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Response of travelling bottlenose dolphins (*Tursiops aduncus*) to experimental approaches by a powerboat in Jervis Bay, New South Wales, Australia

Michelle Lemon[a,*], *Tim P. Lynch*[a,b], *Douglas H. Cato*[c], *Robert G. Harcourt*[a]

[a]*Marine Mammal Research Group, Graduate School of the Environment, Macquarie University, Sydney, New South Wales 2109, Australia*
[b]*Jervis Bay Marine Park, Huskisson, 2540 New South Wales, Australia*
[c]*Defence Science and Technology Organisation, Pyrmont, 2009 Sydney, Australia*

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ABSTRACT

Powerboats are potentially a significant source of disturbance to coastal cetaceans. Information is scarce, however, on the nature of interactions between powerboats and dolphins, particularly when both surface and acoustic behaviour are combined. The surface behaviour and acoustic response of travelling dolphins to approaches by a powerboat were assessed by a series of experimental trials between November 2001 and November 2003 in Jervis Bay, New South Wales, Australia. Dolphin behaviour was monitored continuously from an independent research boat before, during and after a powerboat approached ($n = 12$). Treatments were interspersed with control observations ($n = 12$). Changes in surface behaviour indicated differences between the treatment and control periods ($z = 2.24$, $p = 0.025$), with dolphins tending to alter their surface behaviour when exposed to the powerboat approach. Analysis also revealed a change in the direction of travel by dolphin groups when approached ($z = 3.22$, $p = 0.001$). Changes in surface behaviour occurred at vessel approach distances outside the minimum approach distance of 30 m for recreational and commercial vessels, as proposed by the New South Wales National Parks and Wildlife Service. In contrast, there were no changes in dolphin whistle rates ($F_{3,12} = 0.74$, $p = 0.54$) or the duration of echolocation click bouts ($F_{3,12} = 0.76$, $p = 0.59$) when approached. These findings indicate that powerboats do affect the surface behaviour and direction of travelling inshore bottlenose dolphins in Jervis Bay; however it appears that this impact is not reflected in their acoustic behaviour.

1. Introduction

Marine mammals inhabiting areas close to urban centres are at risk of disturbance from human activities (Richardson et al., 1995; Allen and Read, 2000). In particular, small motorised vessels have increased as a source of anthropogenic noise in coastal waters due to their rise in popularity (Allen and Read, 2000; Buckstaff, 2004).

Sound is an important sensory modality for cetaceans; for communication, to detect both predators and prey and to interpret their environment (Au, 2000; Tyack and Clark, 2000). Anthropogenic activities that occur in inshore waters may therefore induce modifications to the acoustic behaviour of cetaceans and/or may reduce their ability to communicate, navigate or orientate in their environment (Richardson et al., 1995).

* *Corresponding author*: Tel.: +61 417 672 979; fax: +61 2 9850 7972.
E-mail address: mlemon@gse.mq.edu.au (M. Lemon).
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The effect of human disturbance is frequently measured in terms of an animal's change in observed behaviour (Beale and Monaghan, 2004), with the extent of these changes used as a measure of the species susceptibility to disturbance (Gill et al., 2001; Blumstein et al., 2003). In the case of small cetaceans, their response to motorised vessels varies considerably; from attraction to flight, or in some cases, indifference (e.g., Avecedo, 1991; Janik and Thompson, 1996; Gregory and Rowden, 2001). The response of small cetaceans to motorised vessels may be a reaction to noise; rather than to visual cues. For instance, Hector's dolphins, *Cephalorhynchus hectori*, in New Zealand react to approaching vessels at a distance of 2 to 3 km, far beyond the water visibility in the area (Bejder et al., 1999). However, other researchers have suggested that responses to boats may be a combination of both acoustic and visual cues (Richardson et al., 1995; Lesage et al., 1999; David, 2002). Reactions to vessels may also be related to the dolphins' surface behaviour at the time of the approach; and may also differ between populations. In a study by Constantine and Baker (1997), bottlenose dolphins, *Tursiops truncatus*, in New Zealand waters exposed to vessels were more prone to disturbance if socialising, but less likely if foraging. By contrast, in Florida, USA, Shane (1990) demonstrated that a change in behaviour was least common when bottlenose dolphins were actively socialising. All of these studies have in common that frequent interactions with boats resulted in short-term avoidance by dolphins of foraging areas, disruption to surface behaviour such as changes in surfacing and breathing patterns, and changes to group orientation, size and cohesion (e.g., Janik and Thompson, 1996; Allen and Read, 2000; Nowacek et al., 2001; Hastie et al., 2003; Goodwin and Cotton, 2004). The long-term effects of continual exposure however, have yet to be demonstrated unequivocally.

When approached by boats, delphinids have been shown to modify their phonation rates, possibly to enhance signal detectability (Lesage et al., 1999; Scarpaci et al., 2000; Van Parijs and Corkeron, 2001; Buckstaff, 2004). For example, bottlenose dolphins in Florida increased whistling rate at the onset of approaches by powerboats; however no changes occurred in whistle duration or frequency characteristics (Buckstaff, 2004). In Victoria Australia, Scarpaci et al. (2000) found that whistle rates of bottlenose dolphins were significantly greater in the presence of commercial dolphin-watch/swim boats. They suggested that group cohesion may have been affected due to physical separation of individuals, or that the increase in background noise required the dolphins to increase whistling rate to retain acoustic contact. Van Parijs and Corkeron (2001) found similar evidence of Indo-Pacific humpback dolphins, *Sousa chinensis*, increasing whistle rate after vessels passed through the study area, and once again, suggested that vessel noise may have affected group cohesion.

Inshore populations of bottlenose dolphins have discrete home ranges, and consequently, may be particularly vulnerable to anthropogenic impacts. In coastal areas of the Australian state of New South Wales, the Indo-Pacific bottlenose dolphin, *Tursiops aduncus*, inhabit some of the nation's busiest waterways. One such resident population inhabits Jervis Bay, on the southeast coast of New South Wales. Jervis Bay is a popular site for recreational fishing and in the last 10 years the amount of fishing effort has more than doubled (Lynch et al., 2004). During peak periods, at any one time, between 100 and 200 small motorised vessels may be operating in the bay (Lynch, unpublished data). There is significant community and government concern for the appropriate management of the resident dolphins, with the main goal being conservation; however, a secondary incentive is to determine the sustainability of the growing ecotourism industry based on this dolphin population. Previous research on these dolphins (Mandelc, 1997; Möller, 2001; Möller and Beheregaray, 2001; Möller et al., 2002) have demonstrated that their preferred habitats, seagrass meadows and rocky substrata, are also frequently used by recreational fishers (Lynch, in press), who often combine fishing activities with opportunistic interactions with dolphins (Lemon, pers. obs.).

While there has been increasing scientific effort to quantify surface behavioural responses of delphinids to recreational vessel disturbance (e.g., Janik and Thompson, 1996; Allen and Read, 2000; Nowacek et al., 2001; Hastie et al., 2003; Goodwin and Cotton, 2004), there has been limited research on their corresponding acoustic response (Scarpaci et al., 2000; Van Parijs and Corkeron, 2001; Buckstaff, 2004), and no studies, to our knowledge, that quantify both vocal and non-vocal behaviour of bottlenose dolphins in response to boat disturbance. The daily movement patterns of inshore dolphins are often governed by prey distribution and availability (Shane, 1990), and account for 40% of the daily activity patterns of dolphins in Jervis Bay (Lemon, unpublished data), thus it is important to recognise if travelling dolphins are potentially disrupted by powerboats. Research to date, on the response of inshore dolphins to vessels has been primarily observational, rather than experimental (Bejder and Samuels, 2003). Without controls, it is uncertain how observed behaviour of dolphins in the presence of vessels differs from their behaviour in the absence of vessels (Richardson et al., 1995). We attempted to address these issues by investigating the vocal and non-vocal response of inshore bottlenose dolphins to approaches by powerboats in Jervis Bay, with a controlled before, during and after experimental design. Our experiment was designed to simulate powerboat approaches to dolphins as established in a pilot study of similar recreational boat use. The results will assist in management of coastal cetaceans in New South Wales, and for determining recommendations for the most appropriate approach distances of recreational vessels to inshore delphinids.

2. Methods

2.1. Study site

Jervis Bay (35°07′S, 150°42′E) is located on the southeast coast of Australia. There are two commercial dolphin-watch vessels operating on a year-round basis at this location, as well as dive and fishing charters, and recreational and commercial fishing operations. Jervis Bay is also a training area for the Australian Defence Force.

2.2. Dolphin population

Approximately 120 resident and transient Indo-Pacific bottlenose dolphins inhabits Jervis Bay (Möller, 2001). The dolphins have a demonstrated preference for the periphery of the Bay in waters of less than 11 m, and are frequently sighted over seagrass and rocky habitats (Mandelc, 1997).

2.3. Field methods

Experimental approaches to focal dolphin groups were undertaken between November 2001 and November 2003 in a 5.6 m aluminium powerboat with a 90 hp two-stroke outboard motor, which is similar to other types of recreational boats in Jervis Bay. We observed the dolphins from a separate research boat (3.3 m inflatable, 25 hp two-stroke outboard motor or Minnkota 42 lb electric motor). To avoid confusion in terminology, the boat used in the experimental approaches is referred to as the 'powerboat' and the boat used for the observations and recordings is referred to as the 'research boat'. We conducted surveys to locate dolphins by circumnavigating the Bay in the research boat at a speed of approximately 10 knots, measured using a Geographic Positioning System (Lowrance Globalmap 100). Groups of dolphins, rather than individuals, were sampled as our objective was to understand interactions on the group level as bottlenose dolphins are a social species. We defined a group as any dolphin in association with another within a 100 m radius, moving in the same direction and often engaged in the same activity (Shane et al., 1986). Group composition was determined by visual observations of body size, and included adults, calves and newborns. Calves were defined as dolphins that were two-thirds or less the length of an adult, and swimming consistently beside or slightly behind an adult. Newborns were defined as dolphins with visible foetal folds in close association with a female, assumed to be the mother, and typically head slapped when breathing (Shane, 1990). It is recommended that vessels do not approach dolphin groups with very young calves present (Australian and New Zealand Environment and Conservation Council, 2000), thus no groups that included foetal fold calves were targeted for our experiments.

When a focal group was sighted, we turned the research boat's two-stroke motor off and engaged the electric motor in order to minimise noise disturbance while maintaining position with the dolphin group. During observations, we positioned the research boat to the rear and side of the group at a distance of approximately 50 m, measured using a laser rangefinder (Bushnells, 400 Yardage Pro).

At the beginning of each encounter, we recorded the following details; time, estimate of dolphin group size, surface behaviour, group composition, a compass bearing of the group's travel direction, wind direction and wind speed. Observations of the dolphins ceased when the wind speed approached Beaufort 3, as sightings then became less reliable (Barco et al., 1999), or when the group moved greater than an estimated 250 m from the research vessel.

2.3.1. Surface behaviour

Dolphin surface behaviour was recorded using instantaneous sampling every minute (Altmann, 1974), assigning one of five behavioural states, which were modelled on the descriptions by Shane (1990) and Constantine et al. (2004). Dolphin behavioural states included, travelling: dolphins engaged in linear directional movement between 1.5 and 3 knots (dolphins travelling at greater than 3 knots were not recorded due to difficulty in maintaining position with the research boat using the electric motor); foraging: referring to either individual or coordinated pursuit of prey by the dolphin group; milling: where dolphins were moving in varying directions with no observable surface behaviour; social activity: where dolphins were engaged in physical contact with each other, which may include mating or chasing behaviour; or travel/forage: where dolphins were travelling slowly, but still exhibiting foraging behaviour. From the total dataset, only travelling groups of dolphins were targeted in our experimental trials, as this was the most frequent behaviour observed during three years of field observations and statistical significance could only be achieved with this behavioural state.

2.3.2. Acoustic behaviour

Underwater sounds were recorded continuously from the research vessel during sampling. Sounds were received by a High Tech Inc. hydrophone (model HTI-96-MIN, sensitivity: -164 dB *re* 1 V/μPa, frequency response: 5 Hz–30 kHz) and recorded on digital audio tape recorder (TCD-D100; standard play frequency response 5 Hz–22 kHz; long play frequency response 5 Hz–4.5 kHz). The hydrophone was suspended one metre from the side of the boat, through a modified extension pole, to a depth of between two to three metres. Time of underwater sounds was recorded on the digital audio tape, along with concurrent verbal notes to coincide with instantaneous sampling of surface behaviour.

2.4. Experimental design

2.4.1. Treatments

Upon locating a travelling group of dolphins, we randomly assigned the group to either a control or treatment condition. Each experimental trial consisted of four phases totalling nine minutes (measured using a stop-watch) during which the dolphins' acoustic and surface behaviour were recorded. The four phases were: (1) 'pre-exposure' period with the powerboat stationary and engine off (three minutes); (2) 'on-approach' period with the powerboat approaching the focal group (one minute); (3) 'exposure' period with the power- boat moving slowly alongside the group (two minutes); (4) 'post-exposure' period when the powerboat had departed from the area (three minutes). During the three minute pre-exposure period, we recorded the vocal and non-vocal behaviour of the dolphins from the research boat, which was approximately 50 m from the focal group. This distance was chosen as it is the minimum approach distance proposed by the Australian and New Zealand Environment and Conservation Council to minimise any potential disturbance from boats. Following the pre-exposure period: (1) the on-approach period; (2) began when we radioed the powerboat operator to approach the dolphins at a speed of approximately 15 knots, starting forward of the group along a line at a 45° angle to the direction the group was travelling. When the approaching powerboat was approximately 100 m from the group we directed the operator to slow to five knots and the three minute exposure period (3) commenced. During the exposure period, the powerboat maintained a speed of approximately three knots, depending on the speed of the group, and a distance of approximately 100 m. To ensure consistency between experimental trials, we measured the distance of the focal group from the powerboat with a laser rangefinder. The powerboat operator remained in constant radio contact with the research boat, and at no point was the powerboat positioned directly ahead of the dolphins. After the exposure period, the powerboat departed from the immediate area. When the powerboat was several hundred metres away, the operator stopped the vessel and shut off the engines, at this point we commenced the post-exposure period (4).

2.4.2. *Controls*

In the control trials, we recorded the surface and acoustic behaviour of the dolphins from the research vessel. We did this for a period of nine minutes and during this time we only operated the electric motor.

2.4.3. *Experimental criteria*

Potential limitations of our experiment were any factors that affected the quality of sound recordings, for example the distance of the dolphins from the hydrophone. To limit this, we aborted trials when any of the following occurred: other vessels came within 500 m of the research boat (measured using rangefinders); the dolphins moved greater than 200 m away from the research boat; or if the powerboat came within 50 m of research vessel during the trials. Any of these would have had an adverse impact upon the signal-to-noise ratio of the underwater recordings.

2.5. *Analyses*

2.5.1. *Surface behaviour*

The reaction of the dolphins to the powerboat was evaluated on the basis of the predominant group activity and the orientation of the focal group with respect to the research boat. Each recording period was split into one minute sampling units. Throughout the trials, we scored changes in surface behaviour, within that one minute sampling period, from one state to another, as 'change' or 'no change'. We also noted the transition behaviour.

A change in the direction of travel during a one minute sampling period was scored if the focal group altered their heading relative to that of the preceding one minute sampling period. A change of at least 45° (as measured by compass bearing) relative to the direction the group was travelling was the minimum criteria for the altered heading. For example, the orientation of the focal group at the end of a sampling period was 0°, and during the next sampling minute the group changed their orientation by 45° or more, a change was noted. If the change in direction was greater than 135°, we recorded this change as *reverse*. For the experimental trials, when we observed a change it was also recorded as either being *towards* or *away* from the powerboat.

2.5.2. *Acoustic behaviour*

Underwater sounds were analysed as real time spectrograms (Fast Fourier Transform size: 512, screen time axis of 5 s, frequency range: 0–20,000 Hz, resolution 40 Hz, Hanning window) with the acoustic analysis program Spectrogram version 9.0 (Visualization Software LLC, 2003). To determine if the dolphins altered their calling rates throughout the experiment, their phonations were classified as either tonal whistles, burst-pulsed sounds or echolocation clicks (Popper, 1980).

To ascertain whether the calling rate changed for each experiment (treatment or control), the number of whistles (number per minute) and duration of echolocation bouts (seconds per minute), during each one minute sampling period were counted. To account for varying group size, the number of phonations was divided by the number of dolphins present. Calling rates were calculated as the total number of whistles or burst-pulses per dolphin (including adults and calves) per minute or total duration of echolocation click bouts per dolphin per minute. Whistle rates were also calculated for all behavioural activities encountered during the field season (not including the period when trials were undertaken) to determine if phonation rate changed with behaviour.

Nine minutes of recordings per trial were used for analysis which corresponded to three minutes of 'no-boat' (pre-exposure), three minutes of 'on-boat' exposure and three minutes of 'no-boat' (post-exposure) period.

2.6. *Statistical analysis*

Changes in surface behaviour (from travelling to non-travelling, or changes in direction of travel) were analysed using logistic regression models, as the response variable was dichotomous (0, 1 or change or no change). In order to take account of the multiple observations for each group, a population averaged 'generalised estimating equation' analysis was used, as implemented in Stata 9 (Statacorp, 2004). Data on calling rates were tested for differences using a repeated measure generalised linear model analysis of variance and 'Huynh–Feldt' statistics (Winer et al., 1991). This test was chosen as it is a robust test that is appropriate for modelling non-normally distributed data. Comparative analyses were undertaken on the mean number of phonations produced (whistles and duration of echolocation click bouts) in each treatment and corresponding control phase. Further statistical analysis was undertaken using non-parametric Mann–Whitney U tests. Analyses were undertaken using SPSS 12.0.1, JMP Version 4.0.2 and Systat 10.

2.7. *Masking by received levels of vessels*

During trials, it was noted that the noise from the powerboat was at its loudest when approaching the focal group, as recorded by the research boat, and so there was the possibility of boat noise masking the dolphin whistles. To determine if masking may have occurred during this period, the received noise level of the powerboat during the on-approach period was compared to the sound levels during the other experimental periods, including the pre-exposure (equal to ambient noise) and exposure period (powerboat moving slowly alongside the focal group during each trial). Noise spectra (sampling rate 44,100; Fast Fourier Transform size: 1024; spectral line resolution 43.07 Hz; Hanning window) were determined, averaging over a one minute recording of each experimental period using the program SpectraPLUS (FFT Spectral Analysis System, Version 2.32.04). Noise spectrum levels (dB *re* 1 μPa^2/Hz) were calculated against frequency (Hz) (200 Hz–14.5 kHz) for the ambient noise (pre-exposure), 'on-approach' period of the treatment powerboat, and 'exposure period' when the powerboat was moving alongside the dolphin group.

The masking level for a human listener was calculated by comparing the measured levels of the boat noise with the expected levels of the dolphin whistles. Whistles are sufficiently tonal to use the critical ratio (i.e., the amount by which a tonal signal must exceed the spectrum level background noise to be audible) to determine the signal-to-noise ratio at the masking threshold. The critical ratio for a human listener of 25 dB in the 8 kHz frequency range was used (Johnson, 1968) since this frequency is representative of the dolphin whistles in the study area. The expected received levels of the whistles were calculated from source levels by allowing for the propagation loss to the hydrophone. We used source levels measured in a study of wild bottlenose dolphins, *T. truncatus* (Janik, 2000), which indicated mean values (±SD) of 158 ± 6.4 dB *re* 1 μPa at 1 m (minimum: 134 dB *re* 1 μPa at 1 m, maximum: 169 dB *re* 1 μPa at 1 m). Transmission was assumed to be by spherical spreading and the transmission loss (TL) from the source to the receiver was calculated using the equation $TL = 20 \log r_2$ dB, where r_2 is the range from the sound source to the distant point.

3. Results

Data were collected over a period of 60 days (310 h). From a total of 112 encounters with dolphins and 26 experimental attempts, 12 treatment approaches and 12 control periods satisfied the experimental criteria. Of the 12 treatment approaches, 83% of the trials included calves, compared with 92% of the control periods. No groups with foetal fold calves were targeted in these experiments. Mean group size of the dolphins was 10.8 ± 3.2.

3.1. *Surface behaviour*

Focal dolphin groups changed their surface behaviour, from travelling to milling, in nine out of 12 approaches by the powerboat. The difference between the behaviour of the control and experimental groups was significant, $z = 2.24$, $p = 0.025$; Fig. 1(a). No other behaviour change was recorded. Furthermore, dolphins changed their direction of travel and oriented away from the approaching powerboat during nine experiments ($z = 3.22$, $p = 0.001$; Fig. 1(b)). Five of these groups retur- ned to the original direction of travel when the powerboat had departed the area during the post-

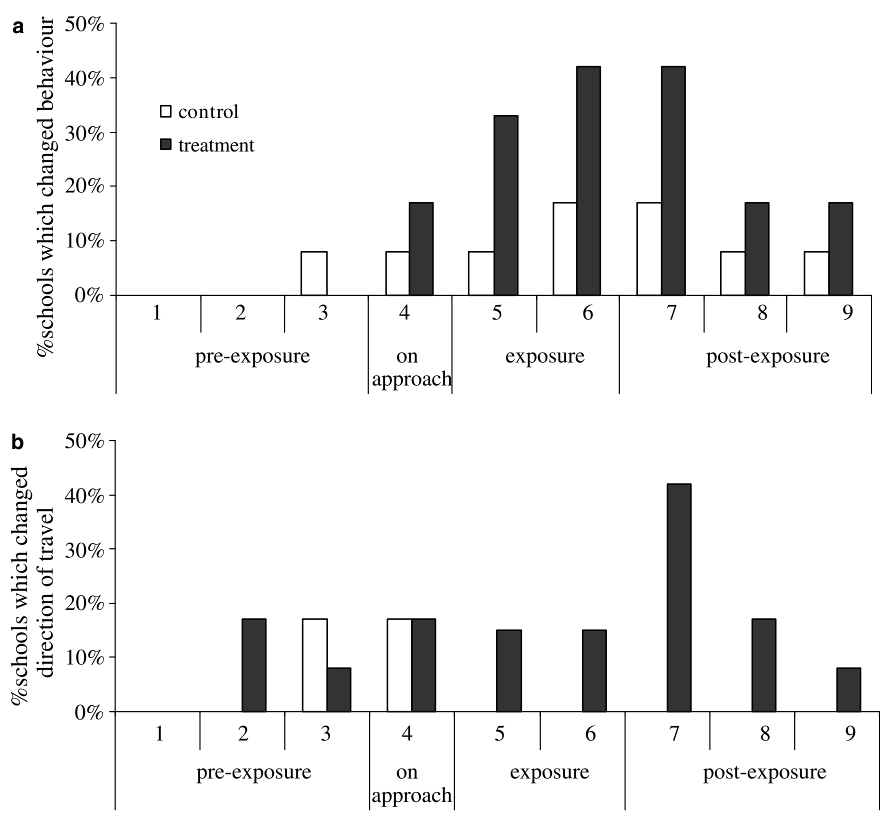

Fig. 1 – Percentage of focal dolphin groups that changed their surface behaviour from travelling to non-travelling behaviour (a), and changed their direction of travel (b) during the trials.

exposure period. There was a non-linear association (adjusting for the linear effect of time) between time and surface behaviour ($z = 3.36$, $p = 0.001$), and between time and direction of travel ($z = 2.74$, $p = 0.006$). The effects of condition were tested with time held constant. Analyses based on the ordered data for each group, using the runs tests, showed that there was no overall autocorrelation amongst the observations.

3.2. *Acoustic behaviour*

Acoustic analyses indicated negligible burst-pulsed sounds and so these phonations were excluded from further consideration. Whistle frequencies varied from 4.7 kHz (±2.1 kHz) to 9.9 kHz (±2.8 kHz). There was no difference in whistle rate between the treatments and controls (Huynh–Feldt statistics, $F_{3,12} = 0.738$, $p = 0.542$; Fig. 2(a)) and no significant effect of time (i.e., between each minute) during either the treatment or control periods ($F_{3,12} = 1.312$, $p = 0.277$). No differences were found in the duration of echolocation click bouts (seconds/individual/minute) of focal groups between the treatment and controls ($F_{3,12} = 0.76$, $p = 0.59$; Fig. 2(b)).

No significant difference in phonation rates were found between any treatment and corresponding control time periods: 'pre-exposure' period (whistles: $U = 79.5$, $p = 0.64$; echolocation click bouts: $U = 51.0$, $p = 0.16$), 'on-approach' period (whistles: $U = 78.5$, $p = 0.51$; echolocation click bouts: $U = 66.0$, $p = 0.55$), 'exposure' period (whistles: $U = 72.5$, $p = 0.97$; echolocation click bouts: $U = 44.5$, $p = 0.08$), and 'post-exposure' period (whistles: $U = 94.0$, $p = 0.14$; echolocation click bouts: $U = 65.0$, $p = 0.57$).

Whistle rate was calculated for each of the five observed behaviours encountered during the field sessions when there was no exposure to the treatment boat. Mean whistle rates (number/individual/minute) for each observed behaviour were, travel: 0.10 (SE 0.02), forage: 0.48 (SE 0.17), social: 1.05 (SE 0.39), travel/forage: 0.25 (SE 0.06), milling: 0.27 (SE 0.14) (Fig. 3).

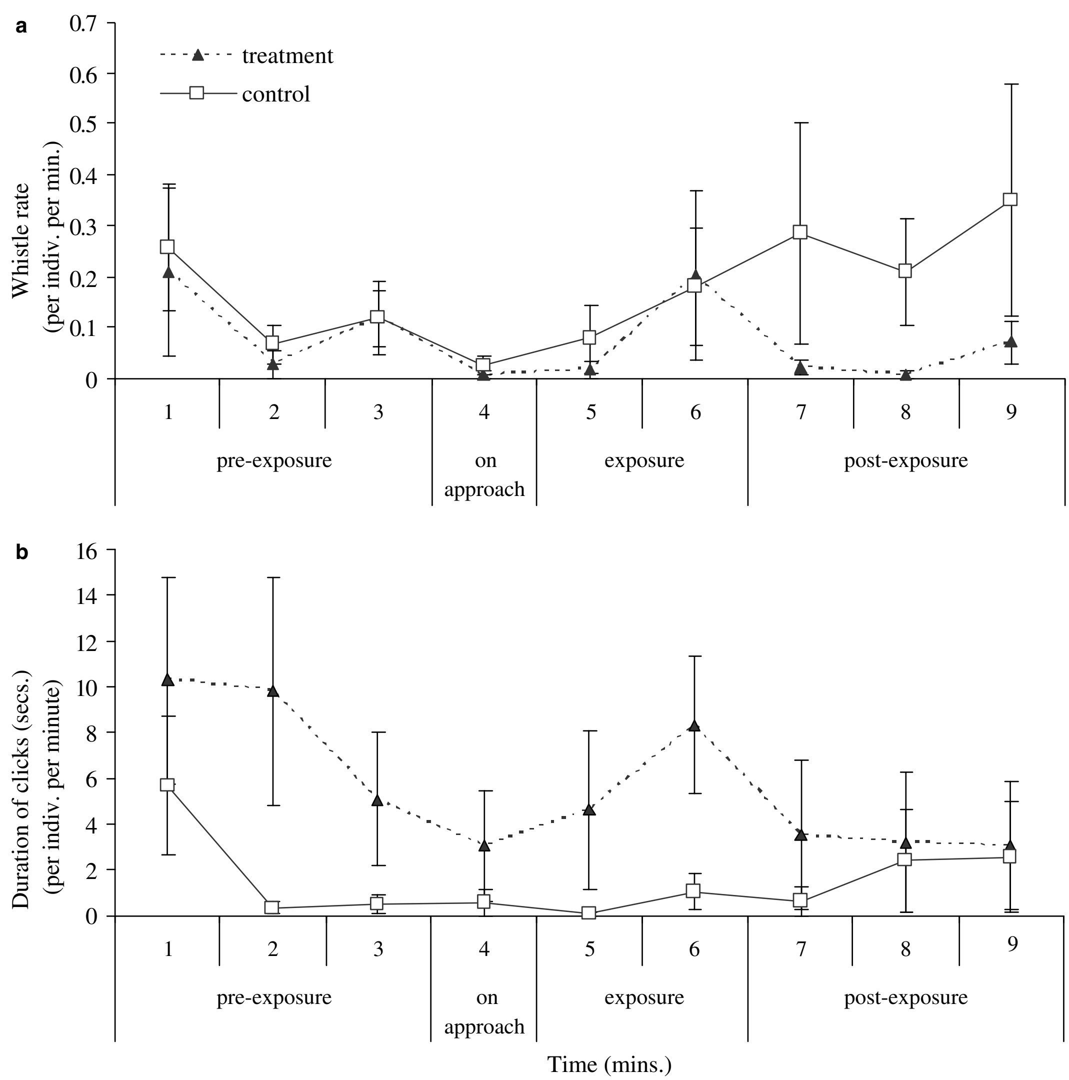

Fig. 2 – (a) Mean number (±SE) of whistles produced by travelling dolphins during the treatments (*n* = 12) and control periods (*n* = 12), per individual per minute of observation. (b) The duration of echolocation click bouts (±SE) produced by travelling dolphin groups during treatment (*n* = 12) and control periods (*n* = 12), per individual per minute of observation.

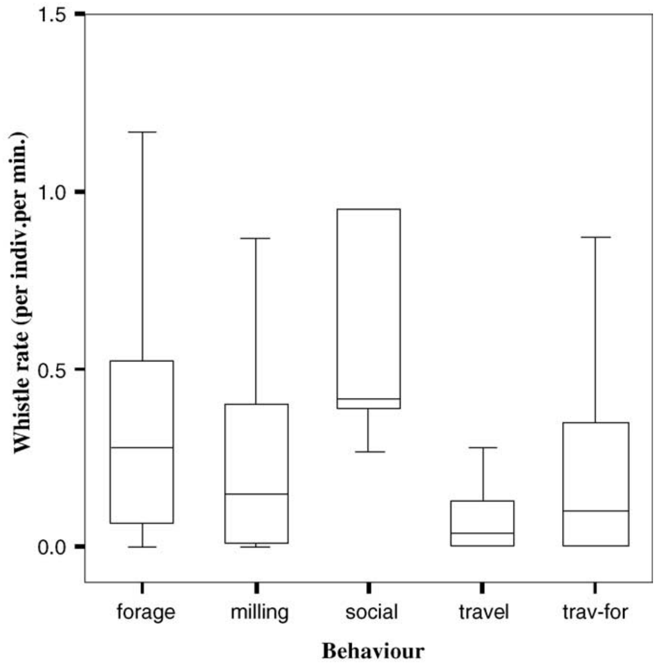

Fig. 3 – Median rates of production of whistles (number/individual/minute of observation) in five different behavioural states of dolphins observed during non-experiment periods in Jervis Bay in 2002 and 2003. The line in each box denotes the median, the lower and upper edges of the box are the 25% and 75% values, and the two whiskers represent the 10% and 90% values for whistle rate.

3.3. *Masking by received levels of vessels*

The powerboat noise spectra during the exposure period and the ambient noise, recorded from the research boat hydrophone are illustrated in Fig. 4. In the frequency range of the whistles, the received boat noise was about 7 dB above the ambient noise, and the level at 8 kHz was 53 *re* 1 μPa^2/Hz compared with the ambient noise level of 46 dB *re* 1 μPa^2/Hz. From this, the masking threshold for whistles was estimated to be 70 dB *re* 1 μPa for ambient noise and 78 dB *re* 1 μPa for the powerboat noise. The maximum distance of the dolphins from the research boat during the trials was 100 m, so that the maximum propagation loss, estimated by spherical spreading, would have been 40 dB. Using the source levels measured by Janik (2000), it is estimated that whistle levels at the hydrophone would have been at least 118 ± 6.4 dB *re* 1 μPa and thus about 34 dB above the masking threshold. At the lowest source level measured by Janik of 134 dB *re* 1 μPa at 1 m, a whistle at a distance of 100 m would exceed the masking threshold by 16 dB, well above the level required to

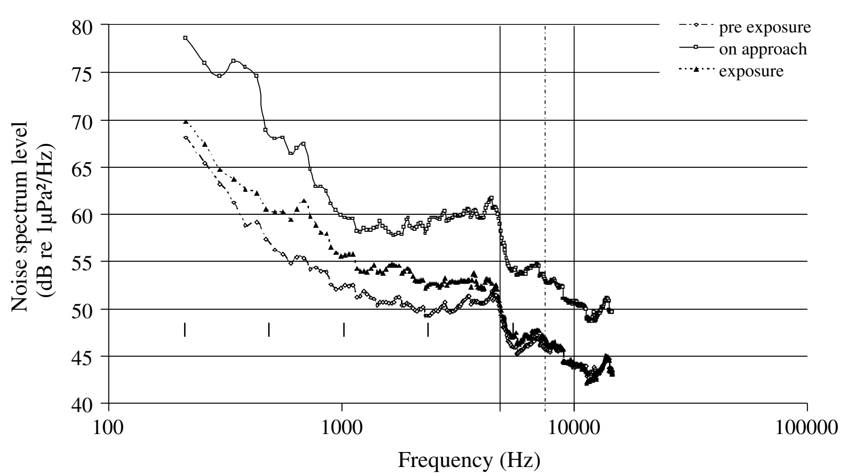

Fig. 4 – Spectra of the noise of selected powerboat approaches plotted against frequency (Hz) for the on approach and exposure periods, as well as the ambient noise spectrum measured during the pre-exposure period. The solid vertical lines indicate the frequency range of the dolphin whistles, while the dashed line is the representative frequency (8 kHz) used in this analysis.

be detectable. The spherical spreading assumption may be an overestimate of the propagation loss in this shallow water, so the minimum whistle noise levels may be higher than calculated. Thus, whistle levels received by the hydrophone should all have been well above the masking threshold, and as such, masking should not have affected these results.

Since the duration of click bouts rather than the number of clicks was measured, the result is less likely to be affected by masking, since the audible click bouts should be a representative sample of all bouts.

4. Discussion

This study has demonstrated that powerboat approaches alter the surface behaviour and direction of travelling coastal dolphins in Jervis Bay, Australia, at the exposure distance of approximately 100 m. Coinciding phonation rates however, were not affected. It appeared that dolphins became aware of the approaching vessel and consequently changed their surface behaviour from travelling to milling, a 'transition' behaviour (Constantine et al., 2004), and changed their direction of travel away from the powerboat. Interestingly, when the powerboat had departed the area and the noise from the boat had ceased, the dolphins often returned to their preceding behaviour, travelling in the original direction.

Because of their close proximity to urban environments, coastal cetaceans are exposed to anthropogenic activities. When vessels frequent areas near inshore cetaceans, there will undoubtedly be a limited interaction between them, for example dolphins' bow-riding. However, the fact that a reaction was observed even during the brief exposure (three minutes) in this study suggests that dolphins were aware of any vessel in their immediate environment. It may be that coastal dolphins are able to detect and localise incoming vessels at varying distances depending on the received noise level and the environmental conditions, and adapt their behaviour accordingly. Dolphins may use acoustic cues to gauge their distance to an approaching boat and based on that knowledge, plan their subsequent movements (Nowacek et al., 2001). Our research has focused specifically on understanding the effect of powerboats on travelling bottlenose dolphins using 'before-after control-impact' style experimentation where the original behavioural state is undisturbed, thus providing a control. This kind of sampling is widely used in investigations of environmental impacts. The principle of this sampling is that an anthropogenic disturbance, i.e., the 'impact', will cause a change from the state before or after the interaction that is different from the natural change in the control situation (Underwood, 1992).

If animals perceive a situation to be threatening, they are likely to adopt avoidance tactics similar to those observed when escaping a predator (Lima and Dill, 1990). Cetaceans can respond by displaying vertical avoidance, such as increasing their dive duration, or adopting horizontal avoidance by changing their swimming direction, for example killer whales, *Orcinus orca*, exposed to approaches by a boat adopted a less predictable path than when no vessels were present (Williams et al., 2002). The dolphins in the current study displayed horizontal avoidance by altering their travel direction away from the approaching powerboat. Short-term behavioural responses of delphinids to boats have been illustrated in previous studies, for example changes in swimming direction (Au and Perryman, 1982; Nowacek et al., 2001) and in breathing rates (Janik and Thompson, 1996), increased swimming speed (Kruse, 1998; Nowacek et al., 2001) and dive times (Ng and Leung, 2003), and changes in calling rates (Lesage et al., 1999; Scarpaci et al., 2000; Van Parijs and Corkeron, 2001; Buckstaff, 2004).

Research investigating changes in acoustic behaviour has generally focussed on foraging dolphins or on groups whose behaviour at the time of observation was not necessarily noted. Only one other published study has explored call rates of travelling delphinids in response to vessels. Foote et al. (2004) reported that travelling killer whales did not alter call rates in response to the presence of boats, although significant increases in call duration were observed. Dolphins in Jervis Bay did not change their phonation rates as a result of powerboat approaches. These results contrast with studies elsewhere that have identified changes in whistle rates of delphinids in response to the presence of powerboats (Van Parijs and Corkeron, 2001; Buckstaff, 2004). However, travelling dolphins in Jervis Bay are less vocal than when engaged in other activities, which has been also recognised in other delphinid populations (Van Parijs and Corkeron, 2001; Boisseau, 2005). Whistles are primarily used for individual recognition of conspecifics in a social group (Caldwell et al., 1990), and as contact calls (e.g., Smolker et al., 1993; Janik and Slater, 1998; Smolker and Pepper, 1999), and it is suggested that in turbid coastal waters, dolphins may rely on acoustic signals to maintain contact with conspecifics (Popper, 1980). Dolphins in Jervis Bay (mean group size of 10.8 ± 3.2) may be able to coordinate visual and physical contact when travelling without using increased acoustic signals, possibly as a result of the clear water conditions at this location (Ward, 1995), where horizontal visibility may be as great as 20 m. This may be particularly important if vessel noise does indeed mask communication signals. Results from this study support the notion that dolphins minimise acoustic communication while travelling. Low overall phonation rates in travelling delphinids has also been recognised in Pacific humpback dolphins, *S. chinensis*, (Van Parijs and Corkeron, 2001) and bottlenose dolphins, *T. truncatus*, in New Zealand (Boisseau, 2005).

In this study, there was no significant change in the duration of echolocation click bouts prior to the boat approaches or while the boat was in contact with the dolphins. Echolocation clicks are used by dolphins to perceive their environment and to detect and recognise prey, predators and obstacles (Au, 1993). Travelling groups of resident dolphins are likely to be familiar with their environment and conspecifics. They may therefore be able to navigate and orientate more efficiently, and accordingly produce fewer clicks. In Florida, bottlenose dolphins' resident to a relatively small area produced fewer echolocation clicks than dolphins inhabiting a much larger geographic area (Jones and Sayigh, 2002). The dolphins in Jervis Bay appear to act in a similar manner.

The dolphin population of Jervis Bay has been stable since the mid 1990s (Mandelc and Fairweather, 1995; Mandelc, 1997; Möller, 2001; Möller et al., 2002), coexisting with increasing proximal anthropogenic activities, such as recreational fishing boats (Lynch et al., 2004). Despite the dolphins' long-term exposure to human activities, changes in surface behaviour and direction of travel were short-term effects observed in response to controlled powerboat approaches. These changes in behaviour occurred at a distance of approximately 100 m, well outside the minimum suggested approach distance of 30 m as proposed by the New South Wales National Parks and Wildlife Service (National Parks and Wildlife Amendment (Marine Mammals) Regulation 2004, under the National Parks and Wildlife Act 1974).

Cetacean phonation rates have been used previously to assess anthropogenic disturbance, such as boat traffic (e.g., Van Parijs and Corkeron, 2001). Results from the present study have however, demonstrated that powerboats do not appear to affect the vocal production of resident travelling bottlenose dolphins, even when there is a significant effect on their surface behaviour and direction of travel. Results obtained from acoustic monitoring however, may be more indicative of anthropogenic impact when dolphins are exhibiting behaviours other than travelling at the outset. Further, an acoustic response may occur during other behavioural activities that were not detected in this study.

Cetaceans inhabiting coastal areas are undoubtedly influenced by human activities. As demonstrated in this study, a single anthropogenic event may cause a short-term disruption in dolphin behaviour, and it is possible that an accumulation of these effects may lead ultimately to long-term changes. However, long-term cumulative effects of vessel disturbance remain to be determined. It is important to establish baseline information on, for example, background noise levels, in order to assess changes in delphinid behaviour and long-term impacts from anthropogenic activities. Results from the present study may assist in the management of coastal delphinids around Australia, but it is proposed that longer-term monitoring of both the surface and acoustic behaviour of dolphins is necessary to assess potential impacts of both recreational and commercial boating activity and determine methods for minimising potentially detrimental interactions.

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REFERENCES

Allen, M.C., Read, A.J., 2000. Habitat selection of foraging bottlenose dolphins in relation to boat density near Clearwater, Florida. Marine Mammal Science 16, 815–824.

Altmann, J., 1974. Observational study of behavior: sampling methods. Behaviour 49, 227–267.

Australian and New Zealand Environment and Conservation Council, 2000. Australian National Guidelines for Cetacean Observation and Areas of Special Interest for Cetacean Observation. Environment Australia, Canberra.

Au, D., Perryman, W., 1982. Movement and speed of dolphin schools responding to an approaching ship. Fishery Bulletin 80, 371–379.

Au, W.W.L., 1993. The Sonar of Dolphins. Springer-Verlag, New York.

Au, W.W.L., 2000. Echolocation in dolphins. In: Au, W.W.L., Popper, A.N., Fay, R.R. (Eds.), Hearing by Whales and Dolphins. Springer-Verlag, New York, pp. 364–408.

Avecedo, A., 1991. Interactions between boats and bottlenose dolphins, *Tursiops truncatus*, in the entrance to Ensenada De La Paz, Mexico. Aquatic Mammals 17, 120–124.

Barco, S.G., Swingle, W.M., McLellan, W.A., Harris, R.N., Pabst, D.A., 1999. Local abundance and distribution of bottlenose dolphins (*Tursiops truncatus*) in the nearshore waters of Virginia Beach, Virginia. Marine Mammal Science 15, 394–408.

Beale, C.M., Monaghan, P., 2004. Behavioural responses to human disturbance: a matter of choice. Animal Behaviour 68, 1065–1069.

Bejder, L., Dawson, S.M., Harraway, J.A., 1999. Responses by Hector's dolphins to boats and swimmers in Porpoise Bay, New Zealand. Marine Mammal Science 15, 738–750.

Bejder, L., Samuels, A., 2003. Evaluating the effects of nature-based tourism on cetaceans. In: Gales, N., Hindell, M., Kirkwood, R. (Eds.), Marine Mammals: Fisheries, Tourism and Management Issues. CSIRO Publishing, Victoria, pp. 229–256.

Blumstein, D.T., Anthony, L.L., Harcourt, R.G., Ross, G., 2003. Testing a key assumption of wildlife buffer zones: is flight initiation distance a species-specific trait. Biological Conservation 110, 97–100.

Boisseau, O.J., 2005. The Acoustic Behaviour of Resident Bottlenose Dolphins in Fiordland, New Zealand. PhD thesis. University of Otago, Dunedin, New Zealand.

Buckstaff, K.C., 2004. Effects of watercraft noise on the acoustic behaviour of bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. Marine Mammal Science 20, 709–725.

Caldwell, M.C., Caldwell, D.K., Tyack, P.L., 1990. Review of the signature whistle hypothesis for the Atlantic bottlenose dolphin. In: Leatherwood, S., Reeves, R.R. (Eds.), The Bottlenose Dolphin. Academic Press, San Diego, California, pp. 199–234.

Constantine, R., Baker, C.S., 1997. Monitoring the Commercial Swim-with-Dolphin Operations in the Bay of Islands, New Zealand. Department of Conservation, Wellington, New Zealand.

Constantine, R., Brunton, D.H., Dennis, T., 2004. Local abundance and distribution of bottlenose dolphins (*Tursiops truncatus*) in the nearshore waters of Virginia Beach, Virginia. Biological Conservation 117, 299–307.

David, L., 2002. Disturbance to Mediterranean cetaceans caused by vessel traffic. In: Notarbartolo di Sciara, G. (Ed.), Cetaceans of the Mediterranean and Black Seas: State of knowledge and conservation strategies. p. 21. Report to the ACCOBAMS Secretariat, Section 11, Monaco.
Foote, A.D., Osborne, R.W., Hoelzel, A.R., 2004. Whale-call response to masking boat noise. Nature 428, 910.
Gill, J.A., Norris, K.S., Sutherland, W.J., 2001. Why behavioural responses may not reflect the population consequences of human disturbance. Biological Conservation 97, 265–268.
Goodwin, L., Cotton, P.A., 2004. Effects of boat traffic on the behaviour of bottlenose dolphins (*Tursiops truncatus*). Aquatic Mammals 30, 279–283.
Gregory, P.R., Rowden, A.A., 2001. Behaviour patterns of bottlenose dolphins (*Tursiops truncatus*) relative to tidal state, time-of-day, and boat traffic in Cardigan Bay, West Wales. Aquatic Mammals 27, 105–113.
Hastie, G.D., Wilson, B., Tufft, L.H., Thompson, P.M., 2003. Bottlenose dolphins increase breathing synchrony in response to boat traffic. Marine Mammal Science 19, 74–84.
Janik, V.M., 2000. Source levels and the estimated active space of bottlenose dolphin (*Tursiops truncatus*) whistles in the Moray Firth, Scotland. Journal of Comparative Psychology, 673–680.
Janik, V.M., Slater, P.J.B., 1998. Context-specific use suggests that bottlenose dolphin signature whistles are cohesion calls. Animal Behaviour 56, 829–838.
Janik, V.M., Thompson, P.M., 1996. Changes in surfacing patterns of bottlenose dolphins in response to boat traffic. Marine Mammal Science 12, 597–602.
Jones, G.J., Sayigh, L.S., 2002. Geographic variation in rates of vocal production of free-ranging bottlenose dolphins. Marine Mammal Science 18, 374–393.
Johnson, C.S., 1968. Masked tonal thresholds in the bottlenosed porpoise. Journal of Acoustical Society of America 44, 965–967.
Kruse, S., 1998. The Interactions between killer whales and boats in Johnstone Strait, B.C.. In: Pryor, K., Norris, K.S. (Eds.), Dolphin Societies: Discoveries and Puzzles. University of California Press, Berkeley, pp. 149–159.
Lesage, V., Barrette, C., Kingsley, M.C.S., Sjare, B., 1999. The effect of vessel noise on the vocal behaviour of belguas in the St. Lawrence River estuary, Canada. Marine Mammal Science 15, 65–84.
Lima, S.L., Dill, L.M., 1990. Behavioural decisions made under the risk of predation: a review and prospectus. Canadian Journal of Zoology 68, 619–640.
Lynch, T., in press. A test of theoretical assumptions behind design of marine protected areas. Conservation Biology.
Lynch, T.P., Wilkinson, E., Melling, L., Hamilton, R., Macready, A., Feary, S., 2004. Conflict and impacts of divers and anglers in a marine park. Environmental Management 33, 196–211.
Mandelc, F., 1997. Ecology and Conservation of the Bottlenose Dolphin (*Tursiops truncatus*) in Jervis Bay, NSW. PhD thesis. Graduate School of the Environment, Macquarie University, Sydney, Australia.
Mandelc, F.G., Fairweather, P.G., 1995. Jervis Bay's dolphins: conservation and management. In: Cho, G., Georges, A., Stoutjesdijk, R. (Eds.), Jervis Bay: A Place of Cultural, Scientific and Educational Value. Australian Nature Conservation Agency, Canberra, pp. 152–156.
Möller, L.M., 2001. Social Organisation and Genetic Relationships of Coastal Bottlenose Dolphins in Southeastern Australia. PhD thesis. Graduate School of the Environment, Macquarie University, Sydney, Australia.
Möller, L.M., Beheregaray, L.B., 2001. Coastal bottlenose dolphins from southeastern Australia are *Tursiops aduncus* according to sequences of the mitochondrial DNA control region. Marine Mammal Science 17, 249–263.
Möller, L.M., Allen, S.J., Harcourt, R.G., 2002. Group characteristics, site fidelity and seasonal abundance of bottlenose dolphins *Tursiops aduncus* in Jervis Bay and Port Stephens, southeastern Australia. Australian Mammalogy 24, 11–21.
Ng, S.L., Leung, S., 2003. Behavioural response of Indo-Pacific humpback dolphin (*Sousa chinensis*) to vessel traffic. Marine Environmental Research 56, 555–567.
Nowacek, S.M., Wells, R.S., Solow, A.R., 2001. Short-term effects of boat traffic on bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. Marine Mammal Science 17, 673–688.
Popper, A.N., 1980. Sound emission and detection by delphinids. In: Herman, L.M. (Ed.), Cetacean Behavior: Mechanisms and Functions. John Wiley and Sons Inc., New York, pp. 1–52.
Richardson, W.J., Greene Jr., C.R., Malme, C.I., Thomson, D.H., 1995. Marine Mammals and Noise. Academic Press, San Diego, California.
Scarpaci, C., Bigger, S.W., Corkeron, P.J., Nugegoda, D., 2000. Bottlenose dolphins (*Tursiops truncatus*) increase whistling in the presence 'swim-with-dolphin' tour operations. Journal of Cetacean Research and Management 2, 183–185.
Shane, S.H., 1990. Behavior and ecology of the bottlenose dolphin at Sanibel Island, Florida. In: Leatherwood, S., Reeves, R.R. (Eds.), The Bottlenose Dolphin. Academic Press, San Diego, California, pp. 245–266.
Shane, S.H., Wells, R.S., Würsig, B., 1986. Ecology, behaviour and social organisation of the bottlenose dolphin: a review. Marine Mammal Science 2, 34–63.
Smolker, R.S., Pepper, J.W., 1999. Whistle convergence among allied male bottlenose dolphins (Delphinidae, *Tursiops* sp.). Ethology 105, 595–617.
Smolker, R.S., Mann, J., Smuts, B.B., 1993. Use of signature whistles during separations and reunions by wild bottlenose dolphin mothers and infants. Behavioural Ecology and Sociobiology 33, 393–402.
Statacorp., 2004. Stata Statistical Software: Release 9.0. Stata Corporation, College Station, Texas.
Tyack, P.L., Clark, C.W., 2000. Communication and acoustic behaviour of dolphins and whales. In: Au, W.W.L., Popper, A.N., Fay, R.R. (Eds.), Hearing by Whales and Dolphins. Springer-Verlag, New York, pp. 156–224.
Underwood, A.J., 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. Journal of Experimental Marine Biology and Ecology 161, 145–178.
Van Parijs, S.M., Corkeron, P.J., 2001. Boat traffic affects the acoustic behaviour of Pacific humpback dolphins, *Sousa chinensis*. Journal of the Marine Biological Association of the United Kingdom 81, 533–538.
Ward, T., 1995. Water quality. In: Cho, G., Georges, A., Stoutjesdijk, R. (Eds.), Jervis Bay: A Place of Cultural, Scientific and Educational Value. Australian Nature Conservation Agency, Canberra, pp. 3–8.
Williams, R., Trites, A.W., Bain, D.E., 2002. Behavioural responses of killer whales (*Orcinus orca*) to whale-watching boats: opportunistic observations and experimental approaches. Journal of Zoology, London 256, 255–270.
Winer, B., Brown, D., Michels, K., 1991. Statistical Principles in Experimental Design, third ed. McGraw-Hill, New York.