

NOTE

# Boat noise disrupts orientation behaviour in a coral reef fish

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**ABSTRACT:** Coral reef fish larvae use sound to find suitable habitat during their vital settlement stage. Yet boat noise, which can cause stress and avoidance behaviour, and may cause masking via reduction of perceptual space, is common around coral islands and continental shelf habitats due to boat activity associated with fishing, tourism and transport of passengers and cargo. In a choice chamber experiment with settlement-stage coral reef fish larvae of the species *Apogon doryssa*, the directional responses of larvae were tested to 5 different noise types: Reef, Reef+Boat, Ocean, Ocean+Boat and White noise. The results showed that 69% of fish swam towards Reef playback compared with only 56% during Reef+Boat playback, while 44% of fish larvae moved away from Reef+Boat playback compared to only 8% during Reef playback. Significant directional responses were not observed during White noise, Ocean noise or Ocean+Boat noise playback. Overall, this study suggests that anthropogenic noise could have a disruptive effect on the response of fish larvae to natural reef sound, with implications for settlement and population dynamics in coral reef habitats disturbed by boat traffic.

**KEY WORDS:** Anthropogenic impact · Boat noise · Larval fish · Settlement behaviour · Settlement cue

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## INTRODUCTION

Human activities such as construction, transportation, communication, exploration and extraction of raw materials create underwater acoustic noise pollution that travels faster and attenuates more slowly than in air (e.g. Hildebrand 2009, Ainslie 2010, Slabbekoorn et al. 2010). As international concern grows, an increasing number of studies are showing that anthropogenic noise impacts marine species

across a range of physiological, cognitive and behavioural processes, at individual and community scales (e.g. Allen & Read 2000, Slabbekoorn et al. 2010). Most studies of underwater noise have focussed on high-intensity events such as pile driving and sonar (e.g. Brandt et al. 2011, Rodkin et al. 2012). However, the lower intensity noise from boats, which is ubiquitous in populated coastal areas, is often ignored (although for exceptions see Picciulin et al. 2010, Jung & Swearer 2011, Bracciali et al. 2012). This source

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of noise has the potential for extensive effects and is likely to be especially damaging where human populations overlap with sensitive habitats where high numbers of endemic and rare species use sound, such as on coral reefs.

Reefs are naturally noisy places: fish and invertebrates produce feeding and territorial biotic sounds, while wind, waves and currents create abiotic noise (for review, see Arvedlund & Kavanagh 2009). Many species of fish and invertebrates are known to use these natural sounds for important life-history decisions, including as an orientation cue (Tolimieri et al. 2000, Simpson et al. 2004, Leis et al. 2011), and for selecting suitable habitat for settlement at the end of the pelagic period (Simpson et al. 2005). Masking (failure to recognise the occurrence of one type of stimulus as a result of the interfering presence of another stimulus), the distracting effect of noise and the avoidance of sounds have all been shown in the laboratory and in some cases are predicted in natural conditions based on auditory capabilities and noise levels (e.g. Fay 1974, Clark et al. 2009, Purser & Radford 2011). In the context of coral reef fish settlement, boat noise has the potential to disrupt the use of crucial acoustic cues. However, to date there is no experimental evidence that anthropogenic noise can disrupt the normal use of acoustic cues by fish in a semi-natural environment.

Here, choice chambers (Tolimieri et al. 2004) were used in a field experiment (Moorea Island, French Polynesia) to test the effect of boat noise on the response of a species of cardinalfish, *Apogon doryssa* Jordan and Seale, 1906, to reef noise, while controlling for ambient noise (using ocean noise) and the loudness of playbacks (using white noise). Several cardinalfishes (Apogonidae) from other parts of the world, like many other species of coral reef fish, show a positive directional response to reef noise (Simpson et al. 2005). Therefore, we predicted that *A. doryssa* larvae would swim towards playbacks of reef noise. We also predicted that they would show no preference for ocean or white noise, but show a disruption to directional behaviour when boat noise was played with reef noise.

## MATERIALS AND METHODS

### Sound treatments

The present study was conducted from Moorea Island (French Polynesia). Sound recordings were made at night at a depth of 5 m outside the barrier

reef of Moorea using a hydrophone (HiTech HTI-96-MIN with inbuilt preamplifier; sensitivity:  $-165$  dB re  $1$  V/ $\mu$ Pa; frequency range 2–30 kHz; High Tech) and a solid-state recorder (Edirol R-09HR 16-bit recorder; sampling rate 44.1 kHz; Roland Systems). 'Reef' and control 'Ocean' recordings were made in 3 different locations along the north coast of Moorea, separated by 1.5 km, on each of 3 different nights. Reef locations were 20 m and Ocean locations were 2 km from the barrier reef. 'Reef+Boat' and 'Ocean+Boat' recordings were matched to Reef and Ocean location and time of night, but with 1 of 2 outboard motor boats passing multiple times at 20 m. Boats were driven by D.L. and recorded by S.H. One boat was driven at a time and the distance at which the boat passed (20 m), turned (100 m) and boat speed (slow, medium, fast) were controlled.

Recordings were clipped into 30 s samples so that when boats were present a whole pass was sampled. Boats were present throughout the boat noise playback treatments. Minimum distance was 20 m and maximum distance was 50 m (where the boat turned around to come back for another pass, but the recording was cut so samples could be pseudorandomly rearranged to control for location, speed and boat). Five 1 min replicate playbacks per treatment were then constructed using different mixtures of 30 s samples. All playbacks were highpass filtered at 200 Hz to avoid near-field effects (Mann 2006) during playbacks, as underwater loudspeakers (UW-30, frequency response 0.1 to 10 kHz, University Sound, powered by 300 W amplifiers, XXLAM-2100, Power Sound) were situated 10 m from the experimental chambers. Sections of the chamber were defined as 'near', 'middle' and 'far' in relation to proximity to the loudspeaker after the chamber was divided into 3 sections at the end of each trial. Fig. 1 shows original recordings and playbacks in each chamber section as signal to noise ratios to the ambient noise at the experimental site.

### Experimental design

Larvae of *Apogon doryssa*, a readily available species of cardinalfish, were collected just prior to settlement between dusk and dawn during March and April 2011 using crest nets (Lecchini et al. 2006) at the barrier reef off the west coast of Moorea. Fish larvae were collected from the nets at sunrise and transferred to a laboratory aquarium (59 × 39 cm, water depth: 14 cm) that was placed on sound-insulating material (5 mm thick polystyrene), away from pass-

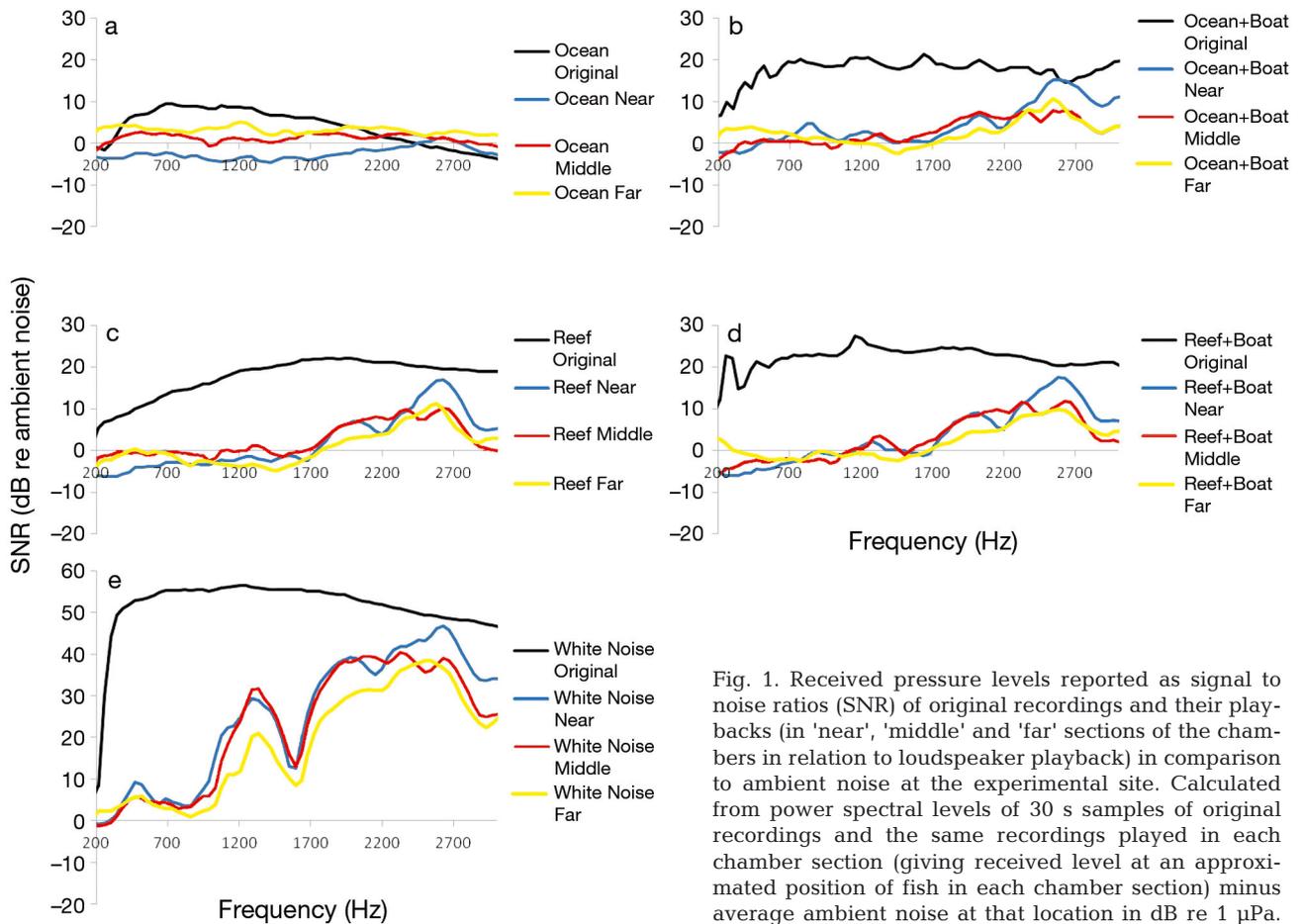


Fig. 1. Received pressure levels reported as signal to noise ratios (SNR) of original recordings and their playbacks (in 'near', 'middle' and 'far' sections of the chambers in relation to loudspeaker playback) in comparison to ambient noise at the experimental site. Calculated from power spectral levels of 30 s samples of original recordings and the same recordings played in each chamber section (giving received level at an approximated position of fish in each chamber section) minus average ambient noise at that location in dB re 1  $\mu$ Pa. FFT length: 1024, overlap: 50 %, Hamming window

ing researchers and with a constant supply of oxygenated seawater, piped in below the surface, to keep noise to a minimum (background noise = 78.27 peak sound pressure spectrum level in dB re 1  $\mu$ Pa between 200 and 3000 Hz of 30 s sample, FFT length 1024, geometric mean across all frequency bands between 200 and 3000 Hz = 64.91 dB re 1  $\mu$ Pa). As most larval coral reef fish settle at night (Lecchini et al. 2004), fish were used in choice chamber experiments in the lagoon adjacent to the research station the following night. The experiment was carried out on 8 different nights between 24 March and 24 April 2011. Treatment presentation was balanced over time by running 1 trial of each treatment before repeating any and randomising the order of treatments in each repeat. Ambient noise at the experimental site was 77.71 peak sound pressure level in dB re 1  $\mu$ Pa between 200 and 3000 Hz (mean of six 30 s samples, FFT length 1024, mean of all frequency bands between 200 and 3000 Hz = 69.85 dB re 1  $\mu$ Pa).

The choice chambers used were similar in concept to those used in earlier studies (Simpson et al. 2010),

consisting of 3 m cylindrical plastic polythene tubes 30 cm in diameter, situated in a calm sandy area of the lagoon on the north coast of Moorea, just below the surface, where water was 1.2 to 1.5 m deep. Three chambers were orientated parallel to the shore and barrier reef to control for potential directional cues. Chambers were also parallel to each other and were separated by 1.85 m, which precluded the transmission of visual cues between adjacent chambers, as verified using an underwater camera. Sealable openings at the centre allowed the introduction of fish larvae, and openings at each end allowed live release of fish at the end of each trial. One loudspeaker was placed at each end of the chambers, located at 10 m distance from the nearest end of the chambers. One *Apogon doryssa* larva was used per chamber for each trial in an independent subject design (each fish was used only once). Individual fish were randomly allocated to treatments and chambers, and the order and side of playback of the 5 treatments (Reef, Reef+Boat, Ocean, Ocean+Boat, White noise) were balanced (only 1

loudspeaker at a time was playing sound). Fish were allowed 5 min settling time, during which they were allowed to swim freely in the chambers, before 1 min of playback (preliminary trials showed that 1 min was long enough to see a directional response). At the end of each trial, chambers were divided into 3 equal-length sections; 2 experimenters that stood quietly on either side of the experimental chambers (2 m from the centre of the outer chambers, in line with the middle of the chambers) until the end of the trial closed the 3 chambers simultaneously by meeting hands in the middle of each of the 2 predefined locations for closing the chambers. Time to close the chambers was approximately 5 s. One experimenter then held the sections closed while the other tied them with elastic bungees allowing both experimenters to search for the fish in the tubes using underwater head torches. The location of each fish was then determined as near, middle or far according to the proximity of the chamber section to the loudspeaker playing.

### Statistical analysis

Chi-squared tests were used to test whether the distribution of fish at the end of each treatment differed from an even expected distribution. Subsequently, Reef+Boat was tested against an expected distribution of the same proportions as the results in the Reef treatment. Yates' corrections were used where expected counts were below 5.

## RESULTS

As expected, there was no significant directional response and no preference for either the middle or the ends of the chambers in either of the control treatments (white noise:  $\chi^2 = 0.40$ ,  $df = 2$ ,  $N = 15$ ,  $p > 0.80$ ; ocean noise:  $\chi^2 = 2.38$ ,  $df = 2$ ,  $N = 16$ ,  $p > 0.30$ ; Fig. 2). Also as expected, fish were significantly attracted to reef noise; 69% of fish swam towards reef playbacks and 8% swam away ( $\chi^2 = 8.17$ ,  $df = 2$ ,  $N = 13$ ,  $p < 0.05$ ; Fig. 2).

The addition of boat noise to ocean noise did not result in a distribution that differed significantly from chance ( $\chi^2 = 3.69$ ,  $df = 2$ ,  $N = 12$ ,  $p > 0.10$ ; Fig. 2). However, when boat noise was played with reef noise, the distribution was significantly non-uniform because no fish stayed in the centre of the chamber, while approximately equal numbers moved in either direction; 56% swam towards the playback and 44%

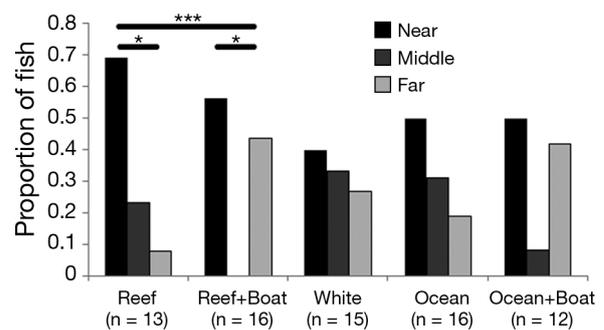


Fig. 2. *Apogon doryssa*. Proportion of fish in each section of the choice chamber relative to direction of the active loudspeaker playing back the sound for each trial (chambers were divided into 3 sections: 'near', 'middle' and 'far' according to proximity to the loudspeaker). Sample sizes are given in parentheses. Asterisks show the p-values of chi-squared tests for the comparisons of distributions indicated by the associated bars: \* $p < 0.05$ , \*\*\* $p < 0.001$

swam away ( $\chi^2 = 8.38$ ,  $df = 2$ ,  $N = 16$ ,  $p < 0.05$ ; Fig. 2). Moreover, the directional response to reef noise was significantly altered (Reef+Boat distribution tested against an expected distribution of the same proportions as the results in the Reef treatment:  $\chi^2 = 31.09$ ,  $df = 2$ ,  $N = 16$ ,  $p < 0.001$ ; Fig. 2).

## DISCUSSION

We found a positive directional response to reef noise, indicating that larval *Apogon doryssa* from French Polynesia respond to reef noise, similar to cardinalfish in other parts of the world (Simpson et al. 2005). However, we also demonstrated, for the first time, that boat noise can disrupt this natural behaviour; a greater proportion of fish were found in the choice chamber section farthest from the loudspeaker, and a smaller proportion of fish was found in the near and middle sections when boat noise was played with reef noise, compared to when reef noise alone was played back (Fig. 2). These differences were not due simply to a difference in sound pressure level; while playbacks of reef, ocean and boat treatments naturally varied in sound pressure level, there was no difference in the response of fish to Ocean (the quietest) or White noise (the loudest) playbacks when compared with expected even distributions. A number of fish were found at the end of the chamber nearest the loudspeaker during playback of Reef+Boat noise, which is consistent with a recent paper showing that the number of fish arriving at light traps playing boat sound with natural sound was greater than at light traps with no sound

(Jung & Swearer 2011). However, the greatest observable differences in our choice chamber experiment were the proportions of fish swimming away from the playback and choosing the middle section; this would not have been observable in a light trap experiment, where only positive responses can be recorded.

Use of reef noise as an orientation cue during settlement is seemingly common among a variety of fish and invertebrate taxa (e.g. Tolimieri et al. 2000, 2004, Simpson et al. 2004, 2005, Montgomery et al. 2006, Leis et al. 2011), although other cues are likely also used (Arvedlund & Kavanagh 2009, Huijbers et al. 2012). If boat noise disrupts this crucial process, larvae may spend a longer time swimming in the plankton, resulting in increased energetic costs and predation risk. Although a proper consideration of the mechanisms for the observed disruption in directional behaviour is beyond the scope of this experiment, we believe that the avoidance of the middle section during Reef+Boat playback precludes masking as a mechanism for this response. Instead we suggest that individual differences may be driving the apparently divergent response, i.e. some fish are attracted while others are repelled by the playback. Potential drivers for these differences include hearing ability, boldness, ability to deal with stressors and previous experience of boat noise, some of which could be elucidated with controlled testing of individuals after taking part in a choice chamber experiment like this one. Previous experience could be controlled if larvae were reared in controlled exposure environments. An alternative hypothesis is that boat noise may scare fish, causing them to scatter more randomly.

Boat noise was not consistently avoided during our study, which is also in line with the recent result of Jung & Swearer (2011), who noted that boat noise played alone did not reduce the number of fish caught in light traps when compared with traps playing no sound. The lack of a significant effect of boat noise played with ocean noise could be because there is no baseline directional response in *Apogon doryssa* to ocean noise that could be interrupted, because they had already experienced boat noise in the ocean and become conditioned to this sound (Simpson et al. 2010), or because boat noise in the ocean does not represent a threat that necessitates a behavioural response. However, failure to avoid boats in the open ocean could be detrimental to fish; at a closer proximity and the resulting greater sound intensity, physiological effects such as stress hormone (cortisol) release, increased heart rate and tem-

porary auditory threshold shifts (Kight & Swaddle 2011) may be more likely. These physiological changes may reduce foraging efficiency, increase energetic costs and inhibit the auditory detection of reef habitats.

The extent of the disruptive effect of boat noise will depend on the level of boat noise (affected by boat number, size, load, engine size, propeller characteristics, speed and age), the level of reef sound (affected by reef quality as well as proximity; Kennedy et al. 2010), fish auditory ability, which can change through ontogeny (Wright et al. 2011), whether larvae are affected by boat noise during the day as well as at night, and the persistence of the effect after the boat has passed. Directional daytime swimming in response to reef noise was reported by Leis et al. (1996), who found that fish swim away from reefs (irrespective of currents) during daylight hours, perhaps to avoid reef-based predators. Thus the more intense boat traffic experienced around coral reef environments during the day may also have consequences for survival. Ways to investigate the range over which boat noise has an immediate impact on the directional response to reef noise include: (1) recording reefs and boats at a variety of distances and testing responses to these recordings in the same choice chamber set-up as described here, or (2) running choice chamber experiments at different distances from reefs while an experimenter drives a boat near the reef and at different distances. The persistence of these effects could be established by waiting before dividing the chambers. The data from these experiments, along with acoustic recordings of boat traffic and information about sound propagation, benthos and topography could be used to inform a model which predicts the areas impacted by boat traffic that could be particularly useful for impact assessments or protected area management.

To conclude, our controlled experiment conducted in semi-natural conditions suggests that local, low-intensity noise (relative to alternative sources of anthropogenic noise) has the capacity to disrupt settlement in coral reef fish larvae, which may lead to impacts on recruitment to adult populations. This has direct implications for population dynamics for coral reef habitats disturbed by boat traffic. Small-scale localised noise sources such as outboard motorboats are very widespread (ubiquitous where humans inhabit coastal habitats) and should therefore be considered in the management of fisheries and protected areas. Nevertheless, additional studies should be conducted to better understand the influence of boat noise on fish ecology and physiology.

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