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PII: S0022-0981(06)00456-4
DOI: doi: 10.1016/j.jembe.2006.08.006
Reference: JEMBE 48081

To appear in: *Journal of Experimental Marine Biology and Ecology*

Received date: 20 February 2006
Revised date: 14 August 2006
Accepted date: 15 August 2006

Please cite this article as: Hodgson, Amanda J., Marsh, Helene, Response of dugongs to boat traffic: the risk of disturbance and displacement, *Journal of Experimental Marine Biology and Ecology* (2006), doi: 10.1016/j.jembe.2006.08.006

Response of dugongs to boat traffic: the risk of disturbance and displacement

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Abstract

Disturbance from boats has been documented for many species of marine mammals, especially cetaceans, but has never been quantified for dugongs. Dugongs depend on seagrass for food. This food mostly occurs in shallow coastal areas where boat traffic is high. Thus there is potential for boats to alienate dugongs from critical habitat areas. Using an overhead video observation system ('blimp-cam'), we observed the behaviour of focal dugongs during controlled boat pass experiments and while no boats were present. The percentage of time focal dugongs spent feeding and travelling was unaffected by boat presence, the number of boat passes and whether a pass included a stop and restart (pass continuity). The duration, distance and direction of a focal dugong's subsurface behaviour were unaffected by number, continuity or distance of boat passes. However, focal dugongs were less likely to continue feeding if the boat passed within 50 m, than if the boat passed at a greater distance. Mass movements of dugong feeding herds in response to experimental and opportunistically observed boats were timed on 42 occasions but only lasted an average of 122 s. These movements occurred in response to boats passing at a range of speeds, and at distances of less than 50 m to over 500 m. The levels of boat traffic we observed may reduce dugongs' feeding time budget by a maximum of 0.8 - 6%. Thus at present boats appear unlikely to be having a substantive effect on the energy intake of dugong populations at our study site on the Moreton Banks near Brisbane, Australia. However, boat traffic is likely to increase in this fast growing region, raising concern about the future impact of boats on this and other dugong populations.

Keywords: behaviour, blimp, boat traffic, disturbance, dugong, feeding

1. Introduction

Marine mammal populations continue to be threatened by direct human impacts such as hunting and incidental takes in fisheries and are under increasing pressure from the indirect effects of habitat modification (Marsh et al., 2003). Indirect effects include pollution, reductions in food availability, disturbance, and displacement from key habitats. Boat traffic is an example of human activity that has the potential to both disturb and displace marine mammals (Richardson et al., 1995). Disturbance occurs when marine mammals respond to the noise or perceived risk of boat strikes. Persistent interruptions of important behaviours such as feeding, courtship and mating can be energetically costly and affect the reproductive success of individuals. If, together with the direct risk of boat strike, disturbance from boats costs marine mammals more than the benefits of the resources available in an area, populations may be displaced. However, displacement is not necessarily the most significant effect of boat traffic. Animals can move and stay away from the disturbed area only when resources are available elsewhere. If animals can move to suitable habitat they may be less affected than animals forced to remain and tolerate the effects of disturbance (Gill et al., 2001). Both the reduction of habitat availability and the costs of disturbance can affect the survival of individual marine mammals and therefore entire populations.

In comparison with other marine mammals, there is a relatively large amount of literature on the behavioural responses of cetaceans to boats. Many short term behavioural responses have been documented, including changes in swim direction (Nowacek et al., 2001a; Williams et al., 2002; Lemon et al., 2006), increased swim speed (Kruse, 1991), shortened surfacing times (Gordon et al., 1992; Blane and Jaakson, 1994), lengthened interbreath intervals (Stacey and Hvenegaard, 2002; Lusseau, 2003a), reductions in inter-individual distances (Bejder et al., 1999; Jelinski et al., 2002), changes in the types of surface behaviours exhibited (Baker and Herman, 1989; Corkeron, 1995; Lemon et al., 2006), reductions in resting behaviour (Lusseau, 2003b; Constantine et al., 2004), an increase in breathing synchronicity between individuals (Hastie et al., 2003) and increased rates of whistle production (Buckstaff, 2004).

Variations in behavioural responses occur according to the characteristics of the boat traffic. In general, marine mammals tend to be most tolerant of boats moving at a consistent speed and least tolerant of fast, erratically moving boats (Richardson et al., 1995; McCauley et al., 1996). Responses of some cetaceans increase as the level of boat traffic increases, (Evans et al., 1992; Blane and Jaakson, 1994; Barr and Slooten, 1999), and the distance of the passing boat decreases (Nowacek et al., 2001a).

While short term behavioural responses to boats are relatively easy to assess, few studies quantify the long term effects of boat traffic, such as displacement (Richardson et al., 1995). Some exceptions include displacement of belugas (Delphinapterus leucas) in Alaska, which move from a river to a nearby bay when disturbed by boat noise in Bristol Bay (Stewart et al., 1982), and have disappeared from Cook Inlet, which is a high boat traffic area (Speckman and Piatt, 2000). Bottlenose dolphins (Tursiops truncatus) in Florida show a preference for deeper channels rather than their primary foraging habitats when boat traffic densities are high (Allen and Read, 2000). In New Zealand, this species avoids Milford Sound during periods of high boat traffic (Lusseau, 2005).

Although most of the work on the disturbance of marine mammals by boats has concentrated on cetaceans, there is equal, and perhaps even greater potential for boat disturbance to affect sirenians. As herbivores, sirenians are limited to the shallow and protected coastal or riverine areas where their forage is found (Heinsohn et al., 1977; Hartman, 1979; Anderson, 1981; Reynolds and Odell, 1991). Similarly, most recreational boat traffic occurs in protected coastal areas, and, through modifications in design, boats are increasingly able to travel in shallow water at high speed (Wright et al., 1995). Concern about the impact of boat traffic on sirenians has largely centred on the high incidence of boat strikes of the Florida manatee (Trichechus manatus latirostris). Approximately 25% of all known deaths of manatees in Florida are caused by boat strikes (Florida Fish and Wildlife Conservation Commission, n.d.). Similarly, along the urban coast of Queensland, boat strike mortality of dugongs is becoming increasingly common (Limpus et al., 2003) and dugongs are particularly vulnerable to boats travelling at high speed (Hodgson, 2004).

Short term behavioural responses indicative of disturbance from boats have been documented for both dugongs (Preen, 1992) and Florida manatees (Nowacek et al., 2004). Florida manatees increase swim speed and swim to deep water or channels when boats are within 25 – 50 m, and these responses are intensified when boat distance and water depth decrease (Nowacek et al., 2004). To date only qualitative observations of the response of dugongs to boats have been recorded (Anderson, 1981; Preen, 1992). During cliff-top observations, Anderson (1982) estimated that a dugong herd moved 500 m in response to a boat with an outboard motor passing slowly at a distance of 150 m from the herd. Preen (1992) suggested that dugongs could detect a speed boat from at least 1 km, but did not describe the behavioural responses indicative of detection.

Changes in the distribution of Florida manatees have been attributed to boat traffic (Provancha and Provancha, 1988; Buckingham et al., 1999). Florida manatees appear to be seeking areas of low boat traffic, increasing their use of sanctuaries where boating is prohibited in correlation with increased boating outside sanctuaries (Buckingham et al., 1999; Reynolds, 1999). There has, however, been no research on potential for the displacement of dugongs as a result of boat traffic, despite the persistent anecdotal reports from Indigenous hunters that such displacement has occurred in response to boat traffic in many areas (Johannes and MacFarlane, 1991; Kwan, 2002). Preen (1992) also suggested that boat traffic may have reduced dugongs' use of the western side of Moreton Bay. However, seagrass loss has also occurred in this area (Abal and Dennison, 1996).

Rapid increases in boat traffic along the urban coastline in Australia emphasise the importance of examining the potential for dugongs to be disturbed and/or displaced by boats. In Queensland there were over 198,700 boats registered in 2005, 97% of which were recreational boats (Queensland Transport, 2005). This represents a 45% increase in boat numbers since 1996 (Maritime Safety Queensland, 2005). In this study we quantify the impact of boat traffic on dugongs by observing their short-term response to both experimental and opportunistic boat passes. These observations are then related to the ‘undisturbed’ behaviour of dugongs, in an effort to assess the long-term biological significance of disturbance responses.

Methods

Study site

The response of dugongs to opportunistic boat passes (i.e., independent boaters) was recorded over 60 days during two field seasons, from August to October 2001, and from June to August 2002. Experimental boat passes were conducted from 23rd June to 29th July 2002. All field work was conducted on the Moreton Banks in Moreton Bay (153.3º E, 27.5º S), near the major city of Brisbane in southeast Queensland, Australia. This region is experiencing the highest rate of population growth in Australia with an average increase of 55,000 people per year over the last two decades (Queensland Government Office of Urban Management, 2005). Large herds of dugongs (up to 459 animals, with typical herd size of about 150 dugongs (Preen, 1992)) regularly use this area, which is classified as a Dugong and Turtle Go Slow Zone by the Queensland Parks and Wildlife Service. Boats are restricted to below planing speed on the banks to the 2 m low tide contour. Most observations of dugongs were within this boundary. This area has relatively clear water with 1 to 5 m horizontal visibility (Preen, 1992).

Observation platform

The behaviour of the dugongs was observed using a "blimp-cam": a tethered, helium-filled aerostat (balloon) carrying a remote-control surveillance camera (described in detail in Hodgson, 2004). The balloon was flown at approximately 50 m above the research boat. The pan/tilt, focus, zoom and iris of the video camera were operated via a controller and monitor on board the research boat. The research boat was anchored next to the dugong herd so as to eliminate the confounding effects of engine-noise disturbance from this boat.

All data were extracted from the video footage upon completion of the field work.

Experimental boat passes

The experimental boat was a 3.5 m aluminium dinghy with a 20 HP outboard engine, a commonly used engine size in the area. This boat was operated by a crew member directed via radio from the research boat. The experimental boat was set a course that would take it along a straight line from its initial position 1 km from the dugong herd to a point 50 m from the outer limit of the herd, and then along the same trajectory to 1 km past the herd (Fig. 1). We set this distance limit from the edge of the herd prior to beginning the first pass in each experiment in order to minimise the risk of boat strikes. However dugongs moved during the experiments so this distance did not remain constant. The speed of the experimental passes was approximately 7 knots to keep the boat below planing speed, which was the speed limit in the area.

Two variables were altered during the experiments to provide four possible treatments (Fig. 1):

(1) Number of passes

   a. the boat passed the dugongs once only
   b. the boat was driven back and forth along the same path five times.

(2) Continuity

   a. the boat was driven straight past the dugongs at a consistent speed
   b. when the boat reached the dugongs, the engine was switched off and on again immediately, and the pass continued.

Over 19 days, we aimed to conduct four experiments (one of each treatment where weather permitted) in alternating order each day with a minimum of half an hour between experiments. We successfully conducted 65 experiments.

Continuous behaviour of focal dugongs

Focal dugongs were randomly chosen, and continuous behavioural data were recorded (Altmann, 1974) during each experimental boat pass, as well as while no boats were passing. Mother-calf pairs were excluded to minimise individual variability in behaviour. It is possible that individuals were sampled more than once during these experiments as individuals could not be identified. However, herd sizes were variable, consisting of up to 200 animals, and herds are open and unstable, continually splitting and reforming throughout the day (Preen, 1992; Hodgson, 2004). The size and dynamic nature of the herds meant the probability of resampling the same individuals on any one day, or sampling individuals within the same herd throughout the study period, was low. Thus the results are unlikely to be biased by: (1) resampling the same individual many times, or (2) particular herds becoming habituated to our experimental dinghy.

Continuous behavioural samples lasted for 4.5 min, as this was the minimum time taken to conduct one boat pass. Shorter samples resulting from dugongs travelling beyond our field of view were eliminated, possibly biasing our sampling to dugongs that were not disturbed (i.e., not travelling away from the passing boat), thereby reducing the likelihood of observing an effect of the boat. We checked for this bias by comparing the sampling truncation rate for behavioural samples with no boat passing (26%; N = 97) with that during boat pass experiments (19%; N = 75). We concluded that the comparisons between undisturbed and disturbed dugongs should not have been affected by any bias against dugongs that responded to the passing boat.

The position of the focal dugong relative to the rest of the herd (group type) was scored at the commencement of each focal follow:

- main herd – in the largest group (all individuals within 3 body lengths of one another) visible
- subgroup – in a group separated from the main herd by more than three body lengths
- scattered – not within three body lengths of any other dugong

Feeding and travelling behaviours were used in the analysis, as few data were recorded for other behaviours such as resting and socialising. Six two-way ANOVAs were conducted to compare the effects of various factors on: (1) the proportion of time each focal individual spent travelling and (2) the proportion of time each focal individual spent feeding. The between-subjects factor was either: (1) boat presence, (2) pass number, or (3) pass continuity. The within-subjects factor was group type in each analysis. When examining the effects of the number of boat passes, only the results from the first, fourth and fifth passes were used, as these were most likely to show a significant result if dugongs became increasingly sensitised to boat noise throughout the experiments. The percentage of time spent feeding was square-root transformed in order to meet the assumption of normality of variance in all three ANOVAs testing this response. The large number of tests (6 ANOVAs each with tests for 2 or 3 factors and an interaction) used gave a high probability of at least one test being significant by chance alone for a Type 1 error rate of 0.05). We have reported actual P values and interpreted significant results with caution, rather than adjusting P values.

Behaviour during the closest approach interval

A trained observer recorded the estimated distance and bearing of the focal dugong from the research boat each time it surfaced. We plotted the movements of the focal dugong relative to the passing dinghy according to the GPS locations of both the research boat and the dinghy. We assumed the total error of the distance estimates between the dugong and the dinghy consisted of: (1) 2 x GPS unit error ≤ 15 m, and (2) observer distance estimate error, which averaged 15 m during training (Hodgson, 2004). Thus the maximum error was assumed to be 45 m, though some errors likely cancelled each other out. Our distance estimates should be considered with this error in mind.

The closest approach interval was the submergence interval (interval between two breaths and thus between two plotted locations) of the focal dugong at the time the passing boat was closest to this animal. During the closest approach interval of each pass we recorded the focal dugong's: (1) activity, (2) subsurface time, (3) travel distance, and (4) travel direction (Fig. 2).

The activity of the focal dugong during the closest approach interval, and the first full subsurface interval of each focal follow with no boat present, was recorded as feeding only, travelling only, or travelling and feeding. A chi-squared homogeneity test was conducted to determine whether boat presence and closest approach distance affected the activity of the focal dugong during the closest approach interval. One-tailed Fisher's exact tests were used to test whether dugongs were more likely to be feeding (and not travelling) when there was no boat than when a boat was present, and when the boat was passing beyond 50 m rather than within 50 m.

The travel direction of the focal dugong during the closest approach interval (according to the straight line between the two surfacings) was classified as 'same/away' or 'towards/opposite/stationary' from the path of the passing boat. We considered the former category as indicative of a response, as herd movements usually occurred away from passing boats, and the latter as no response. To test the effect of the closest approach distance on focal dugongs' travel direction, the distance of the dinghy was classed as either < 50 m, 50 – 200 m, or > 200 m. We used a Pearson's chi squared analysis to determine whether there was an effect of distance on the likelihood of dugongs responding to the boat.

Opportunistic observations

Experiments were limited by zoning speed restrictions at the study site, the cautious distance limits set to minimise the risk of the experimental boat hitting dugongs, and the use of a single boat type. Therefore we also incorporate data on the responses of dugongs to independent boats passing within approximately 1 km of the herds. These boats varied in type and often approached the dugongs at faster speeds and closer distances than we were permitted during our experiments.

The distance of the passing boat from the edge of the dugong herd was determined using one of the following techniques: (1) measured using a laser range finder in the field, (2) estimated visually in the field or (3) estimated from the video footage using the average length of dugongs as a guide.

Duration of herd responses to boats

While focal individuals were followed during boat pass experiments, the zoom of the camera was kept wide to keep as many other dugongs in view as possible. The response of the herd was based on the subset of the herd videoed. During opportunistic passes, we kept the maximum number of dugongs in frame and periodically panned to the passing boat to assess its relative location. Assessment of herd responses to both experimental and opportunistic passes was limited to herds of greater than 10 individuals and in which most dugongs were feeding with obvious plumes (trails of suspended sediment resulting from dugongs extracting seagrass) before the boat passed. This minimised the effects of varying activity states between passes and among individuals.

All herd movements occurring while boats were present were assumed to be a response to the boat. The herd response was timed from the instant that over 50% of the dugongs visible stopped feeding and started travelling, to the instant when over 50% of dugongs stopped travelling and started feeding. Where herd movements occurred with an intermittent period of feeding while the boat was still passing, the time of each movement either side of the feeding period was combined to obtain the total duration of the response to that pass.

We scrutinised the video record on two independent occasions four weeks apart to ensure that the herd movements could be unambiguously timed with consistent results. The error value is the difference between the two estimates, which were compared using a paired t test as an assessment of accuracy. In subsequent analysis, the duration of the herd responses was the average of the two evaluations for each pass.

The response times obtained during opportunistic boat passes were classified according to whether the boat approach distance was less than or greater than 50 m. The estimates of the distance of opportunistic boats from the herds as they passed were not considered accurate enough to have additional distance categories. These two subsets of data had unequal variances even when transformed. They were compared using a one-tailed Mann-Whitney test where the null hypothesis was that the duration of response was not greater when boats passed within 50 m than if the boats did not come within 50 m. Opportunistic passes were also categorised as fast (above planing speed) or slow (below planing speed). We used a t test to determine whether there was a difference in response time with boat speed.

Duration of individual responses to boats

To investigate further the duration of time that individual dugongs spent responding to boats, we measured the response time of focal individuals during the boat-pass experiments for which herd responses were observed. The length of the individual response was the time between the onset and cessation of travelling behaviour by the focal individual that coincided with the herd response. A paired t-test determined whether there was a difference in the response times of the focal individual and its herd.

Limitations

Analyses of data from boat-pass experiments were limited by the sample size of passes for each combination of variables. Sample sizes were too small to conduct more sophisticated tests than those outlined above. We interpreted the results in this context.

All results are provided as means ± standard errors.

Results

Continuous behaviour of focal dugongs

Analysis of the video footage showed that the proportion of time focal dugongs spent feeding and travelling during 4.5 min behavioural samples was not significantly affected by any of the following: (1) whether or not a boat was passing, (2) the number of passes made (based on the first, fourth and fifth passes), or (3) the continuity of the passes (continuous or with a stop and restart halfway) (Table 1). Dugongs actually spent a higher proportion of time feeding during the 4.5 min behavioural sample when the boat was passing than during samples when no boat was present (Fig. 3). However, this difference was not significant (Table 1).

The interactions between dugong group type and boat presence, pass number and pass continuity were not statistically significant (Table 1). However, all six ANOVAs showed a significant effect of group type (i.e., within main herd, subgroup or scattered) on the focal dugong's feeding and travelling behaviour (Table 1, Fig. 3). Focal dugongs feed at a significantly higher rate when part of the main herd, and they travelled more when within a subgroup or scattered (i.e., not within a group).

Behaviour during closest approach interval

The activity of the focal dugong was the only behaviour affected by the closest-approach distance of the passing boat. According to a chi squared test of homogeneity, the feeding and travelling behaviour of the focal dugong was affected by boat presence / distance ($\chi^2 = 13.37$, df = 6, P = 0.04; Table 2). Post hoc tests showed that it was the distance of the passing boat that significantly affected the proportion of dugongs classified as feeding only (Fisher's exact one-tailed test, P = 0.03) rather than the presence or absence of a boat (Fisher's exact one-tailed test, P = 0.37). Dugongs were less likely to remain feeding when boats passed within 50 m than if the boats passed further away.

Subsurface times during the closest approach interval ranged from 10 to 322 s, while the distance travelled by the focal dugong ranged from 0 to 122 m. However, these variances were not related to boat distance. Nor were subsurface time and distance travelled related to the number of times the boat had passed or the continuity of the pass.

The closest approach distance of the boat did not affect the travel direction of the dugongs. There was no significant difference in the likelihood of dugongs responding by swimming in the same direction or away from the boat according to the three distance categories (Table 3; $\chi^2 = 2.96$, df = 2, P = 0.23).

Duration of herd responses to boats

A total of 26 experimental boat passes, and 16 opportunistic boat passes satisfied the criteria for assessing herd response. Dugong herds exhibited mass movements in which > 50% of animals interrupted their feeding, travelled in a coordinated group, and then resumed feeding. The two independent measurements of the duration of each response were not significantly different (t = -0.74, df = 41, P = 0.46). The overall average length of herd responses was 122 ± 14 s.

Ten of the 16 opportunistic boat passes for which the duration of the herd response was timed approached within 50 m of the herd. The distances of the remaining six boats ranged from 50 to >500 m. The mean duration of responses to opportunistic boat passes within 50 m (117 ± 15 s) was not significantly different from the response time when boats passed at distances greater than 50 m (161 ± 34 s; Mann-Whitney U 0.05(1),6,10 = 26, P = 0.71). The water depth near the herd was < 2 m for all but one opportunistic boat pass. Five of the 16 boats were travelling above planing speed. Dugongs spent more time responding to boats that were travelling below planing speed (mean = 169 ± 29 s) than to those travelling above planing speed (mean = 90 ± 21 s), although this difference was not significant (t = 1.70, df = 14, P = 0.11).

Duration of individual responses to boats

The average time spent responding to the experimental boat by the focal individual was 92 s, a time not significantly different from the corresponding estimate of the herd response time (paired t = 0.51, df = 19, P = 0.62).

Discussion

Response in relation to boat distance

The behaviour of most focal dugongs was not measurably affected by experimental boat passes unless the boat was within 50 m. Dugongs were significantly less likely to continue feeding as the boat passed within 50 m than if the boat passed beyond 50 m. Although we found no significant effect of boat distance (< or > 50 m) on the duration of herd responses to opportunistic boat passes, most (10 out of 16) obvious mass movements, where dugong herds interrupted their feeding, travelled, and resumed feeding, occurred in response to boats within 50 m. This result corresponds with the response of Florida manatees to boats, which is typically initiated when the boat is at a distance of 25 – 50 m (Nowacek et al., 2004).

In contrast, we found no correlation between the distance of focal individuals to the experimental boat and their subsurface interval, travel distance or travel direction relative to the boat. Although the combination of group type and boat presence did not affect the proportion of time individual dugongs spent feeding or travelling, their behaviour was affected by the presence of other dugongs. Herding behaviour appeared to ameliorate the influence of boat distance on the response of individuals. The mass herd responses to boats passing suggest that the likelihood of an individual responding to the boat depends not only on the distance of the individual to the boat, but also the distance of the whole herd, together with the combined effects of herd composition, herd behaviour and variations in individual responses to boats. Individually recognisable Florida manatees display variation in response to boats which may be ascribed to the age, exposure to boats, reproductive state, hearing ability or activity of each manatee (Nowacek et al., 2004). Although dugongs were not individually recognisable during our study, herd composition certainly varied as the number of individuals present differed on different days during the experiments.

Four mass movements of dugong herds were apparently a response to independent boats passing more than 500 m away. During aerial surveys, Preen (1992) also observed herd movements appearing to be responses to boats at a distance of over 1 km. In a preliminary study of manatee responses to experimental boat approaches using digital acoustic data logger tags (DTAGs) in Belize, increased activity indicated that a manatee detected a boat at approximately 800 m away (Nowacek et al., 2001b). Considering that it is likely that both dugongs and manatees can sometimes detect boats in the order of hundreds of metres away, what factors determine the detection distance and the response of the animals? Many factors affect the propagation of boat noise, including the engine type, boat speed, and environmental factors such as water depth, sediment type and topography (Richardson et al., 1995; McCauley et al., 1996). In this study, the four boats which apparently elicited a response from more than 500 m away varied in engine type and speed. The dugongs were in < 2 m of water on all four occasions. More observations are clearly needed to produce conclusive results or identify general trends.

Response in relation to water depth

Even though the shortest herd response time (45 s) was recorded for a herd in water 4 m deep, most of our observations of the responses of dugong herds to boats were limited to shallow water (< 2 m). Based on anecdotal aerial observations, Preen (1992) suggested that dugongs in deep water show little response to boats compared with dugongs in shallow water. Florida manatees also change swim speed more frequently when boats pass them in shallow water (< 2 m) than in deep water (Nowacek et al., 2004).

Water depth affects the real and perceived threat of boat strike. Shallow water limits the opportunity for dugongs to avoid boats by diving. As most of our observations were in shallow water, we were unable to identify a tendency for dugongs to dive in response to boats. However, deep water can be a refuge for marine mammals, and vertical avoidance of boats by diving is a strategy employed by bottlenose dolphins (Nowacek et al., 2001a; Lusseau, 2003a), humpback whales (Baker and Herman, 1989), and belugas and narwhals (Finley et al., 1990). The effect of water depth on the response to boats can be likened to the effect of refuge distance on the response of terrestrial animals to predators (Frid and Dill, 2002). To limit the costs of fleeing from predators (including abandoning a feeding site, lost feeding time, and energy expenditure), terrestrial animals tolerate closer approaches by predators the closer they are to a refuge site (Ydenberg and Dill, 1986). In deep water, dugongs have the option of diving to seek refuge from boats, or to remain feeding on the bottom. If dugongs in deep water perceive that remaining at the bottom is safe, they would be expected to spend less time, and thus expend less energy, responding to boats than dugongs in shallow water. Thus water depth is an important factor that needs further investigation in determining the response of dugongs to boat disturbance.

Biological significance of responses observed in Moreton Bay

Research to assess the biological significance of disturbance generally aims to determine the effect of disturbance on population size, which is dependent on survival and reproductive success (Gill et al., 1996; Gill et al., 2001). Like animals responding to predation, animals responding to disturbance face a trade-off between disturbance rates and the amount of a given resource that is available in a particular habitat patch (Gill et al., 1996; Frid and Dill, 2002; Cooper et al., 2003). The decision to move when disturbance reaches a particular level must be based on factors similar to those which govern the level of acceptable predation risk: the quality and level of investment in the current site, the distance and quality of other sites, and the relative level of disturbance or competition at other sites (Gill et al., 2001).

Dugongs predominately display a delayed, short-term response to boats. Thus according to the low levels of boat traffic observed during our study, dugongs on the Moreton Banks would not spend substantial amounts of time moving as a result of boat disturbance. The rate of boat disturbance we observed ranged from 0.2 boats per hour (boats < 50 m) to 1.5 boats per hour (boats < 1 km, Hodgson, 2004). Using the average time spent responding to opportunistic boat passes (122 s), and assuming boat disturbance occurs only during daylight hours (i.e., 12 hours per day), we estimate that dugongs on the Moreton Banks are disturbed for between 4 min 53 s and 36 min 36 s per day. Assuming that all boat passes occurred while dugongs were feeding, this represents 0.8 to 6% of the time spent feeding throughout the diel cycle (Hodgson, 2004).

Two further considerations must be noted here however. Firstly, our fieldwork was conducted during winter, and boat traffic increases significantly over the summer, particularly during the holiday period between Christmas and mid-January (Brenda Healey, pers. comm.). Boat traffic in summer needs to be quantified so that its potential impact on dugongs can be evaluated. Secondly, although our results were not statistically significant, dugongs spent more time responding to boats that travelled slowly than those travelling fast. Our small sample size of only five boats travelling above planing speed limits our ability to detect an impact of boat speed on the duration of disturbance. Slow moving boats are likely to be within hearing range of dugongs for a longer period of time than fast boats, which could translate to longer disturbance responses. However, it would be inappropriate to allow higher speed limits within important dugong habitat areas, as this would increase the risk of dugong deaths from boat strikes (Hodgson, 2004). This issue highlights the need for further research into how the characteristics of boat noise and the distance of the boat affect the response of dugongs.

Potential energetic costs of boat disturbance to dugongs include: (1) a reduction in energy intake, (2) the energy expended while moving, and (3) the possible cost of moving to a different patch on the seagrass beds. Disturbed dugongs may be forced to spend time searching for alternative feed patches and may be forced to feed on less desirable patches with lower nutritional value. Disturbance may also interfere with the 'cultivation' grazing strategy practised by dugongs in Moreton Bay (Preen, 1995; Hodgson, 2004) whereby they move across the seagrass banks systematically over a period of months, cropping the seagrass in a manner that promotes growth of a favoured pioneer species with high nutritional value in the new shoots produced. This pattern of seagrass patch use may be interrupted by dugongs continually moving in response to boats. During periods of high boat traffic dugongs may not be able to graze intensely enough to affect the species composition of the seagrass. Thus the amount of favoured seagrass available could be reduced.

Despite the potential effects of having to move to different seagrass patches, the level of boat traffic we observed on the Moreton Banks appears unlikely to cause a reduction in dugong survivorship through disturbance alone. However, the trade-off between resource use and disturbance needs to be considered before applying the results obtained in this study to dugongs in other areas. Dugongs grazed seagrass beds approximately 10 km^2 in area during our study, enabling them to move in response to boats and resume feeding immediately. On smaller, isolated seagrass beds, responses to boats may force dugongs off the seagrass patch until the disturbance ceases, reducing the availability of food by limiting by the time dugongs spend foraging. Food availability is known to influence dugong population dynamics as dugongs delay breeding when food is limited (Marsh, 1999; Kwan, 2002). A large-scale reduction in food availability through disturbance could therefore affect dugong numbers by reducing fecundity. This effect is particularly important when combined with other impacts that reduce adult survivorship, such as boat strikes.

Our observations of dugongs' response to boats are also indicative of the direct impact of boats to dugongs through boat strike. The limited response we recorded, and in particular, the fact that dugongs did not tend to be swimming away from the experiment boat, demonstrates of the high risk of boat strike to dugongs (Hodgson, 2004). We were not able to conduct boat pass experiments at high speeds. However, observations of dugongs' responses to boats passing opportunistically at speeds higher than the 'non-planing' speed limit, show that the delayed response exhibited by dugongs to boats makes them particularly vulnerable to high speed boats (Hodgson, 2004).

Conclusions and management considerations

Boats caused relatively short interruptions to dugong feeding herds on the Moreton Banks during our study, reducing feeding time by a maximum of 0.8 to 6%. However, if the number of registered boats in Queensland continues to increase rapidly, as it has done over the past nine years (Maritime Safety Queensland, 2005), this rate of disturbance is likely to increase. Interrupting feeding at rates higher than our estimated maximum of 6% of the daily time budget may affect dugongs at the population level by limiting food intake and triggering reduced fecundity. Management initiatives such as the Dugong Protection Areas along the Queensland coast, and the rezoning of the Great Barrier Reef Marine Park to increase ‘no-take areas’, will only work if the areas zoned to protect dugongs continue to be highly used by dugongs (Marsh, 2000). The effect of boat disturbance on habitat quality should be closely monitored, particularly where high boat traffic occurs in small and/or isolated dugong habitats or in conservation areas designed to protect dugongs.

Acknowledgements

Thankyou to the many volunteers who assisted with our field work. This project was funded by the Cooperative Research Centre for the Great Barrier Reef World Heritage Area, James Cook University, the Sea World Research and Rescue Foundation, the Pew Foundation, the Australian Defence Force, the Capalaba Lions Club, the Great Barrier Reef Marine Park Authority, and Digital Blue Photography. Considerable in-kind support was provided by Tangalooma Wild Dolphin Resort (Bruce and Betty Osborne) and in particular Trevor Hassard. The project was approved by the James Cook University Ethics Review Committee (A646_01 and A1024) and was conducted under Queensland Parks and Wildlife permits E6/000023/01/SAA, and QS2002/CVL25. This manuscript was improved by comments from Ivan Lawler, Monica Gagliano and three anonymous reviewers.

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Table 1. The six ANOVAs testing the effect of experimental boat passes on the behaviour of focal dugongs showed that the boat had no significant effect on proportion of spent time feeding or travelling. Three between-subjects factors were tested: (1) boat presence - whether or not the experimental boat is passing, (2) pass number - one, four or five, and (3) pass continuity - continuous or stop/start. The common within-subjects factor is group type (within main herd, sub-group or scattered). P < 0.05 in bold.

Dependent Variable	Source of Variance	df	Mean Squares	F	P
Proportion of time feeding	Boat Presence	1	6.74	0.80	0.37
	Group type	2	107.26	12.68	**0.00**
	Boat Presence * Group type	2	3.85	0.46	0.64
	Error	104	8.46		
	Pass Number	3	2.57	0.30	0.83
	Group type	2	89.87	10.47	**0.00**
	Pass Number * Group type	6	6.65	0.78	0.59
	Error	98	8.58		
	Pass Continuity	2	3.10	0.37	0.69
	Group type	2	102.86	12.21	**0.00**
	Pass Continuity * Group type	4	6.53	0.78	0.54
	Error	101	8.43		
Proportion of time travelling	Boat Presence	1	80.47	0.10	0.75
	Group type	2	3164.07	3.92	**0.02**
	Boat Presence * Group type	2	85.74	0.11	0.90
	Error	104	808.15		

Pass Number	3	194.55	0.24	0.87
Group type	2	3435.11	4.24	**0.02**
Pass Number * Group type	6	592.12	0.73	0.63
Error	98	810.28		
Pass Continuity	2	715.56	0.88	0.42
Group type	2	3445.43	4.26	**0.02**
Pass Continuity * Group type	4	200.29	0.25	0.91
Error	101	809.77		

Table 2. Observed frequencies with expected frequencies in brackets of focal dugongs exhibiting feeding and travelling behaviours during the closest approach interval according to the presence / distance of the passing boat during experimental boat passes.

	Feeding Only	Travelling Only	Travelling and Feeding
Boat < 50 m	0 (2.14)	6 (3.42)	1 (1.44)
Boat 50 – 200 m	7 (8.55)	13 (13.68)	8 (5.77)
Boat > 200 m	8 (3.66)	2 (5.86)	2 (2.47)
No boat (control)	25 (25.65)	43 (41.04)	16 (17.31)

Table 3. Travel direction of dugong relative to passing experimental boat compared with the distance of the boat from the edge of the herd. Observed frequencies with expected frequencies in brackets.

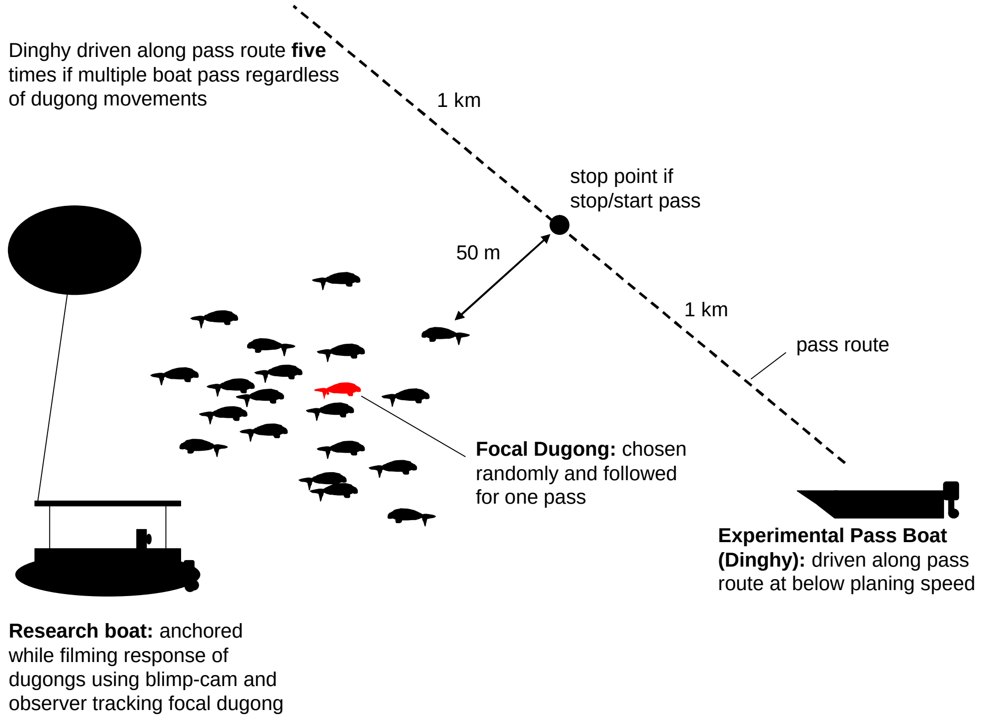
	No Response: Towards/Opposite/None	Response: Same/Away
Boat < 50 m	5 (4.9)	8 (8.1)
Boat 50 - 200 m	23 (27.4)	50 (45.6)
Boat > 200 m	20 (15.8)	22 (26.3)

Figure Captions:

Fig. 1. Design of boat pass experiments. The two variables were number of passes (single pass or five passes), and continuity (continuous pass at constant speed, or engine switched off and on when closest to dugongs).

Fig. 2. Classification of the focal dugong’s travel direction relative to the travel direction of the passing boat during experimental boat passes, grouped as either ‘same/away’ or ‘towards/opposite/stationary’.

Fig. 3. The proportion of time individual dugongs spent feeding and travelling during the experimental boat passes according to boat presence, pass number, pass continuity (whether the pass included a stop and restart), and group type (bars represent mean ± S.E.).



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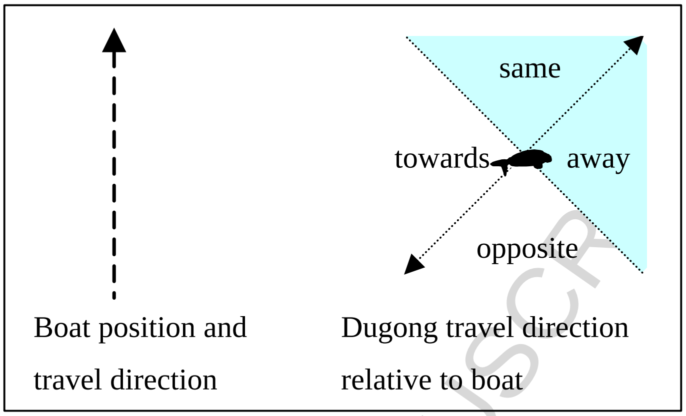

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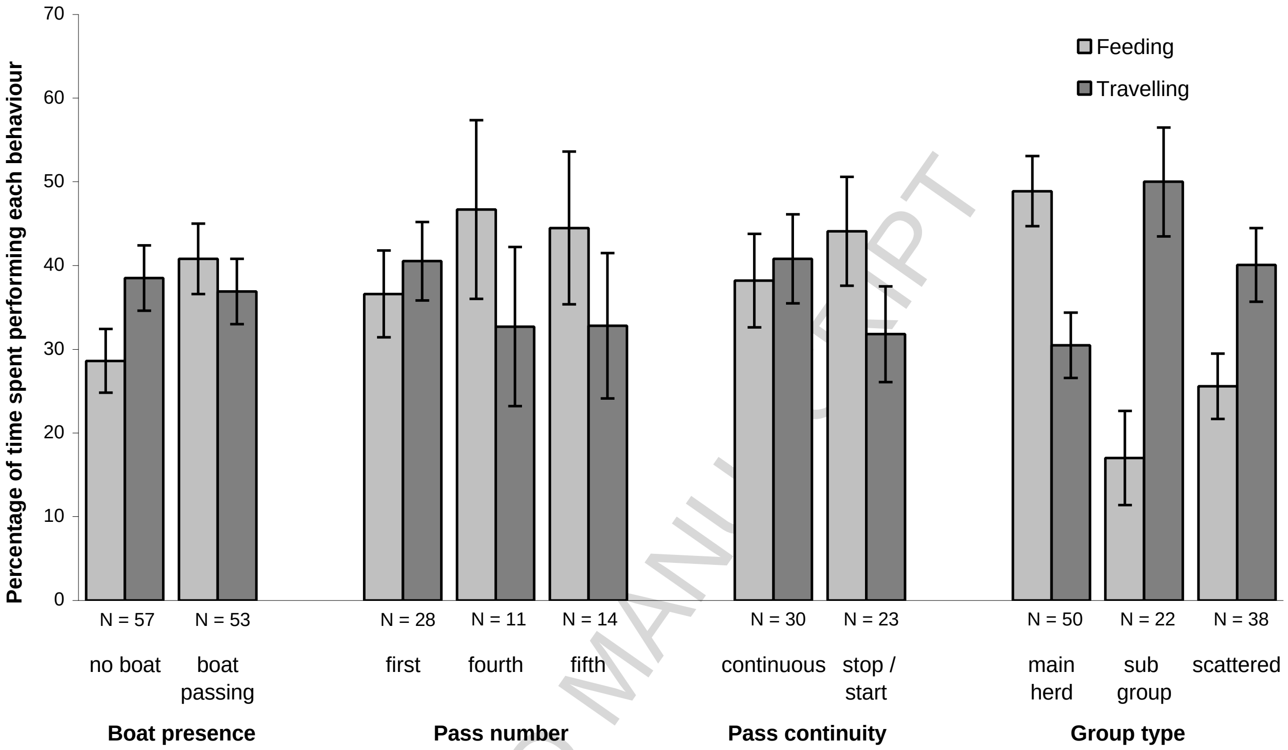

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