to demographic impacts on the population and therefore the exclusion impact from tourism activities may have a snowball effect.

These potentially long-term impacts seriously question the sustainability of the current level of tourism activities in Milford Sound. There is current pressure to further develop this industry in this location. Management actions are required to reduce boat traffic in the fjord, or at least to minimise dolphin – boat interactions by excluding boats from locations used by dolphins. The level of tourism activities cannot be increased without a greater impact on the dolphin population. Moreover, tourism pressure is also increasing in Doubtful (45° 30′ S, 167° 00′ E) and Dusky Sounds (45° 50′ S, 166° 40′ E) where 2 other, separate, populations of bottlenose dolphins reside (Lusseau & Slooten 2002, Lusseau et al. 2003). This study shows that tourism activities can displace dolphins from part of their home range. These results need, therefore, to be taken into consideration when managing other areas in Fiordland. Boat – dolphin interactions cannot increase ad infinitum without negative consequences. It is, therefore, necessary to determine an allowable level of boat interactions and restrict tourism activities in the region to this level.

Acknowledgements. I would like to thank L. Slooten and S. Dawson for giving me the opportunity to work in Fiordland. They also provided valuable comments on this manuscript. This study was funded by the New Zealand Department of Conservation. The New Zealand Whale and Dolphin Trust, the University of Otago (Departments of Zoology and Marine Sciences) contributed additional financial and technical support. I would like to thank the Milford Underwater Observatory for providing their data on oceanographic parameters. I would also like to thank Real Journeys Ltd., Fiordland Ecology Holidays, Milford Kayaks, Red Boat Cruises and Tawaki Dive for providing boat traffic information and dolphin sightings. C. D. Rundgren, M. Taylor, and N. and P. Van der Spek provided information to define the population's home range. Finally, many thanks go to O. Boisseau, S. Mærsk Lusseau, M. Hollander, J. Bertler, and many volunteers for their invaluable help in the field.

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Editorial responsibility: Otto Kinne (Editor-in-Chief), Oldendorf/Luhe, Germany

Submitted: July 15, 2004; Accepted: March 8, 2005
Proofs received from author(s): June 14, 2005