Chapter 129
Small-Boat Noise Impacts Natural Settlement Behavior of Coral Reef Fish Larvae

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Abstract After a pelagic larval phase, settlement-stage coral reef fish must locate a suitable reef habitat for juvenile life. Reef noise, produced by resident fish and invertebrates, provides an important cue for orientation and habitat selection during this process, which must often occur in environments impacted by anthropogenic noise. We adapted an established field-based protocol to test whether recorded boat noise influenced the settlement behavior of reef fish. Fewer fish settled to patch reefs broadcasting boat + reef noise compared with reef noise alone. This study suggests that boat noise, now a common feature of many reefs, can compromise critical settlement behavior of reef fishes.

Keywords Anthropogenic noise • Habitat selection • Patch reefs • Settlement stage

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1 Introduction

Hearing is one of the key sensory systems used by coral reef fishes for guiding orientation and habitat selection during the settlement phase when young individuals return from the plankton and enter into benthic reef habitats to begin juvenile life (Montgomery et al. 2006; Leis et al. 2011). At this time, the young of many of the principal families of reef fishes have been shown to be attracted by reef noise (Tolimieri et al. 2000; Leis et al. 2003; Simpson et al. 2004, 2005a), particularly at the higher frequency components (570–2,000 Hz) produced by invertebrates (Simpson et al. 2005a, 2008a).

Because reef noise is generated by resident fish and invertebrates, different reef and associated coastal habitats have distinct acoustic profiles (Radford et al. 2008, 2010; Kennedy et al. 2010; see Chapter 102 by Piercy et al.). Recent studies show that these different fingerprints of noise emanating from reefs and habitats could provide road maps to locate suitable environments both at settlement and during nocturnal migrations of juveniles (Simpson et al. 2008b). For example, settlement-stage *Haemulon flavolineatum* (French grunt) preferentially select noise from reefs over noise from mangrove and sea grass habitats (Huijbers et al. 2012) and a variety of reef species, including representatives of the Nemipteridae and Pomacentridae (two common and abundant families of reef fishes), are able to use noise to select preferred microhabitats when settling to reefs from the plankton (Radford et al. 2011).

The importance of reef noise as a cue for orientation raises an important question about the potential impacts of anthropogenic noise within these environments on the settlement process of reef fishes. Large human populations occur along the coasts of many tropical regions and, to date, studies of their effects on reef systems have generally focused on overfishing, eutrophication, sedimentation, and other stressors rather than the noise produced by fishing, transport, tourism, recreation, and industrial development (Slabbekoorn et al. 2010), yet these anthropogenic noise sources may present one of the most ubiquitous anthropogenic impacts in both coastal and oceanic environments. Noise pollution is known to affect behavior (Bruintjes and Radford 2013; Wale et al. 2013a), physiology (Wale et al. 2013b), communication (Vasconcelos et al. 2007; Codarin et al. 2009), sensory thresholds (Scholik and Yan 2002), and stress levels (Wysocki et al. 2006) of both aquatic vertebrate and invertebrates.

Recent studies of the effect of boat noise on reef fishes have produced inconsistent results; Jung and Swearer (2011) found that young temperate reef fishes were not deterred from entering traps by boat noise, whereas Holles et al. (2013) used auditory choice chambers to demonstrate a negative impact of boat noise on orientation of settlement-stage reef fish. Both studies provide only limited evidence of the effect of noise on young fish because they only examined one aspect of the settlement process (attraction/avoidance to sound in the former study and orientation in the latter). However, experimental protocols developed by Simpson et al. (2005a) provide a useful and simple means to explore directly the effects of boat noise on a larger part of the settlement process and offer the opportunity to gain a more comprehensive insight into the effect of sound on this aspect of the life history of coral reef fishes. This protocol involves the use of reefs constructed of natural material (live and dead corals) as settlement sites for young fish combined with the deployment of speakers broadcasting boat and reef noise. We used this approach to test the hypothesis that there would be a difference in levels of settlement of young fishes to reefs depending on whether sound systems moored above the reefs were broadcasting nocturnal recordings of the sounds of local reefs or tracks with boat noise overlaid on reef sounds. This experiment provides the first direct evidence of the effect of anthropogenic noise on the settlement process of coral reef fishes.

2 Methods

For eight nights (12–19 November 2012) centered on the new moon (14 November), we tested the effect of the playback of boat noise on the settlement of young reef fish in the shallow (2–5 m depth) back-reef habitat at Lizard Island Research Station, Great Barrier Reef (14°40.939′ S, 145°26.635′ E and 14°41.035′ S, 145°26.613′ E).

Recordings of five different boats, each a 5-m aluminum dinghy with a 30-hp 2-stroke Suzuki outboard moving 10–100 m from the recording station, were made from a kayak to avoid the sound of waves on the hull of the boat with a hydrophone 2 m below the surface in ~5-m-deep water over a sandy bottom and >100 m from reefs. The five nocturnal reef recordings (between 1,920 and 2,020 h) were made with the hydrophone 1 m directly above different natural reefs in water depths of 2–5 m. Reef and boat recordings and compilation tracks made from these recordings were all made using a calibrated omnidirectional HTI-96-MIN hydrophone (frequency response = 2 Hz to 30 kHz, voltage sensitivity = −165 dB re 1 V/μPa; High Tech, Inc., Gulfport, MS) and a Sony PCM-M10 24-Bit recorder (96 kHz sampling rate; Sony Corporation, Tokyo, Japan) that was also fully calibrated using pure sine wave signals, measured in-line with an oscilloscope, and produced by a function generator (TTi RS Components 216-069, TG230, 2 MHz Sweep/Function Generator). Recordings were analyzed using SASLab Pro v5.2.07 (Avisoft Bioacoustics, Berlin, Germany).

For the playback experiment, we used a similar protocol to that of Simpson et al. (2005a) in which a cluster of four 0.25-m^3 experimental patch reefs constructed of live and dead *Pocillopora damicornis* (cauliflower coral) collected locally were arranged 3 m apart in a square formation around a central mooring in 1–4 m depth (depending on tides) on extensive sand flats just offshore of the Research Station. We built two replicate setups 180 m apart and >100 from nearby reefs (Fig. 129.1a).

As young reef fishes settle to coral reef habitats during the night, we moored a sound system consisting of a battery (12 V 7.2 Ah sealed lead-acid), WAV/MP3 player (Philips GoGear VIBE, Koninklijke Philips N.V., Amsterdam, The Netherlands), and amplifier (M033N; 18 W; frequency response: 40–20,000 Hz; Kemo-Electronic GmbH, Langen, Germany) sealed in a watertight housing and attached to an underwater speaker (Lubell Labs University Sound UW-30, frequency

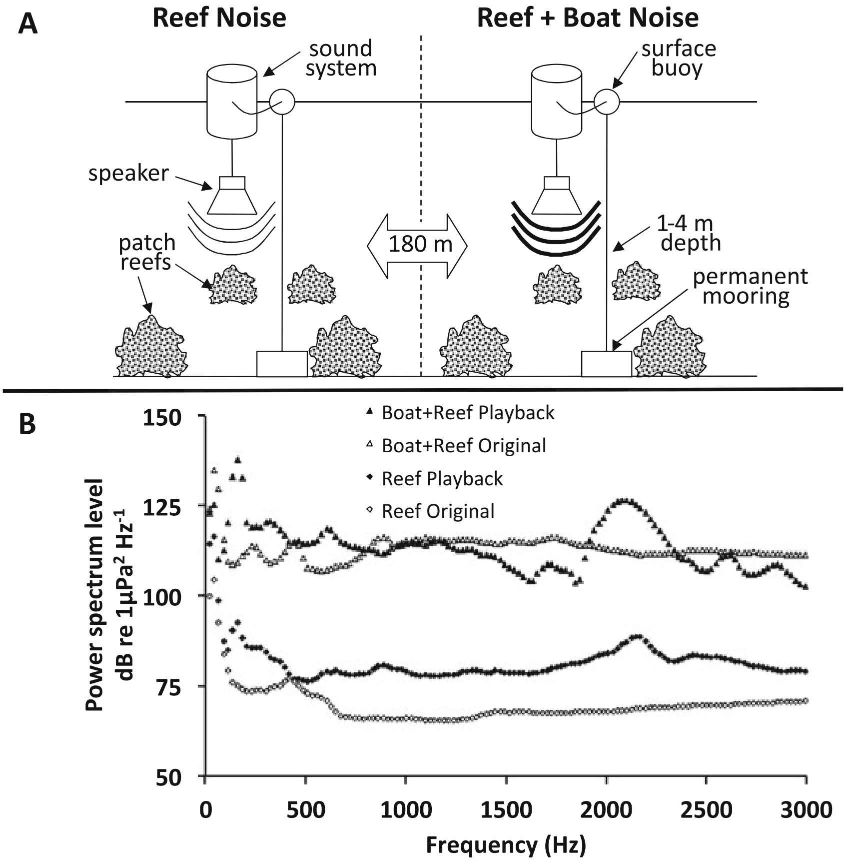

Fig. 129.1 (**a**) Experimental study system showing configuration of reefs and underwater sound playback equipment. (**b**) Averaged power spectra (fast Fourier transform length 4096, 23.4 Hz bandwidth, Hamming window) for acoustic pressure levels in medleys of five original reef (*diamonds*) and reef+boat (*triangles*) recordings (*open symbols*) compared with recordings next to the patch reefs of the same recordings being played back through underwater speakers (*solid symbols*)

response 100–10,000 Hz; University Sound, Columbus, OH) over each patch reef cluster at dusk, with one system playing a recording of one of five nearby coral reefs (each replicate randomly selected) on a continual loop through the night and the other system playing the same recording but with recordings of three of five different research station boats (each replicate randomly selected) overlaid on the same track. The allocation of reef or reef+boat treatments was randomized each night, which resulted in clusters one and two receiving reef+boat noise three and five times, respectively, over the eight nights.

Each morning before 08:00, the sound systems were retrieved and the patch reefs were cleared of newly settled fishes by divers using clove oil and hand nets. All fish were counted and identified.

Where frequency of occurrence was sufficient, the relative numbers of fish arriving on reefs near the speakers playing back reef noise with and without additional boat noise were compared using a Wilcoxon signed-rank test, which is a nonparametric paired analysis that does not require normal distributions of catches through the nights and can be used with small sample sizes ($n = 8$ nights).

3 Results

The recorded noise level of the nocturnal reefs was 112.8 ± 0.1 dB re 1 μPa (root mean square [rms]; 1 s averaging; mean ± SE), whereas the level for boats driving around the hydrophone was 136.1 ± 0.5 dB re 1 μPa. The playback levels for the reef and reef + boat recordings were determined iteratively to generate levels that were similar to those in the original recordings (reef = 117.0 ± 0.3 dB re 1 μPa; reef + boat = 144.4 ± 0.1 dB re 1 μPa). Spectral levels in the playbacks generally replicated the qualitative characteristics of the original recordings (Fig. 129.1b).

Over eight nights of sampling 1,932 fish (61%) were collected from reefs near a speaker playing back reef noise while only 1,229 fish (39%) were collected from reefs that had boat noise in addition to reef noise. Of the 12 species where ≥5 fish were collected, representing five common reef fish families, ten were in greater abundance on reefs without boat noise (Fig. 129.2), although due to limited replication, this difference was only significant for two species, *Pomacentrus nagasakiensis* (Nagasaki damsel; Wilcoxon signed-rank test: $n = 8$, $W = 36$, $P = 0.01$) and *P. amboinensis* (Ambon damsel; $n = 8$, $W = 32$, $P = 0.05$).

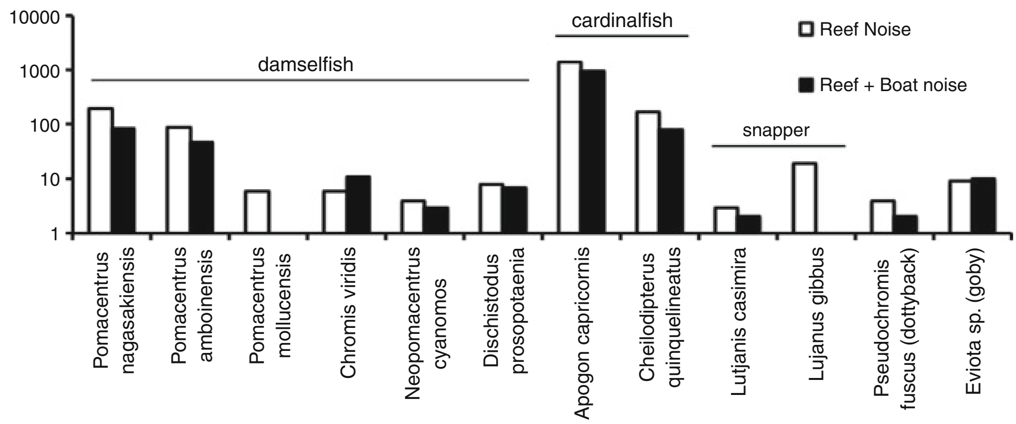

Fig. 129.2 Arrival of settlement-stage larvae and juvenile reef fish on experimental patch reefs with nocturnal reef noise or reef + boat noise playback over eight nights. Species shown are for catches of ≥5 fish

4 Discussion

When a combination of boat and reef noise was broadcast near our experimental patch reefs, we found evidence of reduced settlement of young reef fish compared with patch reefs where only reef noise was broadcast. This result suggests that boat noise may disrupt the normal process of site selection and settlement of young fish returning to reefs. Although limited by sample size, our results suggest that further investigation into the impact of boat noise on such key ecological processes occurring on coral reefs is now warranted.

Boat noise joins a growing (and worrying) list of anthropogenic impacts now thought to have the potential to influence critical life history phenomena of coral reef fishes. Conditions of ocean acidification predicted to occur later this century may also fundamentally alter patterns of replenishment (Munday et al. 2010) through effects on predator–prey relationships (Ferrari et al. 2011) and compromised behavior (e.g., Simpson et al. 2011a). A combination of noise and these other anthropogenic factors may result in the dynamics of reef fish populations becoming increasingly decoupled from the settlement processes due to maladapted orientation, habitat selection, and predator–prey interactions.

Effects of noise pollution in the world's oceans are not likely to be limited to fishes because many other taxa respond directionally to reef noise in an ecologically relevant manner. For example, anthropogenic noise has the potential to also interfere with the avoidance behavior of crustaceans (Simpson et al. 2011b) and orientation in settling crab and lobster larvae (Stanley et al. 2010, 2011, 2012) and coral planulae (Vermeij et al. 2010). Such effects may also carry through to other life history stages (see Chapter 111 by Radford et al.), given that previous acoustic experience has been shown to influence subsequent orientation (Simpson et al. 2010) and antipredator, feeding, and social behaviors (see Chapter 149 by Voellmy et al.). Because many reef fish are reared in nests on reefs by their parents throughout their embryonic stage, during which time they can detect local acoustic conditions (Simpson et al. 2005b), the potential impacts of stress from anthropogenic noise during early development (reviewed by Kight and Swaddle 2011) may have downstream consequences for the ecology of reef fishes.

Although playback of reef and boat noise does not fully replicate the acoustic conditions of natural reefs and real boats, a recent study that measured both acoustic pressure and particle velocity of ambient and boat noise and playback of recordings of these noises suggests that the signal-to-noise ratios of boat playback to ambient noise do not exceed those of a real boat (see Chapter 55 by Holles et al.). Our study represents an initial attempt to take experiments focusing on key ecological processes from the laboratory or enclosures in shallow water using captive animals to the natural setting working with wild animals. By combining these various approaches, we will develop a more complete understanding of the impact of anthropogenic noise on coral reef organisms, with the potential through management to mitigate impacts in sensitive or protected areas.

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