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Distance does matter: close approaches by boats impede feeding and resting behaviour of Indo-Pacific bottlenose dolphins

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Abstract

Context. Potential impacts of human disturbance on animal populations can be measured as behavioural responses and may affect the survival and fecundity of animals. In areas where human–wildlife interactions occur, conservation management needs to be in place to secure both a viable tourism industry and the sustainability of the targeted species.

Aims. We sought to evaluate whether different approach distances by boat have effects on the behaviour and group cohesion of dolphins that are targeted by Australia's largest dolphin-watching industry.

Methods. The effects of different approach distances of boats on the behavioural states of dolphins, group dispersal and direction of movement were investigated in this area by controlled boat experiments conducted between August 2008 and December 2009.

Key results. Results showed that there was significantly less feeding when boats approached dolphin groups to a distance of 50 m than when they did to a distance of 150 m, or with controlled approaches. Resting was also observed significantly less when boats approached to a distance of 50 m than when they approached to a distance of 150 m. The dispersal of dolphin groups was significantly tighter (less dispersed) when boats approached to 50 m than that with 150-m-distance or controlled approaches. Furthermore, the dolphins' direction of movement was less neutral when the experimental boat approaches were carried out at a distance of 50 m than when they were carried out at a distance of 150 m, or with controlled approaches. Similar results were also obtained for dolphin groups including calves.

Conclusions. On the basis of the results from this study, we recommend that the existing New South Wales regulations, which stipulate that dolphin-watching boats keep a distance of 50 m to groups with adults only and 150 m to groups with calves, are maintained within the Port Stephens–Great Lakes Marine Park (PSGLMP).

Implications. Management plans whose stated goals include both sustainability of a dolphin-watching industry and longer-term viability of a dolphin population may reconcile conflicting objectives and improve their decision making by using these empirical measures rather than best guesses.

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Introduction

A widely studied issue in conservation biology is the potential impact of human disturbance on animal populations (e.g. Walther 1969; Born *et al*. 1999; Frid 2001; Blumstein *et al*. 2003; Constantine *et al*. 2004). Whether disturbance affects a population, and how severe this effect is, relies on the impact of the disturbance that can be measured as behavioural responses of the targeted species. Animals may perceive non-lethal disturbance stimuli caused by humans as similar to predation risk (e.g. Walther 1969; Frid and Dill 2002). Frid and Dill (2002) referred to this trade-off as the risk–disturbance hypothesis. The risk–disturbance hypothesis predicts that responses by disturbed animals will track short-term changes in the factors characterising disturbance stimuli, with responses being stronger when the perceived risk is greater.

The animals' responses in turn to both predation risk and disturbance stimuli divert time and energy from other fitness-enhancing activities such as feeding or parental care (Frid and Dill 2002). Thus, these impacts can indirectly affect the survival and fecundity of the targeted animals (Gill *et al*. 2001). These human–animal interactions are based on an overlap of the animals' habitat and the anthropogenic use of the same area, such as for tourism, or recreational and commercial fisheries (e.g. Constantine *et al*. 2004; Bearzi *et al*. 2006; Miller *et al*. 2008). Cetacean-based tourism is one of these growing potential threats and has resulted in increased exposure of dolphin and whale populations to high levels of boat traffic and disturbance (e.g. Bejder *et al*. 2006*b*; Stensland and Berggren 2007; Stamation *et al*. 2010).

In Australia, for example, the whale- and dolphin-watching industry has grown continuously in the past decade, with a total of more than 1 600 000 national and international participants each year (O'Connor *et al*. 2009). In this country, the Commonwealth, state and territory governments have jointly developed the National Guidelines for Whale and Dolphin Watching 2005, which outline the standards that allow people to observe and interact with whales and dolphins in a way that ensures that animals are not harmed (DECC 2005). On the basis of these guidelines, the state of New South Wales (NSW) introduced the NSW National Parks and Wildlife Amendment (Marine Mammals) Regulation 2006 (DECC 2006), which is intended to protect marine mammals such as whales and dolphins while still allowing people to appreciate them in the wild. However, as is common elsewhere, albeit normally implicit rather than explicitly in the legislation, the Regulations 2006 (DECC 2006) allow for specific management controls to be adjusted and/or altered to meet local requirements either for specific targeted populations and species, or so as to meet the needs of local tourism industries. Accordingly, management strategies can be modified depending on the habitat scale of the targeted animals, for example, resident versus non-resident populations, and/or the intensity of interactions with vessels (see e.g. Bejder *et al*. 2006*b*; Stockin *et al*. 2008).

The inshore waters of the Port Stephens–Great Lakes Marine Park (PSGLMP) in NSW, are inhabited by a small, genetically distinct population of Indo-Pacific bottlenose dolphins (*Tursiops aduncus* Ehrenberg, 1833) (Möller *et al*. 2002, 2007; Wiszniewski *et al*. 2010), with an estimated 90 resident individuals (Möller *et al*. 2002), which is the focus of Australia's largest dolphin-watching industry. This resident population of dolphins presumably colonised the embayment when suitable habitat became available as a result of inundation of the river valley ~6500 years ago (Thom and Roy 1985; Möller *et al*. 2007; Wiszniewski *et al*. 2010). The resident population is differentiated from the adjacent coastal communities because of limited genetic exchange with coastal populations and appear to be highly adapted to the environmental and ecological conditions within the embayment (Wiszniewski *et al.* 2009, 2010).

The local dolphin-watching industry has the largest number of boat-based whale-watching tourists in Australia and attracted more than 270 000 visitors in 2008, with 80% of the visitors coming especially for dolphin-watching tours (O'Connor *et al.* 2009). The local dolphin-watching industry commenced in the early 1990s and has since increased its intensity, with up to 15 boats watching at a time, and operates throughout the year (Allen *et al*. 2007). The operators offer up to three daily trips, each lasting for up to 2 h (e.g. Port Stephens Tourism 2010). In 1996, the Port Stephens Commercial Dolphin Watch Association developed a voluntary code of conduct that addressed, among other activities, minimum approach distances. The code of conduct states that dolphin-watching boats should keep a minimum distance of 50 m from a group of dolphins. This code of conduct, however, has not reduced the perceived pressure on the targeted dolphin population (Allen *et al.* 2007). In addition, the NSW regulations (DECC 2006) and the code of conduct differ, for example, in the distances that dolphin-watching vessels have to keep to a group of dolphins with calves. The former stipulates 150 m to groups with calves (DECC 2006), compared with the code of conduct, which recommends a minimum distance of 50 m to all groups of dolphins.

The impact of the daily approaches of dolphin-watching boats in this area was investigated by boat-based surveys from August 2008 to August 2009 (Steckenreuter *et al*. in press). Steckenreuter *et al*. (in press) showed that dolphins' behavioural states and energy budgets were altered in the presence of dolphin-watching boats. Dolphins spent significantly less time feeding and socialising, spent more time milling, and were not observed resting in the presence of dolphin-watching boats. In addition, groups were less dispersed during encounters with dolphin-watching boats and dolphins tended to avoid tour boats. These effects were generally greater as the number of boats increased and the distance of the boats decreased (Steckenreuter *et al*. in press). For small resident communities of animals that are frequently encountered by dolphin-watching boats, these repeated disruptions of behavioural patterns may have a direct impact on the health and the reproductive success of individuals in the targeted population (Bejder *et al*. 2006*b*).

The aim of the present study was to investigate how different boat-approach distances affect dolphin behaviour and group structure in Port Stephens using experimental boat approaches. Previous research on a different population of Indo-Pacific bottlenose dolphins inhabiting Jervis Bay, NSW (Wiszniewski *et al*. 2010), where tourism is at a significantly lower level, showed that travelling dolphins will turn away from a single approaching boat at a distance of 100 m but the study did not assess the structure or composition of groups (Lemon *et al*. 2006). In the present study, we determine whether behavioural states, group dispersal and direction of movement are affected by the approach distance of boats to the dolphin group and whether groups including calves are affected differently. The NSW regulations explicitly distinguish between approach distances by boats to different dolphin groups, with closer approaches allowed to groups including adults only (DECC 2006). Experimental boat approaches were carried out at 50-m and 150-m distance to the dolphins. The goal of the study was to empirically assess the approach distances by group composition stipulated in the NSW regulations (DECC 2006).

Materials and methods

Field data collection of boat approaches

The potential effects of different approach distances of boats on the dolphins were investigated using *experimental* boat approaches at 50 m and 150 m from a 6.2-m rigid inflatable boat with twin 60-hp four-stroke outboard motor between November and December 2009. The controlled approaches were carried out from a 5.5-m aluminium and fibreglass boat with a 60-hp two-stroke outboard motor in August 2008, February–March 2009 and August 2009. The latter were conducted to investigate dolphins' behaviour and group structure when not affected by other boats in the vicinity (more than 300 m away from the dolphin group) and the animals were thus considered relatively undisturbed apart from the research boat. The change of boats occurred when the university upgraded the boat, but was considered negligible in changing the behaviour of the animals because the control boat was manoeuvred in a manner completely different from that of the experimental boat approaches. During experimental approaches at 50 m and 150 m, the research boat was manoeuvred in a way that resembled activities of dolphin-watching boats, which means that gears were changed approximately every 20 s, the speed varied between zero to 12 km h^{-1}, and angles to the group of dolphins were changed frequently. The latter was carried out in a manner that each encountered group was approached from both sides, and the front and back of the group. The experiments were terminated when other watercraft came within a 300-m radius of the dolphin group. Potential resampling of dolphin groups with the majority of the same individuals during a day was minimised by visual inspection of the individuals in a group before each initiation of an experimental approach. Most individuals in this population bear naturals marks on their dorsal fins which make it feasible to identify individual animals.

The surveyed area (Fig. 1) was divided into grids of ~1.5 km^2, starting each survey from a randomly chosen square. When a group of dolphins was approached, scan sampling of focal group follows was used to gain behavioural samples (Mann *et al*. 2000). For consistency, scan sampling was conducted by the same experienced observer throughout the study.

At the beginning of each encounter, we recorded the time, geographic coordinates by using a global positioning system (GPS), estimated group size, group composition, sea state, wind direction, wind speed and cloud cover. The maximum length of time of an experimental boat approach was based on the 30 min of dolphin-watching boat approaches agreed on by the Port Stephens Commercial Dolphin Watch Association (Allen *et al*. 2007) so that a group of dolphins had a limited time being exposed to experimental conditions. Observations were also terminated during precipitation, when sea state reached Beaufort three, or when visibility deteriorated. Scan sampling was used to assess the predominant behavioural state, i.e. when majority of group members of the dolphins in a group engaged in the same activity, such as resting, milling, feeding, socialising and travelling (Table 1), for more than half of the observation time, in 1-min intervals for experimental approaches and 5-min intervals for controlled approaches (see Altmann 1974). During controlled approaches, where the research boat kept a maximum distance from a group of dolphins to reduce any potential changes in behaviour and group cohesion, a longer time interval was chosen to maximise accuracy of these assessments. However, during experimental approaches shorter time intervals were chosen to expose a group of dolphins for only a limited time to experimental conditions, thus minimising potential stress on the animals. This sampling assumed that the behavioural state observed at the surface is representative of that underwater. The emphasis of the analysis focussed on the behavioural states feeding and resting because they represent physiologically important variables that directly affect the energy budget of an individual. Additionally, counts for socialising were very low. Therefore, the behavioural states travelling, socialising and milling were pooled together.

A dolphin group was defined as a set of individuals within a 100-m radius of a central animal and engaged in similar behavioural states for periods of minutes to hours (Irvine *et al*. 1981). Group dispersal consisted of the following three categories: 'more dispersed' (more than five body lengths between individual dolphins), 'average' (one to five body lengths apart) and 'less dispersed' (less than one body length apart) (adapted from Allen *et al*. in press and modified from Bejder *et al*. 1999). Composition and size of the group and the direction of movement were also recorded in 1- and 5-min intervals. The former was divided into adults and calves, which were defined as animals less than half the length of an adult; which is the same definition as in the NSW regulation (DECC 2006). The categories for direction of movement were defined as 'neutral' (individuals do not change their path), 'towards' (approaching the boat, often coupled with bow-riding in the pressure wave of the boat), and 'away' from the

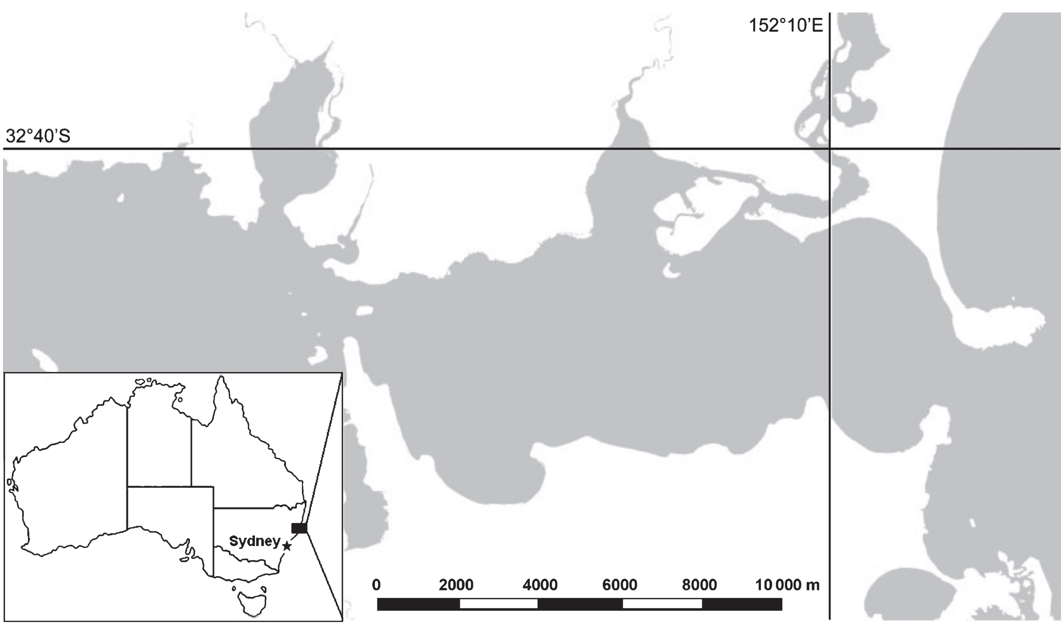

Fig. 1. Study area in Port Stephens as part of the Port Stephens–Great Lakes Marine Park, New South Wales, Australia.

boat (changing direction and moving away). The counts for towards and away were pooled because of a small sample size in the former category. Thus, results for direction of movement have to be interpreted as a general change from a neutral direction of movement.

The distance of the boat to dolphins was estimated by the same observer throughout the study. The error of measures of distance was assumed to be less than 5% on the basis of a series of trials where distances to objects across a body of water were estimated and then measured with a rangefinder.

Data analysis of boat approaches

For the analysis, only data collected between 0800 hours and 1400 hours were included because they were available for all three boat-approach factors. Clustered bar charts were used to explore associations between boat-approach factors and dolphins' behavioural states, group dispersal and direction of movement. Associations between factors and outcomes of the study were further evaluated using the Pearson's chi-square test. Chi-square tests of association between the factors and each outcome were performed to evaluate those specific associations. Because multiple tests were carried out on the same data significance was set at 0.1% (i.e. $\alpha = 0.001$). All statistical tests were performed using the software R (Crawley 2007; R Development Core Team 2009).

Results

Behavioural data were collected during 32 experimental approaches, with a total of 854 counts between November and December 2009; 19 of these approaches had adults and calves present (508 counts). The data of the controlled approaches included 82 encounters, with a total of 922 counts between August 2008 and August 2009; 43 of those encounters had adults and calves present (391 counts). All observations encountered a total of 946 dolphins.

All groups of dolphins

Dolphins' behavioural states varied significantly by boat-approach distance ($\chi^2 = 123.10$; Fig. 2, Table 2). Dolphins fed significantly less when the experimental boat approaches were carried out at 50 m than they did during controlled approaches ($\chi^2 = 50.98$; Table 3) or during approaches to a 150-m distance ($\chi^2 = 27.95$; Table 3). Dolphins rested significantly less when the experimental boat approaches were carried out at 50 m than they did during approaches carried out at 150 m ($\chi^2 = 47.15$; Table 3).

Dolphins' group dispersal also varied significantly by boat-approach distance ($\chi^2 = 172.66$; Fig. 3, Table 2). Dolphins formed significantly tighter (less dispersed) groups when experimental boat approaches were carried out at 50 m than they did during controlled approaches ($\chi^2 = 128.80$; Table 3) or approaches at a 150-m distance ($\chi^2 = 50.52$, Table 3).

Dolphins' direction of movement varied significantly by boat-approach distance ($\chi^2 = 378.49$; Fig. 4, Table 2).

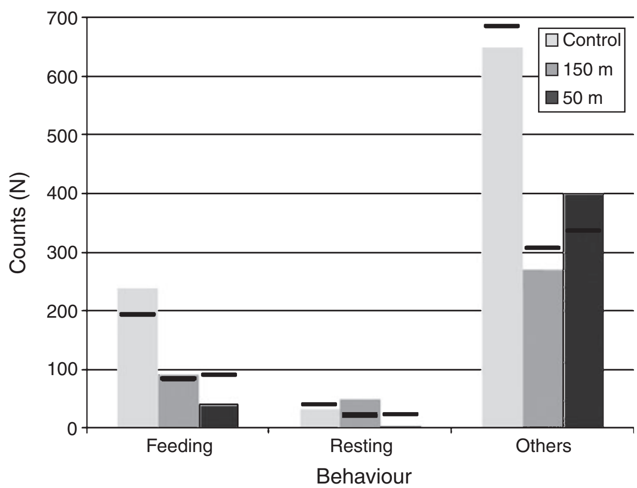

Fig. 2. Effect of distances of experimental boat approaches on the behavioural states of Indo-Pacific bottlenose dolphins in the Port Stephens–Great Lakes Marine Park, New South Wales, Australia; black bars indicate expected values.

Table 1. Ethogram with definitions of behavioural states
Modified from Shane *et al*. 1986

Behavioural state	Definition
Travelling	Dolphins involved in persistent directional movement at speeds greater than resting; may involve porpoising at faster speeds.
Socialising	Dolphins leaping, chasing, and engaged in body contact with each other; involves aspects of play and mating with other dolphins; may serve a social and/or sexual role.
Milling	Dolphins showing frequent changes in direction that sometimes appear as a transitional behaviour between other behavioural states and is sometimes associated with foraging, socialising or play.
Feeding	Dolphins involved in any effort to capture and consume prey as evidenced by chasing fish on the surface, coordinated deep diving with loud exhalations but without contact between individuals, and rapid circle swimming; prey is sometimes observed in the mouth and frequently observed during the foraging bout.
Resting	Dolphins engaged in very slow movements as a tight group, occasionally stationary, and lacks the active components of the other behaviours described.

Table 2. Summary of Pearson's chi-square tests of outcome variable and boat-approach distance
Asterisk indicates significant differences ($P \leq 0.001$)

Group composition	Outcome variable	χ^2	*N*
Groups of dolphins including all groups	Behavioural state	123.10*	1776
	Group dispersal	172.66*	1776
	Direction of movement	378.49*	1776
Groups of dolphins including adults and calves	Behavioural state	82.86*	899
	Group dispersal	125.17*	899
	Direction of movement	262.77*	899

Dolphins exhibited significantly less neutral direction of movement when experimental boat approaches were carried out at 50 m than they did during controlled approaches ($\chi^2 = 293.50$; Table 3) or approaches at a 150-m distance ($\chi^2 = 139.31$, Table 3).

Groups of dolphins including calves

We repeated the analysis including only groups that contained calves. Dolphins' behavioural states varied significantly by boat-approach distance when calves were part of the group ($\chi^2 = 82.86$; Fig. 5, Table 2). Dolphins fed significantly less when the experimental boat approaches were carried out at 50 m than they did during controlled approaches ($\chi^2 = 23.75$; Table 4) or approaches at a 150-m distance ($\chi^2 = 11.20$; Table 4). Dolphins rested significantly less when the experimental boat approaches were carried out at 50 m than they did during controlled approaches ($\chi^2 = 13.28$; Table 4) or approaches at a 150-m distance ($\chi^2 = 50.52$; Table 4).

Dolphins' group dispersal varied significantly by boat-approach distance when calves were part of the group ($\chi^2 = 125.17$; Fig. 6, Table 2). Dolphins formed significantly tighter (less dispersed) groups when experimental boat approaches

Table 3. Summary of chi-square tests of association between outcome variables and boat-approach distances for all dolphin groups
Asterisk indicates significant differences ($P \leq 0.001$)

Outcome variable		Association between outcome variable and boat-approach distance	χ^2	*N*
Behavioural state	Feeding	Control, 150 m	1.91	1333
		Control, 50 m	50.98*	1365
		150 m, 50 m	27.95*	854
	Resting	Control, 150 m	34.27*	1333
		Control, 50 m	9.81	1365
		150 m, 50 m	47.15*	854
	Other	Control, 150 m	3.07	1333
		Control, 50 m	64.41*	1365
		150 m, 50 m	74.64*	854
Group dispersal	Less dispersed	Control, 150 m	9.11	1333
		Control, 50 m	128.80*	1365
		150 m, 50 m	50.52*	854
	Average	Control, 150 m	24.97*	1333
		Control, 50 m	95.61*	1365
		150 m, 50 m	10.56	854
	More dispersed	Control, 150 m	23.36*	1333
		Control, 50 m	9.87	1365
		150 m, 50 m	41.74*	854
Direction of movement	Neutral	Control, 150 m	1.16	1333
		Control, 50 m	293.50*	1365
		150 m, 50 m	139.31*	854

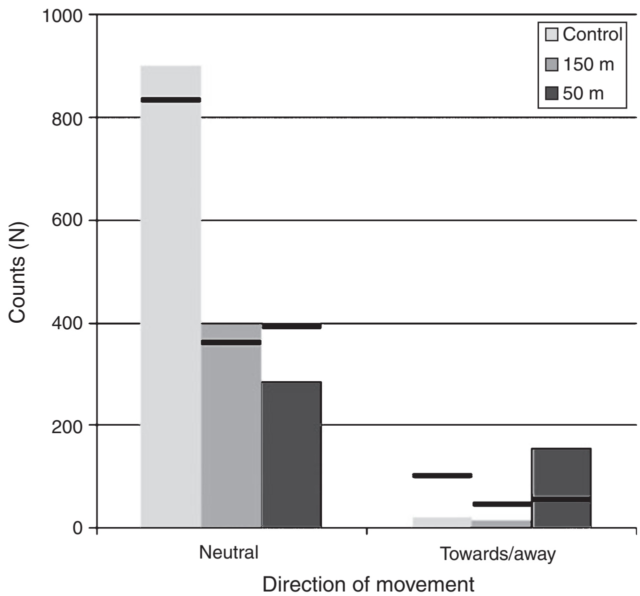

Fig. 4. Effect of distances of experimental boat approaches on the direction of movement of Indo-Pacific bottlenose dolphins in the Port Stephens–Great Lakes Marine Park, New South Wales, Australia; black bars indicate expected values.

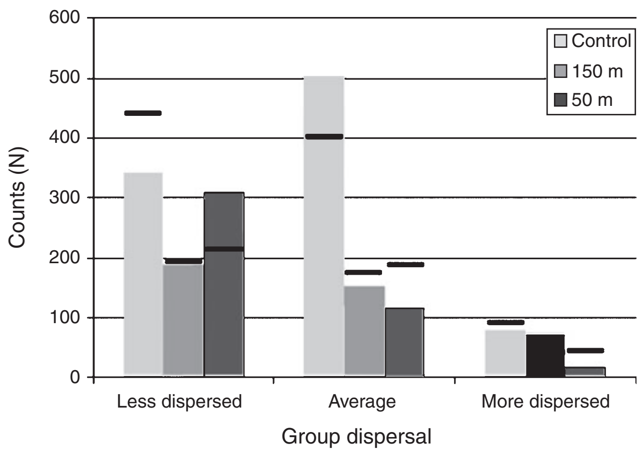

Fig. 3. Effect of distances of experimental boat approaches on the group dispersal of Indo-Pacific bottlenose dolphins in the Port Stephens–Great Lakes Marine Park, New South Wales, Australia; black bars indicate expected values.

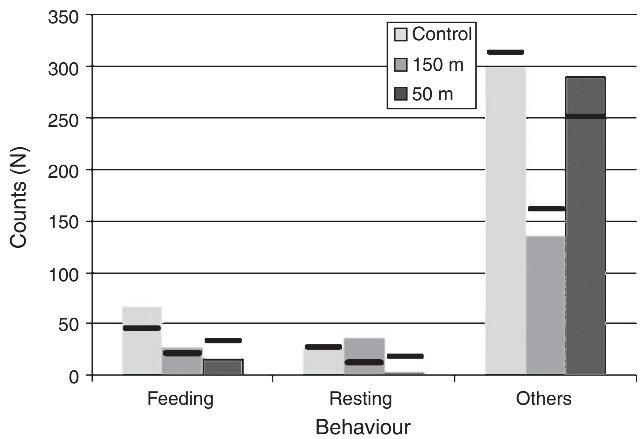

Fig. 5. Effect of distances of experimental boat approaches on the behavioural states of Indo-Pacific bottlenose dolphin groups, including calves, in the Port Stephens–Great Lakes Marine Park, New South Wales, Australia; black bars indicate expected values.

Table 4. Summary of chi-square tests of association between outcome variables and boat-approach distances for dolphin groups including adults and calves

Asterisk indicates significant differences ($P \leq 0.001$)

Outcome variable		Association between outcome variable and boat-approach distance	χ^2	*N*
Behavioural state	Feeding	Control, 150 m	1.20	589
		Control, 50 m	23.75*	701
		150/50 m	11.20*	508
	Resting	Control, 150 m	19.67*	589
		Control, 50 m	13.28*	701
		150 m, 50 m	50.52*	508
	Other	Control, 150 m	4.66	589
		Control, 50 m	39.28*	701
		150 m, 50 m	58.91*	508
Group dispersal	Less dispersed	Control, 150 m	2.02	589
		Control, 50 m	79.41*	701
		150 m, 50 m	41.40*	508
	Average	Control, 150 m	10.19	589
		Control, 50 m	58.63*	701
		150 m, 50 m	8.03	508
	More dispersed	Control, 150 m	18.47*	589
		Control, 50 m	16.32*	701
		150 m, 50 m	51.69*	508
Direction of movement	Neutral	Control, 150 m	0.14	589
		Control, 50 m	191.06*	701
		150 m, 50 m	106.51*	508

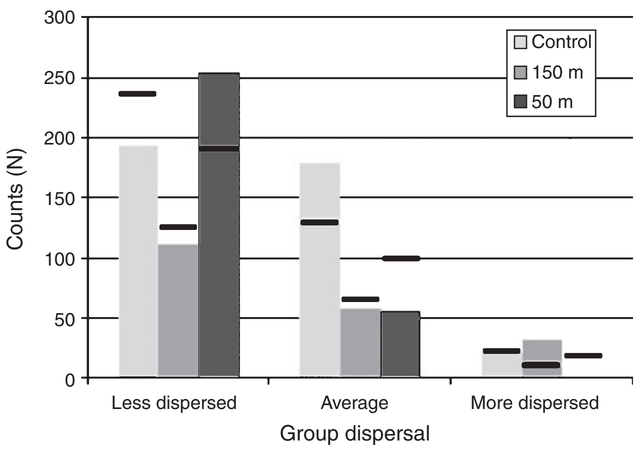

Fig. 6. Effect of distances of experimental boat approaches on the group dispersal of Indo-Pacific bottlenose dolphin groups, including calves, in the Port Stephens–Great Lakes Marine Park, New South Wales, Australia; black bars indicate expected values.

were carried out at 50 m, than they did during controlled approaches ($\chi^2 = 79.41$; Table 4) or approaches at 150-m distance ($\chi^2 = 41.40$; Table 4).

Dolphins' direction of movement varied significantly by boat-approach distance when calves were part of the group ($\chi^2 = 262.77$; Fig. 7, Table 2). Dolphins exhibited significantly less neutral direction of movement when experimental boat approaches were carried out at 50 m than they did during

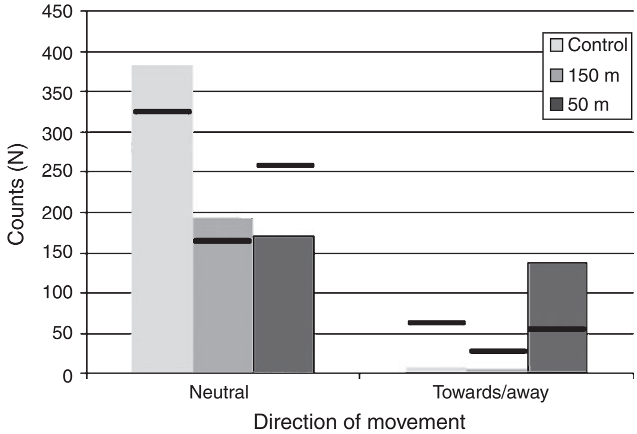

Fig. 7. Effect of distances of experimental boat approaches on the direction of movement of Indo-Pacific bottlenose dolphin groups, including calves, in the Port Stephens–Great Lakes Marine Park, New South Wales, Australia; black bars indicate expected values.

controlled approaches ($\chi^2 = 191.06$; Table 4) or approaches at a 150-m distance ($\chi^2 = 106.51$; Table 4).

Discussion

Interactions with vessels can affect the behaviour of long-lived animals with a complex social structure, such as dolphins, in many different ways (Mann *et al.* 2000). The results of the present study have shown that behavioural states of dolphins are affected by approach distances of boats. There was significantly less feeding and resting when the boat approached a dolphin group to a distance of 50 m than there was with 150-m-distance or controlled approaches. In physiological terms, feeding and resting behaviours, in particular, play a fundamentally important role for dolphins (Bejder and Samuels 2003; Lusseau 2004). The disruption of these vital activities can cause an increase in energy expenditure because of an increased metabolic rate (Bishop 1999). This, in turn, may affect the health of individual animals, their reproductive success and the population on a long-term basis (Gregory and Rowden 2001; Constantine *et al.* 2004). For a small, resident population such as the one in the PSGLMP, a significant decline in local dolphin abundance could be devastating for their long-term viability.

Bejder *et al.* (2006*b*) described a similar case for a resident population of dolphins (*Tursiops* sp.) in Shark Bay, Western Australia (WA). In that study, with only two commercial dolphin-watching vessels operating, the authors found evidence of negative, long-term impacts on the dolphin population (Bejder *et al.* 2006*b*). Allen *et al.* (in press) also recorded more travelling and less resting, feeding and socialising for dolphins in Port Stephens when dolphin-watching boats were present within 100 m. Similar results were found for bottlenose dolphins (*T. truncatus*) in Bunbury, WA, where encounters with dolphin-watching boats within 150 m resulted in more travelling and less feeding and resting (Arcangeli and Crosti 2009). In contrast, Hawkins and Gartside (2009) tested the same distance with Indo-Pacific bottlenose dolphins (*T. aduncus*) in Byron Bay, NSW, and dolphins there spent less time travelling and more time milling and socialising in the presence of one motor vessel or one sailing yacht operating as dolphin-watching boats. However, these interactions with boats lasted for only approximately 3 min each and the overall boat traffic in that area is very small, with only two dolphin-watching boats (Hawkins and Gartside 2009). Other cetacean species appear to show less tolerance towards boat-approach distances. Southern resident killer whales (*Orcinus orca*) along San Juan Island, USA, spent more time travelling and less time feeding when whale-watching boats were as far as 1000 m away from the pod (Lusseau *et al*. 2009). Humpback whales (*Megaptera novaeangliae*) also exhibited less feeding behaviour when encountered by whale-watching boats within 1000 m along the south-eastern coast of Australia (Stamation *et al*. 2010).

The results of the present study also showed that the dispersal of a dolphin group was significantly tighter (less dispersed) when the boat approached to 50 m than that with 150-m or controlled approaches. The same population of dolphins showed similar behaviour in an observational study of actual tour boats (Allen *et al*. in press). For example, group dispersal was 2.6 times more likely to be 'mid' or 'tight' when a tour boat was present within 100 m (Allen *et al*. in press). Bottlenose dolphins (*Tursiops* sp.) in Shark Bay, WA, also showed tighter groups when experimental boat approaches mimicking dolphin-watching boats were carried out at 50 m (Bejder *et al*. 2006*a*). Other bottlenose dolphin (*T. truncatus*) populations exhibited tighter group cohesion at distances of 100 m, such as during experimental boat approaches in Sarasota Bay, Florida (Nowacek *et al*. 2001), and during approaches of high-speed personal watercraft in Mississippi Sound, Mississippi, USA (Miller *et al*. 2008). In Chilean dolphins (*Cephalorhynchus eutropia*) in Yaldad Bay, southern Chile, tighter groups were recorded with boats at distances up to 500 m (Ribeiro *et al*. 2005) and *Stenella* spp. in the eastern Pacific at ~9 km (Au and Perryman 1982).

The dolphins' direction of movement was significantly less neutral when the experimental boat approaches were carried out at a distance of 50 m than that with 150-m-distance or controlled approaches. Bottlenose dolphins (*T. aduncus*) off the southern cost of Zanzibar (Stensland and Berggren 2007) and in Shark Bay, WA (*Tursiops* sp.; Bejder *et al*. 2006*a*), appear to avoid dolphin-watching boats at similar approach distances. This was also the case for estuarine dolphins (*Sotalia guianensis*) in south-eastern Brazil (Filla and Monteiro-Filho 2009). Bottlenose dolphins (*T. aduncus* and *truncatus*) in other areas show movement away from the source of disturbance within 100 m (Nowacek *et al*. 2001; Lemon *et al*. 2006). For other dolphins and whales, responses may occur at far greater approach distances, for example, 400 m for killer whales (Williams *et al*. 2009) and up to ~9 km for *Stenella* spp. (Au and Perryman 1982).

The responses described for the changes in the dolphins' group dispersal and direction of movement can be considered as typical predator-avoidance responses (Howland 1974). These flight responses to human disturbance appear to be because it is perceived by animals as being similar to predation risk (Walther 1969). This disturbance in turn can be considered as a deviation in an individual's behaviour from patterns that would occur in the absence of anthropogenic influences. Consequently, these animals may use significant time and energy avoiding disturbance that could otherwise have been used for fitness-enhancing activities such as feeding, parental care or mating (Frid and Dill 2002). Ultimately, these impacts may indirectly affect the survival and fecundity of the targeted population (Gill *et al*. 2001). However, individuals may also exhibit tolerance of closer approaches to avoid the costs incurred by fleeing. Frid and Dill (2002) referred to this trade-off as the risk–disturbance hypothesis. The risk–disturbance hypothesis predicts that responses by disturbed animals will track short-term changes in the factors characterising disturbance stimuli, with responses being stronger when perceived risk is greater. Nowacek *et al*. (2001) found that not only is the distance of approach a factor determining the extent of how the animals perceive this risk, but also the duration of exposure, with longer exposure times having a greater impact. The changes in behavioural states, group dispersal and direction of movement of a group of dolphins experienced in the present study were based on experimental exposures of a maximum of 30 min. This value was chosen as a result of agreements by the Port Stephens Commercial Dolphin Watch Association to interact with dolphins for no longer than this time interval (Allen *et al*. 2007). However, the maximum accumulated, continuous time that a dolphin group experienced with dolphin-watching boats during a day in this area was observed to be 2 h and 40 min (A. Steckenreuter, pers. obs.). This suggests that the observed impacts during experimental boat approaches may be even greater because dolphins are generally exposed to dolphin-watching boats for longer time periods than that tested. Steckenreuter *et al*. (in press) estimated that each group of dolphins was encountered on average 2.8 and 6.2 times per day in winter and summer, respectively. Nowacek *et al*. (2001) have also shown that if the approach type is erratic, the impact on dolphins appear greater. This is because of a lack of predictability that translates into greater potential disturbance through enhanced risk of encounter (Nowacek *et al*. 2001).

The perceived disturbance of targeted animals and the potential accompanied impacts at a population level have been of concern by various parties for a long time, e.g. the International Fund for Animal Welfare and the International Whaling Commission (IWC 2001). This is of imminent importance when the focus is on small, resident, genetically distinct communities of animals that are frequently encountered by dolphin-watching boats. Under these circumstances, the effects may not be catastrophic but have a cumulative character (Duffus and Dearden 1990). Ultimately, the health and the reproductive success of individuals in the targeted population may be jeopardised by repeated disruptions of essential behavioural states such as foraging, resting and socialising.

In the case of the research area in Port Stephens, the management of recreational and dolphin-watching vessels should be addressed separately because tour vessels generally behave differently towards dolphins than recreational boats (Steckenreuter *et al*. in press). So far, management strategies such as the introduction of a voluntary code of conduct for dolphin-watching boat operators in Port Stephens have failed to minimise the impact of the tourism industry on the local dolphins (Allen *et al*. 2007). The effects of experimental approach distances of boats on the dolphins' behaviour, group structure and composition in the present study have verified the importance of keeping to the existing legislation. Thus, it is recommended that the NSW regulations, which stipulate 50 m to groups with adults only and 150 m to groups with calves, be maintained. It is also recommended that short-term impacts on dolphins and potential long-term impacts on the population continue to be monitored, because approaches at the distance of 50 m, even for groups containing only adults, as well as the number of boats, are known to cause alteration of the dolphins' behavioural states and their group dispersal (Steckenreuter *et al*. in press).

Wildlife viewing poses a dilemma for management authorities. There is a perpetual conflict between optimising viewing opportunities for the tourists whose payment often makes a substantial contribution to the local economy, and ensuring that disturbance from that tourism does not affect the viability of the animals being viewed. Management plans whose stated goals include both sustainability of a dolphin-watching industry and longer term viability of a dolphin population may reconcile these conflicting objectives and improve their decision making by using empirical measures such as those described in the present paper, rather than best guesses. The present study has provided important information for local wildlife-management authorities in Port Stephens, NSW. However, we suggest that the results presented here have implications for the management of dolphin-watching industries elsewhere, particularly new industries. Given the immense expense involved in undertaking controlled boat-approach studies, we suggest that these results provide a baseline for deriving management controls elsewhere. Accordingly, a general rule for conservative management practice might be that when dolphin groups have young calves present, the approach distance should be a minimum of 150 m, unless empirical studies on the local population suggest otherwise.

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