Efficiency and success of coral mariculture can be improved through grazing by herbivorous fish

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Background

To offset the continuous degradation of tropical reefs, coral reef restoration initiatives are rapidly gaining support worldwide. Coral reef restoration, through coral mariculture in nurseries and restocking of degraded reefs with nursery-grown corals, aims to improve the state of reefs to create higher resilience against disturbances. However, one of the limiting aspects of coral mariculture is the fight against fouling that hampers the performance of coral fragments through shading, polyp retraction and smothering. It has been suggested, but not experimentally investigated, to perform coral mariculture near natural reefs to allow roving herbivorous fish to visit the structures and consume fouling organisms. In contrast, other studies advise to isolate coral nurseries from the natural reef in order to eliminate the negative impacts of corallivory (i.e. predation on coral) by fish and invertebrates, but also quantification of the impact of corallivores is lacking. Hence, quantitative studies on the effects of herbivory and corallivory on coral in mariculture are needed. This study aims to address this knowledge gap by answering the following research question: What is the net impact of the local, reef-bound fish community at Wasini Island on the performance of corals in mariculture? It was expected that the benefit of grazing of fouling by herbivorous fish outweighs the cost of coral consumption by corallivorous fish in coral mariculture.

Methods

The net impact of the fish community on coral mariculture was determined by experimental exclusion of fish from mid-water coral nursery structures located at a patch reef at Wasini Island, Kenya (4°39'34"S, 39°22'56"E). The fish-exclusion study was conducted from April to July 2016 (100 d). Three treatments were designed: a caged, uncaged and cage-control coral nursery. The nursery design consisted of a PVC cross holding ten coral fragments (*Acropora verweyi*), held afloat by a 1.5-l PET bottle and kept in place by a 10-kg sinker. The caged treatment had a 0.5 x 0.5 x 0.25 m^3 cage made of galvanised monkey wire (1.3 x 1.3 cm^2 mesh size) attached around the nursery, preventing access for fish. The uncaged treatment lacked such a cage and thus provided unrestricted access to all fish. The cage-control resembled the caged treatment, but had two sides of the cage removed, so that fish would have access to the nursery. Per treatment, fifteen replicate nursery units were deployed and placed near (i.e. within 1 m) of a coral patch to encourage the interest of reef-bound fish.

Coral performance, development of fouling, herbivory and corallivory were compared between the caged and uncaged nursery structures to determine whether the fish community had a net positive or net negative impact on coral in mariculture. The cage-control treatment was compared with the uncaged treatment to check if any differences in coral survival and growth might be caused by the physical presence of the cage itself. Coral performance (growth and survival) was measured monthly. The specific growth rate (SGR) of coral fragments was determined by measuring the increase in Ecological Volume (EV) of each fragment. EV is defined as the total volume occupied by a coral, including the volume of water between its branches. Percentage colony survival was estimated for each fragment. To link patterns found in coral performance to the activity of fish, we quantified fouling, herbivory and corallivory. Remote underwater video identified fish species and quantified the number of bites directed at fouling organisms (herbivory) and coral fragments (corallivory). As bite size scales to fish body mass, number of bites were transformed to mass-scaled bites and standardized for time (bites g min^{-1}) to estimate the impact of feeding. At the end of the 100-day experiment, fouling was collected, categorized, sun-dried and weighed. Coral predation was quantified by identifying all new bite marks monthly. To characterize the local fish community, the fish community structure and fish abundance were determined using stationary fish census.

Results

All data are presented as mean ± SE. Over time, the treatments differed significantly in SGR (two-way mixed ANOVA; $F_{2,39} = 18.20$, $p < 0.001$), survival (two-way mixed ANOVA; $F_{2,40} = 17.96$, $p < 0.001$), fouling (MANOVA; $F_{2,36} = 24.23$, $p < 0.001$), herbivory (MANOVA; $F_{2,40} = 11.50$, $p < 0.001$) and corallivory (MANOVA; $F_{2,40} = 5.35$, $p = 0.009$). SGR in the caged nursery structure (0.0047 ± 0.0010 d^{-1}) was significantly lower than in both the uncaged (0.0078 ± 0.0010 d^{-1}) and cage-control (0.0099 ± 0.0010 d^{-1}) nursery structures (Tukey; $p = 0.003$ and $p < 0.001$, respectively). Average survival in caged nursery structures (89 ± 3%) was significantly lower (Tukey; $p < 0.001$) than in both the uncaged (98 ± 2%) and cage-control (99 ± 1%). At 484 ± 43 g m^{-2}, total fouling density was significantly higher (Games-Howell; $p < 0.001$) in the caged treatment than in both the uncaged (61 ± 15 g m^{-2}) and cage-control (78 ± 17 g m^{-2}). Macroalgal density was more than 100-fold higher in the caged treatment. The uncaged (83 ± 35 bites g min^{-1}) and cage-control (74 ± 21 bites g min^{-1}) treatments did not differ significantly in grazing pressure, with rates being substantially lower in the caged treatment (0 ± 1 bites g min^{-1}) (Games-Howell; $p < 0.01$). Grazing on the nursery structures was strongly dominated by a single species of surgeonfish, *Ctenochaetus striatus*, which took a sum of 205,096 mass-scaled bites (77% of total standardized bites). *C. striatus* was also the most abundant roving herbivorous fish present (155 fish ha^{-1}) in the study area. A total of 1450 mass-scaled bites on coral tissue were recorded for the uncaged and cage-control treatment. The most dominant fish targeting coral tissue were: *Chaetodon melannotus*, *Chaetodon trifasciatus* and *Chaetodon kleinii*. Every month, bite marks on coral skeleton were found on average on 10% of the coral fragments.

Conclusion

The uncaged and cage-control treatments generated equivalent results on nearly all aspects, indicating that cage artefacts have not confounded the results of this study. *C. striatus* and other grazing fish forestalled the development of an abundant fouling community on the uncaged and cage-control nursery structures. Thus, the role of roving herbivorous fish in controlling algal biomass on coral nursery structures has been clearly demonstrated. Growth and survival after 100 d were high for the uncaged and cage-control fragments. The observed decreases in survival and growth of caged coral are most likely attributable to competitive mechanisms of fouling organisms, such as overgrowth, shading and abrasion, in particular by macroalgae. A 9% higher survival and a 40% increase in SGR in the uncaged treatment indicate meaningful advantages of growing coral near natural fish communities. This study on *Acropora verweyi* maricultured near natural reefs shows some negative impact of corallivory on growth of coral fragments, but this is not nearly offsetting the beneficial effects of herbivory, as reflected by the better growth and survival in the uncaged and cage-control nurseries. As hypothesised, the advantage of having biological fouling control by herbivorous fish is shown to outweigh the negative impacts of incidental corallivory on the survival and growth of *A. verweyi*. Coral that was easily accessible to the natural fish assemblage attained very high levels of survival and good coral growth without the need of human-assisted cleaning for a period of 100 d. Such free animal-assisted cleaning not only promotes coral survival and growth, but also reduces human cleaning time and thus project costs, ultimately benefitting the restoration of reefs.