



Short communication

The effects of coral bleaching on settlement preferences and growth of juvenile butterflyfishes



A.J. Cole, R.J. Lawton, C. Pisapia, M.S. Pratchett*

ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Queensland 4811, Australia

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ABSTRACT

Coral bleaching and associated mortality is an increasingly prominent threat to coral reef ecosystems. Although the effects of bleaching-induced coral mortality on reef fishes have been well demonstrated, corals can remain bleached for several weeks prior to recovery or death and little is known about how bleaching affects resident fishes during this time period. This study compared growth rates of two species of juvenile butterflyfishes (*Chaetodon aureofasciatus* and *Chaetodon lunulatus*) that were restricted to feeding upon either bleached or healthy coral tissue of *Acropora spathulata* or *Pocillopora damicornis*. Coral condition (bleached vs. unbleached) had no significant effects on changes in total length or weight over a 23-day period. Likewise, in a habitat choice experiment, juvenile butterflyfishes did not discriminate between healthy and bleached corals, but actively avoided using recently dead colonies. These results indicate that juvenile coral-feeding fishes are relatively robust to short term effects of bleaching events, provided that the corals do recover.

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1. Introduction

Increasing ocean temperatures, directly attributable to global climate change, are resulting in increasingly frequent and severe coral-bleaching episodes. In the last decade, climate-induced coral bleaching has caused widespread coral mortality, contributing greatly to the global degradation of coral reef environments (Hoegh-Guldberg et al., 2007; Hoegh-Guldberg and Bruno 2010). The extensive loss of reef-building corals has significant ramifications for the high diversity of organisms (e.g., coral reef fishes) that associate with coral reefs (Jones et al., 2004; Graham et al., 2006; Wilson et al., 2006; Pratchett et al., 2011). The reef fishes that are most susceptible to declining coral cover are highly specialized coral-dependent species, such as the obligate coral-feeding butterflyfishes (Wilson et al., 2006, 2013; Pratchett et al., 2008a). Several studies have documented the disproportionate declines in the abundance of coral-feeding fishes following severe coral bleaching and coral loss (Kokita and Nakazono, 2001; Sano, 2004; Wilson et al., 2006; Pratchett et al., 2006). However, the effects of short-term or minor bleaching events that do not cause extensive coral mortality are much less clear.

Although coral-dwelling fishes are significantly affected by host coral mortality (Wilson et al., 2006, 2013; Pratchett et al., 2008a), the effects of bleaching *per se* are inconsistent and often minimal (e.g., Bonin et al., 2009; McCormick et al., 2010; Coker et al., 2012). Following a natural bleaching event, Bonin et al. (2009) found no differences in the settlement rate and survivorship of juvenile *Pomacentrus moluccensis* on bleached versus healthy coral hosts in Papua New Guinea. However, following the death of bleached corals, settlement densities significantly declined. Likewise, experimentally induced bleaching of *Seriatopora hystrix* did not cause the resident populations (comprising adults and juveniles) of *Dascyllus aruanus* to relocate to healthy colonies, although all fishes rapidly vacated dead coral hosts (Coker et al., 2012). However, (McCormick et al. (2010) showed that *P. moluccensis* preferentially settle in live coral colonies and avoided settling into bleached, or dead, colonies of the same coral species. Coker et al. (2009) also showed that predation rates on coral-dwelling damselfishes were higher on bleached versus healthy corals, but higher still on dead host coral.

For coral-feeding fishes, recent research suggests that the nutritional quality of bleached coral tissue declines during a bleaching event before the coral actually dies (Cole et al., 2009; Rodríguez-Troncoso et al., 2010; but see Pisapia et al., 2012). Adult coral-feeding fishes exhibit declines in physiological condition immediately after bleaching (Pratchett et al., 2004), which may be attributable to increasing reliance on sub-optimal coral prey, or

* Corresponding author. Tel.: +61 7 4781 5747.

E-mail address: morgan.pratchett@jcu.edu.au (M.S. Pratchett).

nutritional depletion of bleached corals. However, these fishes do not exhibit significant declines in local abundance; adult corallivores may be relatively immune to negative nutritional effects as they can either expand their foraging area to feed on unbleached corals or they can switch to feed on alternative prey corals which are more resistant to bleaching (e.g., Pratchett et al., 2004). In contrast, juvenile coral-feeders may be more susceptible to negative effects during minor bleaching events as they show very limited ability to move between coral colonies until they reach a size of 30–35 mm and rely on their initial settlement coral to meet all of their nutritional requirements (Cole and Pratchett, 2011). If bleached coral has a reduced nutritional content relative to healthy unbleached corals then juveniles inhabiting bleached corals could be at a significant disadvantage and may experience increased mortality rates or considerable sub-lethal effects on growth and condition.

The aim of this study was to determine the consequences for juvenile butterflyfishes that settle into and feed entirely on bleached coral tissue during their early life history. Specifically, we tested whether there was a difference in the growth and condition of juvenile butterflyfishes inhabiting bleached versus healthy corals. We also examined whether habitat condition (healthy, bleached and recently dead coral colonies) influenced the patterns of habitat use by juvenile butterflyfishes. The butterflyfishes used in this study were *Chaetodon aureofasciatus* and *Chaetodon lunulatus*, both of which, settle exclusively to distinct colonies of branching corals (Pratchett et al., 2008b) and had recruited in very high abundance to reef habitats on the western side of Lizard Island, northern Great Barrier Reef, Australia, at this time of the experiment.

2. Methods

2.1. Habitat choice experiment

To determine whether coral condition influences the habitat use of the corallivorous butterflyfishes (*C. aureofasciatus* and *C. lunulatus*), an aquarium choice experiment was undertaken. Small juveniles of *C. lunulatus* were relatively hard to find in late January, as such *C. lunulatus* trials consisted of one *C. lunulatus* (mean = 24.24 mm TL $\pm$ 0.48 SE) and two *C. aureofasciatus*. Proportional habitat use in these trials was only calculated for *C. lunulatus*, with the remaining two fish only used to ensure comparable behaviour to that observed under field conditions where multiple juveniles frequently co-occur within a single coral colony (e.g. Cole and Pratchett, 2011). No aggressive interactions were observed between the three individuals and they were predominantly observed together as a group of three.

To compare among different habitat types, three equivalently sized (25–30 cm diameter) colonies of either *Acropora spathulata* or *Pocillopora damicornis* were added: one healthy, one bleached and one recently dead colony. The three coral colonies were arranged in a triangular configuration with equal distance between the three colonies. A total of 20 replicate trials were performed for each species of fish (*C. aureofasciatus* and *C. lunulatus*), run sequentially in each of four different tanks. The actual colonies used in each trial were randomly assigned from a pool of 10 colonies of each habitat type; likewise the position of each colony inside each tank was also randomly assigned for each trial. Three small juveniles of *C. aureofasciatus* (mean = 15.52 mm TL $\pm$ 0.37 SE) were released into the centre of each tank between 1700 and 1800 h, with the trial beginning the following morning (following Öhman et al., 1998). The habitat used by each of the three fish was recorded at 10 random times during the day (0630–1600 hrs), with each

observation separated by a minimum of 30 min providing a total of 30 data points per trial.

Habitat use was judged based on intimate association between fishes and one or more alternative habitat-types, whereby the fishes were generally found hiding well within the branches of a particular habitat. A small number of fishes were also seen in the water column immediately above one or other habitat-type, but immediately sought shelter within this habitat when observers approached. Two separate 2-way ANOVAs were used to test for differences in the relative use of each of the three habitat treatments by the two butterflyfish species. Residual plots were used to ensure ANOVA assumptions were satisfied. To improve normality and homogeneity of variances, data was $\log_{10}(x + 1)$ transformed. Tukey's Honest Significant Difference (HSD) tests were then used to identify where differences in group means occurred.

2.2. Effect of bleached coral on juvenile growth

To determine whether inhabiting and feeding on bleached coral tissue affects the growth rates of recently settled juvenile corallivores (*C. lunulatus* and *C. aureofasciatus*), an aquarium based growth experiment was undertaken. Two coral species (*A. spathulata* and *P. damicornis*) were used, both of which are commonly used as settlement habitat of juvenile butterflyfishes (Cole and Pratchett, 2011). All corals were collected from the same location (on the eastern side of Lizard Island) and habitat (4–5 m depth on the exposed flanks of individual patch reefs), and only those coral that were physically intact (no missing branches) were used. A fully factorial experimental design was undertaken with 8 replicates for each combination of coral species and condition (bleached versus healthy). In each tank, a minimum of 100 cm² of live coral was provided and regularly checked to ensure it remained in a healthy state for the duration of the experiment. Fresh corals were added to each tank weekly, which ensured that there was always a surplus of coral tissue available. Corals did not show any observable signs of stress during the experiment.

This experiment coincided with a natural (but moderate) bleaching event that began in December 2010, such that healthy and bleached corals were collected from the field; Healthy corals were heavily pigmented, while bleached corals were visibly pale. To ensure that the colonies used in our experiment were actually bleached and not just naturally pale, zooxanthellae densities were quantified for both bleached and healthy corals, following McCowan et al. (2012). Zooxanthellae densities were quantified using individual branches (ca. 7 cm long) taken from the centre of each colony upon collection ($n = 30$ colonies per species). Sample branches were fixed in 10% buffered formalin for at least 1-week and then decalcified using dilute (5–10%) formic acid. Once decalcified, two replicate 5 $\times$ 5 mm tissue sections were cut from of each sample branch, homogenized with 1 ml of 70% ethanol and then immediately placed on to Neubauer Improved Tiefe Depth Profoundeur (0.100 mm) haemocytometer to count the number of zooxanthellae in 3 replicate 0.0025 ml aliquots per tissue section. Zooxanthellae densities (number per cm²) for each branch were then calculated by averaging across sections and aliquots, following McCowan et al. (2012). Bleached colonies of both species had zooxanthellae densities that were 50% lower than healthy colonies which was a significant difference (ANOVA $F_{1,57} = 150.181$, $p < 0.0001$).

The initial length and weight of butterflyfishes was higher for *C. lunulatus* (Length: mean = 24.24 mm TL $\pm$ 0.48 SE, Weight: mean = 405.99 mg TL $\pm$ 1.92 SE), than *C. aureofasciatus* (Length: mean = 15.52 mm TL $\pm$ 0.37 SE, Weight: mean = 135.73 mg TL $\pm$ 0.65 SE) and did not differ significantly between the four treatments for either *C. aureofasciatus* (Length; $F_{1,30} = 0.19$, $p > 0.05$, Weight;

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