

## Juvenile damselfish are affected but desensitize to small motor boat noise



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### ABSTRACT

Anthropogenic noise pollution is rapidly increasing in the marine environment. Anthropogenic noise can mask biotic sounds, disrupting the successful transmission between caller and receiver, and can cause physical, physiological and behavioural changes in some species. The effect of noise pollution produced by small motorboats is of particular interest in shallow, coastal habitats where vessel numbers are steadily increasing. The present field study examined the effect of small motorboat noise on the behaviour of the juvenile common damselfish, *Pomacentrus amboinensis*, and their potential to perform typical behaviours when presented with increased noise over a short time period. Behavioural observations in the field (before, 1, 10 and 20 min after the start of boat noise) found there was an immediate decrease in the boldness and relative distance moved by *P. amboinensis* in response to the noise produced by a boat with a 30 hp 2-stroke engine travelling 30–80 m away. However, fish appeared to return to pre-boat noise exposure behaviours within 20 min. The immediate change in behaviour may alter mortality rates in the short-term, but the potential for de-sensitization to boat noise may allow long-term persistence in noisy environments if they survive the initial disruption.

### 1. Introduction

Noise produced by human activities is one of the most rapidly increasing pollutants in the marine environment (Hildebrand, 2009; Popper and Hastings, 2009; Andrew et al., 2002). Anthropogenic noise occupies many of the same frequencies as biotic sounds and, if sufficiently intense, may lead to the masking of auditory signals used by animals to communicate (Pollack, 1975; Brungart, 2001; McDonald et al., 2006; Normandeau Inc., 2012). Increased noise levels can lead to physiological damage and stress in some species (see Knight and Swaddle, 2011). Sporadic exposure to noise may even affect reproductive success and survival of some marine invertebrates (Aguilar de Soto et al., 2013; Nedelec et al., 2014), with the potential to alter population dynamics, community structure and energy flows within assemblages (Slabbekoorn et al., 2010). While research to date suggests that some forms of noise can greatly impact population processes, anthropogenic noise is one of the least studied sources of pollution (Hawkins et al., 2014).

Research on the impact of anthropogenic noise on marine organisms has primarily focused on how noise from shipping, acoustic surveys or construction affect cetaceans and commercially important fish species (Engås and Løkkeborg, 1996; Sarà et al., 2007; Hatch et al., 2008; Brandt et al., 2011; Erbe et al., 2012; Melcón et al., 2012). Most of these

studies have been conducted away from the structurally complex inshore coastal margin. While the response of these groups is important, most of these organisms have large home ranges and are capable of moving away from the immediate area affected by noise.

Much of the biodiversity in the marine environment occurs in the shallow coastal zone, particularly in tropical coral reef ecosystems. These coastal areas are heavily frequented by a range of vessels including large bulk carriers, fishing vessels and small motorboats. While small motorboats produce neither the amplitude nor low frequency sounds of bulk carriers, they can potentially have substantial impacts on shallow reef communities because of their large number (GBRMPA, 2014) and close proximity to marine organisms. Although legislation has been implemented in Europe to regulate anthropogenic noise pollution (Pottering and Lenarcic, 2008), many coastal countries have no regulation and there is little data on which to base management decisions.

Currently, there is a lack of information on the in situ effect of noise from small motorboats on small site attached species that spend all of their post-settlement life stages at one particular site. Studies investigating the impact of boat noise on fish have mostly been laboratory-based or field studies that have used speaker playback of small boat noise or pure tones rather than actual boats, focusing on potential disruption of communication rather than direct behavioural impacts

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(Vasconcelos et al., 2007; Codarin et al., 2009; Picciulin et al., 2010). Nedelec et al. (2014) found playback of recorded boat noise reduced successful development of tropical sea hare embryos by 21% and increased mortality of recently hatched larvae by 22% compared to controls. The response to visual stimuli was investigated in the laboratory, with Voellmy et al. (2014) finding playback of vessel noise affected anti-predator response. One recent study using noise from real motorboats in the field found that boat noise reduced the escape response of juvenile damselfish and lead to a doubling of the mortality from a small benthic predator (Simpson et al., 2016). Overall, studies to date on fishes suggest that boat noise may adversely affect fish behaviour by reducing their ability to orientate to a favourable environment (Holles et al., 2013) and reduce foraging and polarisation when schooling (Bracciali et al., 2012).

The impact of noise from motorboats covers a spectrum of potential disturbances (Neo et al., 2016a) from infrequent acute events through to more continuous and chronic occurrences associated with marinas, boat channels and harbour entrances. The few studies using actual boats used short-term and intense treatments of noise, and it is often difficult to discern the effects of the surprise from any new stimulus on the organisms from the disruptive influence of the noise that emanates from boats. The present study investigated the influence of noise from small motorboats on the behaviour of a juvenile tropical damselfish, *Pomacentrus amboinensis* (Pomacentridae), and determined their potential capacity to return to pre-disturbance behaviours while exposed to continuous real motorboat noise in the field. Our prediction based of previous studies of the stress response in fishes (e.g., Spiga et al., 2012; Johansson et al., 2016) was that the behaviour of fish would be immediately disrupted by the onset of the noise, but persistent exposure to the stimulus would lead to a slow return to behavioural norms as fish became desensitized. The current study focused on juveniles immediately after settlement as this life stage involves dramatic changes in structure, physiology and behaviour which makes them vulnerable to predators (McCormick et al., 2002; Nilsson et al., 2007). Anything that disrupts their sensory information may affect their ability to assess risk and make appropriate decisions that affect survival (Munday et al., 2010; McCormick and Lönnstedt, 2013). Previous research has shown that recently settled damselfishes generally have good hearing with auditory thresholds that hear best within 100 to 1000 Hz (Kenyon, 1996; Egnér and Mann, 2005; Wright et al., 2011; Colleye et al., 2016), which is a hearing range that directly overlaps with the noise frequencies produced by small motorboats (e.g., Simpson et al., 2016).

## 2. Materials and methods

### 2.1. Study site and species

Small boat traffic on the Great Barrier Reef has greatly expanded over the past 30 years and it is predicted that there will be half a million recreational motorboats using the inshore waters of the GRB by 2040 (GBRMPA, 2014). Many of these motorboats are used for recreational activities such as fishing, scuba diving and snorkelling that are directly over or within very close proximity (< 10 m) to the fish communities that inhabit coral reefs.

The study species, the Ambon damselfish, *Pomacentrus amboinensis*, is protogynous, site attached fish that is a common member of the shallow water fauna of Indo-Pacific reefs (McCormick, 2016). For this species, metamorphosis occurs at the same time as settlement and involves a major change in pigmentation (transparent to coloured) that occurs within hours, but involves little obvious change in shape (McCormick et al., 2002). However, settlement does involve major changes in physiology (Nilsson et al., 2007) and it is likely that marked changes also occur in the sensory systems (Shand, 1997). Research on newly settled *P. amboinensis* has shown that fish enter the reef with high variability in their behavioural traits (e.g., boldness, aggression) and these traits are displayed in a manner that is consistent on small time

scales of hours to days (McCormick and Meekan, 2007; White et al., 2015). Establishment of dominance hierarchies occurs within minutes of settlement (Meekan et al., 2010; Killen et al., 2014).

The present study was conducted in the lagoon at Lizard Island, Great Barrier Reef, Australia (14°41'S, 145°27'E), from November to December 2014. Settlement stage *Pomacentrus amboinensis* juveniles (11 to 13 mm standard length) were collected using light traps moored overnight > 100 m from the reef at two locations on Lizard Island fringing reef. Light traps were positioned 1 m from the surface and catches were collected at 5.30 am each morning. Fish were brought back to the laboratory in 60 L containers filled with aerated seawater. Upon return to the Lizard Island research station, fish were sorted to species level and placed in 35 L flow-through aquaria with aerated seawater entering via a submerged pipe to reduce ambient noise. Fish were fed newly hatched *Artemia* sp. twice a day and held for 48 h prior to use in experiments to make sure they had fully recovered from the stress of capture.

### 2.2. Ethics statement

This research was carried out in accordance with James Cook University ethics guidelines under ethics approval A2081 and conducted in accordance with the Queensland Department of Primary Industries collection permit (170251) and a Great Barrier Reef Marine Park Authority research permit (G12/35117.1). All sampling procedures and/or experimental manipulations were reviewed and approved as part of obtaining the above field and ethics permits.

### 2.3. Experimental procedure

Two study sites were set up 500 m apart consisting of small patch reefs (20 × 20 × 20 cm) made of *Pocillopora damicornis* fragments on sand. Two sites were used to increase replication because of the time necessary for habituation to the patch reefs. In this way a fish could be habituating to the ambient reef conditions of the patch reef at one site while the experiment was being run at the other. Sites were similar but separated by complex barriers of hard coral matrix that were emergent at a very low tide, effectively acoustically isolating the sites. Each experimental site was > 10 m from the nearest hard reef habitat at a depth of 2–3 m, dependent on the tide (range 1 m). Individual juvenile *P. amboinensis* were placed at the separate sites to ensure acclimation to the habitat patch in the absence of boat noise. Fish were transported to study sites in individual 1 L plastic click-seal bags of aerated seawater, placed inside a thick-sided polystyrene foam box, held on the lap of a passenger in a boat to limit noise exposure. Individual fish were released onto a patch reef and a 30 × 30 × 30 cm cage (6 mm<sup>2</sup> mesh) was placed over the top to allow acclimation to their new environment in the absence of a predation threat. Fish were given 30 min of acclimation time prior to the start of a trial. This time period was chosen as a suitable acclimation time based on previous studies observing behaviour of damselfish (Lönnstedt et al., 2013, 2014). Cages were removed before trials and 3 min behavioural observations were recorded on SCUBA following the protocol of McCormick (2009). Five aspects of behaviour were measured: 1) the number of feeding strikes (successful or otherwise); 2) total distance moved (over the 3 min period); 3) maximum distance ventured from shelter, 4) relative distance ventured from shelter (classified by percentage of time spent at 0, 2, 5 and 10 cm from the coral patch), and 5) boldness (recorded on a continuous scale from 0 to 3, where: 0 is hiding in hole and seldom emerging; 1 is retreating to hole when approached and taking > 5 s to re-emerge, weakly or tentatively striking at food; 2 is shying to shelter of patch when startled but quickly emerging, purposeful strikes at food; and 3 is not hiding when approached, exploring around the coral patch, and striking aggressively at food). Other studies using this boldness metric have found it a repeatable and related to survival (e.g., Fuiman et al., 2010; McCormick and Meekan, 2010; White et al., 2015). Recent

studies have shown that 3 min observations are sufficient to quantify the behaviour of juvenile damselfish because individuals have a high degree of repeatability in behaviour over time periods of up to 5 days (McCormick and Meekan 2010; White et al., 2015). Observations were recorded before the acoustic treatments and repeated 1 min, 10 min and 20 min after the beginning of the treatment, after which the trial ended. Fish were exposed to either boat noise ( $n = 19$ ), produced by a 5 m aluminium dinghy with 30 hp 2-stroke outboard engine (Suzuki, DT30) travelling at various speeds (max  $\sim 10$  knots) maintaining a distance 30–80 m from the patch reef, or a silent (ambient reef) control sound treatment ( $n = 20$ ). Ambient reef and boat noise treatments were alternated, and due to the nature of the treatments trials could not be conducted simultaneously. The initial site used for a particular treatment was alternated each day to avoid order effects. A maximum of 2 replicates could be conducted in any full day of fieldwork. Given the complexity of undertaking this experiment in the field, the experiment was conducted over 20 full field days and involved 17 h underwater. Data was collected between 10:00 and 16:00 h and the underwater visibility was always  $> 5$  m.

#### 2.4. Soundscapes

Recordings of the ambient reef sound and boat noise produced during trials were made at one site using a calibrated Soundtrap 202 digital sound recorder (Ocean Instruments, New Zealand, working frequency range of 20 Hz and 60 kHz  $\pm 3$  dB; 16-bit 48 kHz sample rate, maximum level before clipping of 186 dB re 1  $\mu$ Pa) (Fig. 1). The

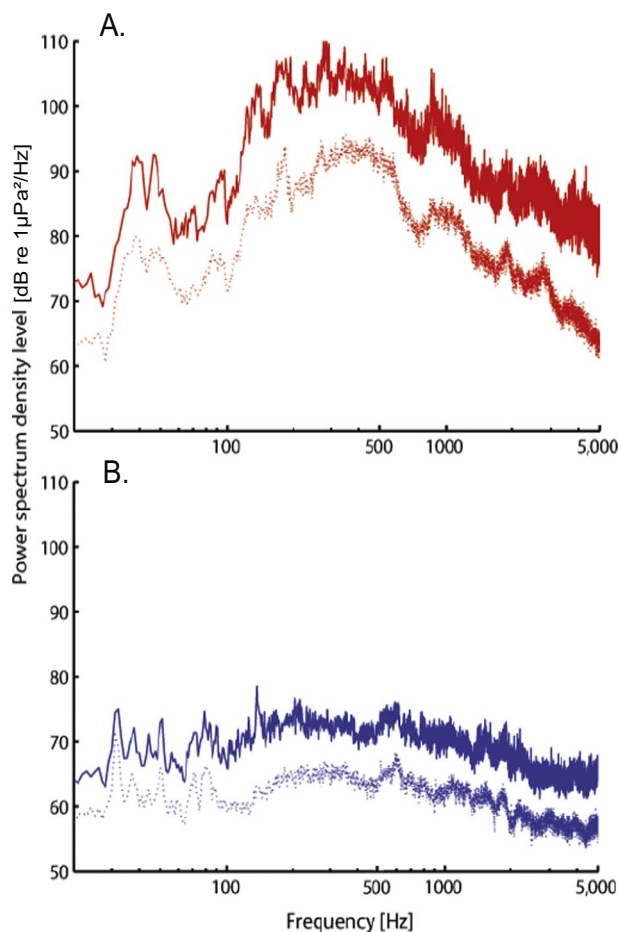


Fig. 1. Comparison of the power spectrum density level of boat noise treatments. A. Boat noise (dB re 1  $\mu$ Pa<sup>2</sup>/Hz) produced during trials (A) and the ambient sound level (B) at the experimental site. Solid line represents the medium sound level, together with the 95% percentile (dotted and lower).

sound recorder was weighted and placed on the sea floor next to the experimental patch reef. This was used to determine the extent to which the treatment (boat noise) altered the underlying ambient soundscape of the experimental sites.

For the comparison of the soundscapes, true boat audio samples were selected by visually and audibly inspecting a spectrogram of the recorded boat sounds. A 60 s sample of the recording was determined to be a suitable representation of boat noise, during which the boat completed about two circuits of the  $\sim 50$  m diameter loop track (i.e., encompassed periods of maximum and minimum noise exposure). Median power spectrum density levels (dB re 1  $\mu$ Pa<sup>2</sup>/Hz) (which describe how the power of a signal is distributed over a range of frequency bands) with 95% percentiles were calculated using custom code supplied by the Centre of Marine Science and Technology (CMST), Curtin University. Audio file processing and analysis was carried out in the software program Matlab™ (v2013a).

Particle acceleration was also measured for the same motorboats used in the present study at the same location and was presented in Simpson et al. (2016, their Fig. 4). Particle acceleration was measured using a calibrated triaxial accelerometer (M20 L; sensitivity following a curve over the frequency range 0–3 kHz; calibrated by manufacturers; Geospectrum Technologies, Dartmouth, Canada) and a digital 4-track recorder (Boss BR-800, 44.1 kHz sampling rate, Roland Corporation, Los Angeles, CA). Recording levels used with each set-up were calibrated using pure sine wave signals from a function generator with a measured voltage recorded in line on an oscilloscope. Data indicated that the spectral power density profiles for acoustic pressure and particle acceleration showed a very similar pattern of difference between treatments, with marked differences between the motorboat and ambient acoustic signatures.

The noise in the aquaria where juvenile fish were maintained prior to use in the field was minimal as shown by acoustic pressure and particle acceleration measured for the exact same aquarium setup by Simpson et al. (2016, their Fig. 4).

While only one motorboat was used in the present study, the frequency spectra obtained mirror that found by another study using exactly the same types of 2-stroke engines and hull design over shallow reef (Simpson et al., 2016). Interestingly, they are also similar to the power frequency spectra of motorboats from a study conducted at a completely different site (Moorea, French Polynesia), using boats of a different hull design and 2-stroke engine capacity (25 hp Yamaha) (Nedelec et al., 2014). Together these findings suggest that the boat noise produced in our study may not be specific to the particular boat used, but is likely to be typical of the power spectra produced by these kinds of (2-stroke) engines.

#### 2.5. Statistical analysis

Data analysis was undertaken using Statistica (Dell, version 13). The relative distance ventured was calculated as the sum of the distance categories (0, 2, 5, 10 cm) weighted by the proportion of time spent within each. Overall difference in behaviour by time and treatment was first investigated using repeated measures (RM) MANOVA with 2 levels of a between factor, acoustic treatment (ambient reef sound, boat noise), 4 levels of time (within-subject factor; 0, 1, 10, 20 min) and 5 behavioural variables (as above). This was used as an omnibus test of the effects of noise treatments through time on overall behaviour and space use of the juvenile fish. The advantage of the multivariate test is that it includes intercorrelations between the dependent behavioural variables that are not included by using univariate tests alone. We then used univariate RM ANOVA tests to explore and describe the nature of the significant difference found with the multivariate approach. Planned comparisons tested the a priori hypothesis that behaviours may differ in the boat noise treatment through time, using the 'before' estimate of behaviour as the reference point. Because it is a planned comparison of an a priori hypothesis no error correction is warranted

(Keppel and Wickens, 2004). Mauchly's test was used to test the assumption of sphericity, which states that the variances of the differences in time must be equal. Sphericity was violated for maximum distance ventured and relative distance ventured so multivariate tests were used to test the within-subject components of the analysis (using Pillai's trace). The assumptions of normality and homogeneity of variance were examined with residual analyses and found acceptable for all variables.

### 3. Results

The power spectra of sound pressure produced by the motorboat used in the study was markedly different from the ambient reef sound at the experimental site (Fig. 1). While the motorboat was active around the study site, power spectral levels were substantially raised above ambient over a broad frequency range, particularly from 100 to 1000 Hz.

All behavioural measures remained consistent for individuals exposed to the ambient control for the length of the trials ( $p > 0.05$ ). There was also no difference between pre-exposure measures for both treatment and control groups (number of bites:  $p = 0.57$ , total distance moved:  $p = 0.36$ , maximum distance ventured:  $p = 0.53$ , relative distance ventured:  $p = 0.29$ , boldness:  $p = 0.09$ ).

There was a significant difference in the overall behaviour of *P. amboinensis* over time and this differed by treatment (RM MANOVA Treatment  $\times$  Time:  $F_{15, 23} = 3.20$ ,  $p = 0.006$ ). The boldness scores of *P. amboinensis* changed significantly over the 20 min study period and this differed between acoustic treatments as evidenced by a significant interaction between Treatment and Time (RMANOVA:  $F_{3, 111} = 8.6$ ,  $p < 0.0001$ ). Planned comparisons showed that boldness reduced 1 min after the onset of boat noise, followed by a gradual return to pre-exposure levels within 20 min (Fig. 2A). The same pattern was evident in relative distance ventured, with a significant interaction between Treatment and Time (RMANOVA: Pillai's trace 0.20,  $F_{3, 35} = 3.00$ ,  $p = 0.04$ ). Relative distance ventured decreased 1 min after the start of the boat noise treatment (Fig. 2B), however there was insufficient power to determine time-specific treatment differences. Bite rate was not influenced by sound treatment ( $F_{1, 37} = 0.92$ ,  $p = 0.34$ ), but showed significant change over time, with an increase in bite rate at 10 min (RMANOVA:  $F_{3, 111} = 3.2$ ,  $p = 0.02$ ; Fig. 2C). Total distance moved over 3 min was not significantly different between sound treatments or over time, and there was no significant interaction (RMANOVA Treatment  $\times$  Time:  $F_{3, 111} = 1.05$ ,  $p = 0.38$ ; Fig. 2D). Maximum distance ventured was also not influenced by sound treatment ( $F_{1, 37} = 1.38$ ,  $p = 0.26$ ), or time (RMANOVA:  $F_{3, 111} = 1.76$ , G-G adjusted  $p = 0.17$ ) and there was no significant interaction (RMANOVA:  $F_{3, 111} = 0.22$ , G-G adjusted  $p = 0.85$ ; Fig. 2E).

### 4. Discussion

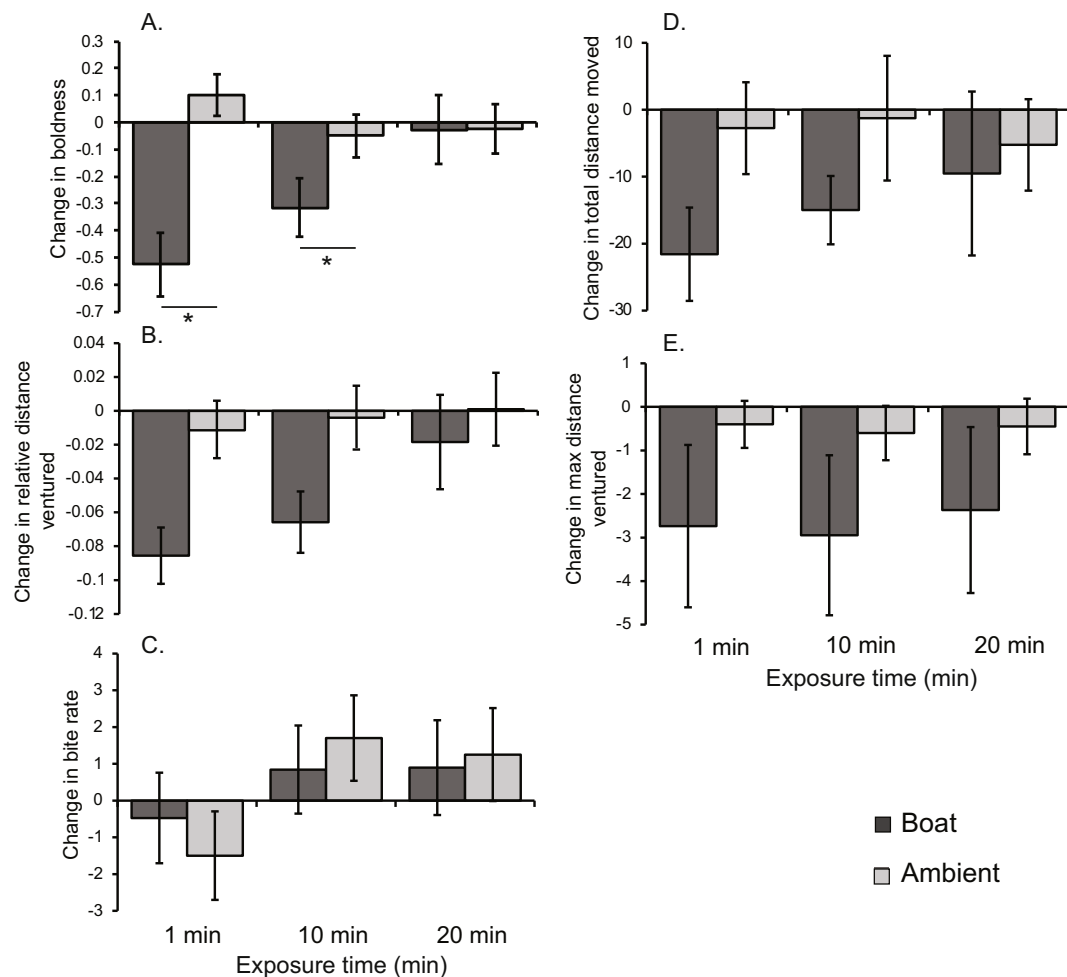
This study demonstrates that the behaviour of newly-settled fish was significantly affected by the operation of a small motor boat nearby. Given that the boat was far enough away that it could not be seen given the underwater visibility, it is most likely that this effect was due to the impact of noise produced by the motorboat. Noise from small boats operating within 30–80 m of the fish affected the activity and boldness of individuals. However, after 20 min of continuous exposure to boat noise, behaviour returned to pre-exposure levels. The findings suggest that fish at this vulnerable life-stage may become desensitized to boat noise over time, although in the short-term they may be impacted by noise through reduced activity and boldness. Research shows ontogenetic changes in the hearing ability of damselfish with marked increases in hearing sensitivity with time since settlement in some species (Kenyon, 1996; Egner and Mann, 2005; Wright et al., 2011), and boat noise may have a greater effect on our species as its hearing sensitivity improves. It would be beneficial to investigate the

response of *P. amboinensis* at a variety of life-stages to determine the species ability to mitigate the effects of noise pollution.

Our study monitored the behaviour of individuals throughout the boat noise exposure and found that behaviour returned to pre-noise levels after 20 min. Few studies have followed the behaviour of individuals to examine how repeated or continuous exposure to noise influence their response. Behavioural decisions are a product of the integration of all other body systems that individually feed into a context-dependent decision framework, and have direct fitness consequences (e.g., who lives or dies under a threat). Other studies have used physiological stress, namely the elevation of the stress-hormone cortisol, to examine habituation to noise, so it may be expected that the physiological responses will work on a slightly different time-frame to the behavioural responses. Johansson et al. (2016) exposed Eurasian perch and roach in enclosures to real motorboat noise and found that a 30 min exposure elevated cortisol levels, but when repeated over an 11-day period cortisol reduced, in one species to control levels, suggesting a level of noise habituation. Two studies, using different techniques, have found that exposure to intermittent noise lead to elevated cortisol compared to continuous noise (Wysocki et al., 2006; Nichols et al., 2015), also suggesting that habituation is possible, but depends on the characteristic duty cycle of the noise. Clearly, future studies should look at the physiological basis to habituation and its temporal scale in the current study system.

It is unknown whether aspects of physiology change on the same time scale as behaviour and whether the behavioural desensitization apparent in the present study is masking underlying physiological stress. Exposure to increased ambient noise has been shown to lead to stress responses (Smith et al., 2004; Wysocki et al., 2006). Smith et al. (2004) examined the response of goldfish (*Carassius auratus*) to white noise and noted a short-term increase in cortisol level, with a reduction in cortisol levels after 1 h of noise exposure, a time-frame similar to the desensitization observed in the present study. Smith et al. (2004) suggested two reasons for an initial stress response and then apparent habituation: 1) fish behaviourally habituate to the increased ambient noise, which leads to a reduction in cortisol levels; or 2) damage to auditory tissues occurs causing a temporary shift in the auditory threshold, leading to a reduction in perceived noise and a reduction in stress. Their data for goldfish supported the second hypothesis. The potential for a temporary or permanent auditory threshold shift was not investigated in this study, but is unlikely due to the low noise levels recorded in the present study compared to those in Smith et al. (2004) (70–110 vs 160–170 dB re 1  $\mu$ Pa; also see Smith and Monroe, 2016).

Previous research suggests that the motorboat-induced reduction in boldness found in the current study may indicate that these fish are more susceptible to predators (Fuiman et al., 2010; McCormick and Meekan, 2010). Newly-settled juveniles are exposed to extreme predation pressure, with estimates of mortality during this transition stage ranging through to absolute, but averaging ~60% over the first two days on the reef for damselfishes (Almany and Webster, 2006). Recent studies have found that there is a relationship between boldness and survival in the field, with fish that are bolder immediately after settlement having higher survival (McCormick and Meekan, 2010). Fuiman et al. (2010) found that *P. wardi* exhibiting low boldness on the reef were more susceptible to predators. The mechanistic link between low boldness and high mortality is poorly understood, but may relate to a covariance with escape performance. This negative relationship between boldness and survival is not unique to *P. amboinensis* and has been found in other organisms. For instance, Godin and Davis (1995) found bolder guppies (*Poecilia reticulata*) that inspected a predator (cichlid, *Aequidens pulcher*) had a reduced risk of predation. Harris et al. (2010) also found that guppies from high predation localities were bolder (i.e., emerged sooner from the shelter) compared to those from low predation localities, again suggesting a survival benefit to boldness. By being more active and willing to explore, bolder animals may be more aware of the activity of predators and may acquire more predator-



**Fig. 2.** Change in fish behaviour with time exposed to boat noise. Mean change ( $\pm$  SE) of: (A) boldness (index 0 to 3), (B) relative distance ventured (cm), (C) number of bites (per 3 min), (D) total distance moved (cm) and (E) maximum distance ventured from shelter (cm) of juvenile *Pomacentrus amboinensis* exposed to boat noise ( $n = 19$ ; dark bars) or ambient control ( $n = 20$ ; light bars) compared to pre-exposure behaviours. Observations lasted 3 min and were repeated before exposure then 1 min, 10 min and 20 min after the start of the sound treatments. Stars indicate statistical significance between control and treatment groups based on  $t$ -tests ( $\alpha = 0.05$ ).

related information than their shy counterparts (Manassa and McCormick, 2013).

A number of recent studies have found that the playback of vessel noise adversely affects the behaviour of aquatic organisms. Simpson et al. (2014) investigated the response of European eels (*Anguilla anguilla*) to a predator threat when exposed to playback ship noise. They found that the response to a simulated predator was delayed, and eels were caught faster in a noisy environment. Studies focusing on crustaceans have found similar results; the response latency of Caribbean hermit crabs (*Coenobita clypeatus*; Chan et al., 2010) and shore crabs (*Carcinus maenas*; Wale et al., 2013) to predators is increased under boat noise playback. These results may translate to higher probability of predation. However, Voellmy et al. (2014) found the effects of the playback of boat noise on two fish species to be species-specific, which may be expected as the hearing capability of fish species has been shown to cover a very wide range of frequencies (Hastings and Popper, 2005). While playback of boat noise had no effect on the response latency of European minnows (*Phoxinus phoxinus*) to a visual predatory threat, three-spined sticklebacks (*Gasterosteus aculeatus*) reacted faster when exposed to boat noise (Voellmy et al., 2014). Increased vigilance due to increased ambient noise levels may be the mechanism underlying faster reaction, similar to when prey are forewarned of a predator through olfactory cues (Ramamamy et al., 2015; McCormick and Allan, 2016). More importantly, this study illustrates the species-specific effects (from negative to positive) that noise may have on varying species.

The increase in vessel traffic in inshore waters around the world will exacerbate the effects that increasing anthropogenic noise have on marine organisms. Anthropogenic noise sources, particularly boats emitting noise below 1 kHz, occupy the same frequency bands that many organisms use to communicate (Hastings and Popper, 2005). The noise energy produced by small motorboats dominates the shallow water marine soundscape around Lizard Island across a broad range of frequencies, particularly 100–1000 Hz. The present study used continuous, though of variable intensity, real boat noise as the stressor. Such exposure to small motorboat noise may only be expected in restricted situations, like busy boat channels and marinas. However, it is important to understand the trajectory of desensitization or possible habituation, and the capacity of fish to deal with continuous noise to inform policies on noise pollution. Subsequent studies should examine the capacity of fish to acclimate behaviourally and physiologically to repeated short bursts of boat sound, a situation more accurately reflecting the environmental conditions experienced by many coastal fishes.

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