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Corallivorous snail removal: evaluation of impact on *Acropora palmata*

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Abstract With the continuing decline of *Acropora palmata* throughout the Caribbean region, impacts of the gastropod corallivore, *Coralliophila abbreviata*, are becoming more noticeable. A snail removal experiment was performed in remnant *A. palmata* populations in the Florida Keys National Marine Sanctuary to quantify the area of coral tissue consumed by ambient snail aggregations and to assess the possible effectiveness of snail removal in conserving live coral tissue. Corals where ambient snail aggregations were removed maintained significantly more live tissue area during the 2-month experiment than those where feeding snail aggregations were left in place. The corals with feeding snails left in place lost more than 3 cm^2 tissue day^{-1} on average. Thus, removal of *C. abbreviata* may be an effective measure for conserving depressed *A. palmata* populations, though secondary effects of such a manipulation remain to be carefully evaluated.

Key words *Acropora palmata* · *Coralliophila abbreviata* · Corallivore · Predator removal

Introduction

The recognition of significant predation by invertebrate corallivores has been largely restricted to Pacific echinoderms such as *Acanthaster planci* and *Eucidaris thouarsii* (e.g. Glynn et al. 1979; Moran 1986). Corallivorous gastropods such as *Drupella* spp. in the Indo-Pacific and *Coralliophila abbreviata* in the Caribbean have also at times been acknowledged for their significant impact on coral prey (Brawley and Adey 1982; Knowlton et al. 1990; Turner 1994). Knowlton et al. (1990) suggested that the impact of *C. abbreviata* may be enhanced when coral prey species abundance was diminished by other factors (e.g. by hurricane damage).

Acropora palmata and *A. cervicornis*, common prey species of *Coralliophila abbreviata*, have undergone widespread decline throughout the Caribbean region (reviewed in Aronson and Precht 2000), leading the US federal agency responsible for marine and estuarine endangered species (NOAA Fisheries) to designate them as candidates under the Endangered Species Act (Diaz-Soltero 1999). In the Florida Keys, USA, multiple factors, including winter cold kills, summer bleaching, hurricanes, and various disease syndromes have contributed to this decline over the past 2 decades (Dustan and Halas 1987; Porter and Meier 1992) and over the past 2 years (personal obserevation). Recent survey work (1998–1999) in the Florida Keys has shown *C. abbreviata* to be present in all eight remnant *A. palmata* patches that were sampled (Baums et al., in preparation) and visually obvious coral loss to snail predation was observed in at least half of these sites.

Efforts to control invertebrate predators (specifically *Acanthaster planci* and *Drupella cornus*) in order to protect coral populations have been made at a range of scales, but have been judged inefficient or unsuccessful (Yamaguchi 1986; Johnson et al. 1990; Osborne and Williams 1992). These studies judged success on their effectiveness of suppressing predator abundance. No effort was made to evaluate success based on improved coral survival and/or growth.

The small-scale experiment described here was designed to evaluate the impact of ambient snail predators on remnant *Acropora palmata* populations (and, hence, the potential effectiveness of targeted predator removal in conserving *A. palmata*). The persistence of coral tissue was quantified in the presence, absence, and after experimental removal of the corallivorous snail, *Coralliophila abbreviata*.

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Methods

The experiment was conducted at two sites in the Florida Keys National Marine Sanctuary, French Reef and Pickles Reef. These sites (5–9 m depth) contain remnant, individual *Acropora palmata* colonies, rather than the characteristic thicket configuration. The irregular, arborescent morphology of *A. palmata* makes quantification of tissue area difficult. Thus, individual snail-infested colonies were selected which had obvious snail feeding scars on exposed surfaces of the colony, to allow access by a Nikonos close-up framer for quantitative photo-monitoring of each treatment. Selected colonies appeared to be otherwise healthy.

An individual branch or basal tissue margin was the experimental unit, as *Coralliophila abbreviata* feed in aggregations along tissue margins advancing from the base of a colony outward to the branch tips. One branch with feeding snails was designated as the predation treatment and snails were left in place; one branch with feeding snails was designated as the removal treatment and the snails were removed from the area; one healthy branch with no snails present was designated as the control. In most cases, all three treatments were designated on a single colony. However, given the small number of colonies in these remnant populations (e.g. only 17 total colonies in the Pickles population) and the small size of many partially dead colonies, this was not always possible and the three treatments for one replicate were spread among adjacent colonies. A cable tie was placed around each experimental unit to provide a benchmark from which to measure tissue margin advance or retreat (i.e., tissue gain or tissue loss).

Ten replicates of each treatment were established between 23–25 June 1999, seven at French reef (involving a total of eleven colonies) and three at Pickles reef (four colonies). The experiment was monitored a total of six times during the 2-month experiment at intervals of 4 to 11 days. At each visit a census of snails present in each replicate was taken, and the snails were repositioned (i.e., snails moving into removal treatments were removed and, if all snails had left a predation treatment replicate, two to four snails were placed there from a nearby colony). Photographs of each replicate were also taken at each visit, with snails left in place. In most cases, the monitoring photographs were taken with a Nikonos close-up framer with 28-mm lens (total area $\sim$300 cm^2) but in cases where coral loss was large (extending beyond the 300-cm^2 framer area), the close-up lens was removed to view a larger area. In these cases, a scaled PVC frame was included in each photograph to aid in calibrating the image for quantifying surface area.

At the end of the experiment, the first and last photograph (59-day duration) from each experimental unit was scanned with a Minolta Dimage Scan Speed F-2800 slide scanner and the images were analyzed (cm^2 of dead tissue) using SigmaScan Pro 4.0 software (Jandel Scientific Software, San Rafael, CA) to quantify change in live coral surface area. In a few cases, an earlier end photograph was chosen from the time series if (1) the entire colony or region of the colony died within the experimental period (two cases) or (2) there was a mismatch in the angle or placement of the last photo in the time series that precluded accurate area determination (six cases). Thus, data for each replicate was standardized to cm^2 of tissue lost per day.

Because treatments were most often situated on the same (or adjacent) colonies, the response variable (cm^2 tissue lost per day) was analyzed using a randomized block design. Treatment and experimental block were the factors in a two-way ANOVA after verifying normality and homogeneity of variances assumptions. Dunn's a priori comparisons were used to compare the predation and removal treatments with the controls.

Results and discussion

For six censuses conducted during the experiment, the experimental removal treatments reduced snail incidence by 81% on average (Table 1).

Table 1 Snail incidence observed at each of six censuses throughout the experiment, given as mean number of snails per replicate (1 SD). Treatment effectiveness is described as the percent reduction in snail incidence in the removal treatment. No snails were found on any of the controls throughout the experiment

Date	Predation treatment	Removal treatment	Reduction (%)
6 July	3.8 (2.3)	0.63 (0.92)	83
10 July	2.5 (1.8)	0 (0)	100
19 July	2.4 (1.4)	0.25 (0.46)	89
23 July	2.6 (2.0)	0.30 (0.67)	88
3 Aug	2.2 (2.1)	0.80 (1.4)	63
23 Aug	1.8 (1.9)	0.70 (1.3)	61
Mean			81

The blocked ANOVA showed a significant treatment effect ($p = 0.003$, Fig. 1) but no significant block effect ($p = 0.191$). *Acropora palmata* colonies lost significantly less tissue when snails were removed than when snails were left in place. The removal treatment did not differ significantly from the healthy controls that had not been subject to snail feeding (Dunn's test, $p > 0.05$, Fig. 1). *Acropora palmata* branches on which snails were left in place suffered a mean loss of live tissue of 3.37 cm^2/day (range 0.08 to 10.9 cm^2/day). Both replicates that displayed complete mortality (out of a total 33 used in the experiment) were in the predation treatment.

These results indicate that *Coralliophila abbreviata* can have a substantial impact in removing coral tissue, and that targeted predator removal can have beneficial impacts in conserving live tissue of *Acropora palmata* colonies. Other sources of mortality may have also been operating in this experiment, such that 3.37 cm^2/day may be an overestimate of snail-induced coral morality. However, the fact that incomplete (81% effective) snail

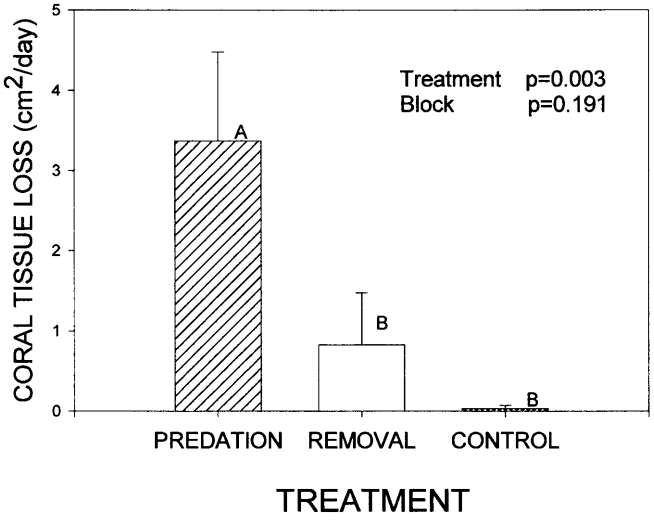

Fig. 1 Tissue loss rates from *Acropora palmata* (mean + 1 SE) under three levels of experimental removal of corallivorous snails. *P*-values are from a blocked ANOVA, $n = 10$. Treatments with the same letter do not differ significantly from each other ($p > 0.05$, Dunn's a priori comparisons)

removal had a large influence on tissue survival strongly suggests that snail predation was the dominant source of the mortality observed in this experiment.

The importance of quantifying surface area of coral loss in this experiment dictated the use of sub-colony experimental units (i.e., individual branches). The resulting coexistence of different treatments on a single colony probably reduced the effectiveness of the removal treatments, as *C. abbreviata* is fairly mobile on *Acropora* hosts (Hayes 1989). If snail removal was undertaken on a larger scale, whole colony removal would likely be more efficient in excluding snails than was observed in this experiment.

Small-scale (and incomplete) corallivorous snail removal in remnant *Acropora palmata* populations in the northern Florida Keys did preserve 75% (mean) more live *A. palmata* tissue than treatments where snails were left alone. Thus, targeted predator removal might be an effective conservation measure. However, effectiveness is far from the only consideration in evaluating the advisability of a management intervention. Other ramifications of such a manipulation in a complex coral reef community (e.g., the role of snails as prey for other reef residents) remain to be carefully evaluated.

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