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Determining trigger values of suspended sediment for behavioral changes in a coral reef fish

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ABSTRACT

Sediment from land use increases water turbidity and threatens the health of inshore coral reefs. This study performed experiments with a damselfish, *Pomacentrus moluccensis*, in four sediment treatments, control (0 mg l^{-1}), 10 mg l^{-1}(~1.7 NTU), 20 mg l^{-1}(~3.3 NTU) and 30 mg l^{-1} (~5 NTU), to determine when sediment triggers a change in habitat use and movement. We reviewed the literature to assess how frequently *P. moluccensis* would experience sub-optimal sediment conditions on the reef. Preference for live coral declined from 49.4% to 23.3% and movement between habitats declined from 2.1 to 0.4 times between 20 mg l^{-1} and 30 mg l^{-1}, suggesting a sediment threshold for behavioral changes. Inshore areas of the Great Barrier Reef, *P. moluccensis* may encounter sub-optimal conditions between 8% and 53% of the time. Changes in these vital processes may have long-term effects on the persistence of populations, particularly as habitat loss on coral reefs increases.

1. Introduction

Habitat degradation is attributable to a range of anthropogenic sources and is a major threat to coastal marine environments worldwide, leading to a loss of biodiversity (e.g. Diaz and Rosenberg, 2008; Lotze et al., 2006; Tilman et al., 2001). As agricultural practices and coastal development have increased on land, coastal marine systems are receiving elevated levels of sediment that threatens the health of the species present in these zones (Brodie et al., 2012; Cloern, 2001; Lotze et al., 2006). Among these shallow marine environments, coral reefs are especially sensitive to increased sediment and turbidity (Brodie et al., 2012; Fabricius, 2005; Furnas, 2003). In the Great Barrier Reef (GBR) region of eastern Australia, the world's largest system of coral reefs, many reefs have been classified as being at high risk from sediment causing significant impacts to the existing marine communities (Devlin et al., 2003). This elevated risk is due to a fivefold increase in suspended sediment loads from rivers since European settlement (Furnas, 2003; Kroon et al., 2012), which has led to elevated turbidity on the GBR (Fabricius et al., 2012).

The effects of sediment on coral health has been widely documented, with elevated turbidity being shown to increase mucous production (Telesnicki and Goldberg, 1995), reduce calcification and tissue growth (Anthony and Fabricius, 2000; Rogers, 1979), and alter the biodiversity and depth range of coral communities (Fabricius, 2005; Fabricius et al., 2005). Several studies have also shown that fish abundance, biomass and species diversity are lower at inshore sites and sites highly impacted by sediment compared to offshore or low impacted sites (Fabricius et al., 2005; Letourneur et al., 1998; Mallela et al., 2007). However, these are correlative studies that do not distinguish between indirect and direct effects of suspended sediment on coral reef fishes. Direct effects of suspended sediment on coral reef fishes may compound the indirect effects of habitat loss, leading to further changes in population dynamics. Recent research has shown that increased turbidity impairs habitat choice and foraging success of coral reef fishes through a reduction in their ability to distinguish visual and chemical cues (Wenger et al., 2011, 2012). Continued quantitative evaluation of the interaction between sediment and coral reef fishes is crucial to increase our understanding of how changing water quality directly affects coral reef fishes.

One of the central interactions that drive the distributions of organisms on coral reefs is the relationship between coral reef fishes and their habitat, because most species of coral reef fishes exhibit strong habitat preferences at settlement (Jones et al., 2004; McCormick et al., 2010; Öhman et al., 1998). Indeed, many show a preference for live coral at settlement even though they do not need the habitat once adult, and declines in the abundance and diversity of coral reef fishes have been linked to an indirect effect of habitat loss (Jones et al., 2004; Wilson et al., 2006). As

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coral reefs are spatially heterogeneous with live coral exhibiting a naturally patchy distribution (Ebeling and Hixon, 1991), fishes use a range of sensory modes such as smell, taste and visual stimuli to make habitat choice decisions (e.g. Lecchini et al., 2005; McCormick et al., 2010; Munday et al., 2009; Sweatman, 1983). Once settled, fish continue to use sensory cues to gain information about their environment (Kroon, 2005; Odling-Smee and Braithwaite, 2003). Though many coral reef fishes tend to be closely associated with a particular habitat, it is common that a fish's home range will include a broad array of habitat patches in order to exploit more resources (Lewis, 1997). Many juvenile fishes also undergo substantial movements after their initial settlement (e.g. McCormick and Makey, 1997). Any change in environmental conditions that restricts the movement of coral reef fish has the potential to reduce growth, condition and survivorship (Coker et al., 2012; Gaillard et al., 2010; Odling-Smee and Braithwaite, 2003). Though suspended sediment is known to impair habitat selection at settlement (Wenger et al., 2011), it is unclear whether this reduction in visibility could also change patterns of habitat use.

When trying to assess how environmental change affects coral reef fishes, it is important to determine when a specific environmental attribute reaches the point where it is producing a response (Briske et al., 2006; Groffman et al., 2006). Previous work has shown a definitive change in behavior at suspended sediment levels of 45 mg l^{-1} (~7 NTU) and above (Wenger et al., 2011, 2012), but it is not known at what point this behavioral change actually occurs. Our aim was to investigate the influence of suspended sediment on habitat selection and movement in a juvenile damselfish, *Pomacentrus moluccensis*. This species was chosen because it is located throughout the entire GBR, both on inshore and outer reefs (AIMS long-term monitoring data). It is found predominately on live coral and has exhibited declines in abundance associated with live coral loss (Bellwood et al., 2006; Syms and Jones, 2000), meaning that it has the potential to be both indirectly and directly affected by suspended sediment. We performed habitat choice experiments over a spectrum of suspended sediment treatments to determine when suspended sediment provoked a change in habitat choice and movement of juveniles. The sediment treatments ranged from clear water through to levels where physiological stress occurs in corals (5 NTU; Cooper et al., 2008).We then used two-channel choice flumes to clarify the sensory cues that were being affected. The study tested the prediction that, based on a reduction in settlement success due to sediment (Wenger et al., 2011), increased turbidity would also restrict movement between corals. Finally, we compared the concentrations of suspended sediment that elicited a response to observed patterns of suspended sediment recorded on reefs in the GBR where *P. moluccensis* lives. This enabled an examination of the frequency that *P. moluccensis* would be likely to experience sub-optimal concentrations of suspended sediment.

2. Methods

2.1. Study species

Juvenile *P. moluccensis* (16.9 ± 0.2, mean standard length ± SE) were used in habitat movement trials to determine the changes in habitat preference and home range use in increasing concentrations of suspended sediment. Additional *P. moluccensis* juveniles (18.3 ± 0.5) were collected to test the effect of bentonite on chemoreception. The fishes were collected from coral reefs in the lagoon at Lizard Island in February 2011 from live coral using a diluted clove oil solution and a hand-net. The collection reefs experience very low levels of turbidity on average (0.8 ± 0.02, Wenger, unpublished data). All fishes were held in 15 L tanks (10 per tank) with filtered aerated seawater and fed *Artemia* nauplii twice a day for 48 h prior to experiments. This time frame was determined based on how quickly the fishes began to swim and eat normally.

2.2. Experiment 1: Habitat choice in increasing levels of suspended sediment

To determine threshold levels of suspended sediment that begin to impair coral reef fishes, we conducted a controlled laboratory experiment on Lizard Island on the northern Great Barrier Reef, Australia (14°40′ S; 145°28′ E). *Pocillopora damicornis*, a complex branching coral used by many coral-dwelling fishes for habitat (e.g. Feary et al., 2007), was chosen for this habitat choice experiment. Three habitat types were used: live coral, partially dead coral (~25% live coral cover), and dead coral (covered by some benthic invertebrates and algae), all of which were structurally intact (Feary et al., 2007). Ten colonies of each habitat type were collected from the Lizard Island lagoon using a hammer and chisel. All colonies were 24 cm in diameter. None of the coral colonies showed any sign of stress throughout the experiment. When trials were not being run, all coral colonies were held in tanks with clear, filtered aerated seawater.

The settlement trials were run in 285 L circular tanks supplied with filtered aerated seawater. Each tank contained one of each of the three different habitat types. The coral heads were placed in a triangle, with the inner edge of each habitat equidistant from each other (42 cm). The outer edge of each habitat was 10 cm from the tank walls. Between each trial, the tanks were emptied, cleaned, and randomly assigned a sediment level. The coral heads were also haphazardly rearranged to different tanks between each trial to ensure that settlement was based on habitat type and not location of the coral heads, direction of sunlight or other outside stimuli.

The habitat choice of each individual tested was recorded in four levels of suspended sediment: control (0 mg l^{-1}), 10 mg l^{-1} (~1.7 NTU), 20 mg l^{-1} (~3.3 NTU) and 30 mg l^{1} (~5 NTU). These levels of suspended sediment were chosen based on the target level set for the GBR of 2.4 NTU (this is the adjusted value from De'ath and Fabricius (2008) using the calibration of mg l^{-1} to NTU proposed by Larcombe et al. (1995) and ecological stress that occurs in corals at 5 NTU (Cooper et al., 2008). Twenty individual *P. moluccensis* were tested in 20 independent trials for each level of suspended sediment ($n = 80$ for entire experiment). A commercially available clay (Australian Bentonite) used in previous turbidity experiments (e.g. Van de Meutter et al., 2005; Wenger et al., 2012, 2011) was used as the sediment. Muddy sediments and clays are common constituents of sediment on the inshore GBR (Carter et al., 1993; McCulloch et al., 2003). Additionally, the particle size of bentonite is in the same size class as particles found in suspension in the GBR (Devlin et al., 2012; Wenger, unpublished data). Before each trial, the water was turned off in the experimental tanks so that no sediment could leave the tanks during the trials. Then, a set amount of sediment was manually dissolved to avoid clumping into a fixed volume of water in the tanks. The water was cycled through each tank from a sump with an external pump. This ensured constant water movement, allowing the sediment to remain in suspension. Once the water was uniformly turbid (~10 min), one fish was placed into a clear Perspex box in the center of each tank. After a 3-min acclimation period, the box was removed and the fish was allowed to choose a habitat. Although it is generally thought that coral reef fishes settle at night, it has been noted that in many damselfish species, including *P. moluccensis,* diurnal settlement represents a substantial portion of observed settlement patterns (e.g. Leis and Carson-Ewart, 2002). Consequently, trials were run throughout the day. This allowed for the use of both visual and chemosensory cues for settlement choice. The habitat choice of each fish was recorded every 10 min for