hypothesis. Journal of Experimental Marine Biology and Ecology 192: 1-14.

Carpenter, R. C. 1990. Mass mortality of *Diadema antillarum*: I. Long term effects on sea urchin population-dynamics and coral reef algal communities. Marine Biology 104: 67-77.

Fadlallah, Y. H., R. H. Karlson, and K. P. Sebens. 1984. A comparative study of sexual reproduction in three species of Panamanian zoanthids (Coelenterata: Anthozoa). Bulletin of Marine Science 35: 80-89.

Humann, P. 1992. Reef creature identification: Florida, Caribbean, Bahamas. Pp. 100-101 *in* N. Deloach, editor. New World Publications, Inc., Jacksonville, Fl, USA.

Karlson, R. H. 1983. Disturbance and monopolization of a spatial resource by *Zoanthus sociatus* (Coelenterata: Anthozoa). Bulletin of Marine Science 33: 118-131.

Lathrop, R. 1980. Differential importance of biotic and abiotic factors in governing zoanthid distributions, according to zone on the East reef at Discovery Bay, Jamaica. (unpublished, Dartmouth Foreign Study)

Sebens, K. P. 1977. Autotrophic and heterotrophic nutrition of coral reef zoanthids. Proceedings, Third International Coral Reef Symposium.

Size, abundance, territoriality, and depth in the yellowline goby (*Gobiosoma horsti*)-yellow tube sponge (*Aplysina fistularis*) commensalism

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Abstract: The yellowline goby, *Gobiosoma horsti*, is a species-specific commensalist with the yellow tube sponge, *Aplysina fistularis*. By inhabiting the atrium of one of these sponges, *Gobiosoma horsti* is provided with shelter and food. It has been documented that sponge selection is based on size, with the largest gobies inhabiting the largest sponges. Personal observation has also shown that variation in sponge size may be correlated with depth. We hypothesized that depth would directly influence sponge size, and thus indirectly influence the size distribution of *Gobiosoma horsti*. We predicted that larger sponges and larger gobies would be found at greater depths. Additionally, we experimentally tested the prediction that *G. horsti* individuals prefer to associate with the same sponge atrium over time. We found that mean log sponge atrial volume was significantly greater at deep depths than shallow depths, mean log number of atria per sponge is greater at shallow depths, and that *G. horsti* size and likelihood of sponge occupancy were greater at deep depths. These results suggest that depth, through direct effects on sponge size, indirectly affects *G. horsti* size and abundance. Experiments in which gobies were removed, fin-clipped, and returned to the same or nearby atrium showed that *G. horsti* generally stayed in or returned to its original atrium over a 24-hour period.

Key Words: Gobiidae, sponges, symbiosis

Introduction

The Gobiidae family consists of a variety of small, bottom-dwelling fish which live in direct contact with the substratum. Some species reside on coral heads while others appear to be commensals of sponges. The exact nature of this goby-sponge relationship is poorly understood. It has been hypothesized that sponges most likely offer protection and provide food for the inhabiting gobies. Territoriality has also been documented in several species (Tyler and Bohlke 1972, Brady and Levesque 1995).

Personal observations have shown that there is a species-specific interaction between the yellowline goby, *Gobiosoma horsti*, and the yellow tube sponge, *Aplysina fistularis*. This sponge is abundant in the fore reef of Discovery Bay, Jamaica, often occurs as clusters of attached tubes, and exhibits large variation in atrium size and volume.

We made a number of predictions about how depth effects sponge size and subsequently influences the size distribution of the yellowline goby. Because of the fragility of these sponges, we predicted that the increased wave action of the shallower waters would limit sponge size and restrict the largest sponges to the deepest waters. It has also been documented that larger gobies typically inhabit larger sponges (Brady and Levesque 1995), thus we expected to find larger gobies at greater depths.

Additional studies were conducted on the degree to which gobies prefer to live within individual sponge atria. Preliminary observations on the gut contents of one yellowline goby revealed a high incidence of sponge spicules, suggesting that sponge is a food resource for the goby and may decrease their need to forage outside their home sponge. It follows that gobies should remain in the same sponge atria over time.

Methods

We examined all yellow tube sponges found between 7 - 20 m depth near Mooring 1 in the West fore reef of Discovery Bay, Jamaica from 6 - 9 March 2001. To determine whether sponge size was correlated with depth, we haphazardly selected 172 sponges in 4 depth

categories (7 - 10 m, 11 - 13 m, 14 -17 m, and 18 - 20 m). Sponge length, osculum diameter, and cluster size were measured, and sponge volume was subsequently calculated. To determine the relationship between goby size and depth, we recorded the relative size of each goby inhabiting the atria of surveyed sponges. Goby sizes were placed in one of three categories: small (< 20mm), medium (20 - 30mm), or large (> 30mm).

We investigated the tendency of gobies to prefer a given atrium within a sponge cluster by performing transplant/replacement experiments. We haphazardly selected ten sponge clusters at a depth of 8 - 13 meters. Within each cluster we haphazardly selected one goby and anesthetized it by injecting a solution of 10% quinaldine and 90% isopropyl alcohol deep into the sponge atrium using a large syringe and surgical tubing. Once captured with an aquarium fish net, the goby's anal fin was clipped for identification, and assigned to either a transplant or replacement trial. Transplanted individuals (n = 4) were moved into an adjacent sponge atrium within the cluster, and replaced individuals (n = 6) were put back into the atrium from which they were taken. We returned the following day and recorded whether the fin-clipped gobies had returned to their original sponge atria for the transplant trials or remained in their initial sponge atria for the replacement trials.

For analysis, we log-transformed sponge atrial volumes and number of atria per sponge and used ANOVA and Tukey-Kramer pairwise comparisons to compare across depth categories. We used Chi-square tests to compare goby sizes and presence/absence in sponge atria across depth categories.

Results

Sponge survey

Mean log sponge atrial volume was significantly greater at deep depths than shallow depths (ANOVA, F = 11.72, df = 1, 66, P = 0.0011; Fig. 1). Specifically, log atrial volume was significantly greater at 18 - 20 m than 7 - 10 m (Tukey-Kramer HSD). *Aplysina fistularis* atria in the 11 - 13 m and 14 - 17 m depth ranges were of intermediate volumes, but not significantly different from the shallowest and deepest ranges. The mean log number of atria per sponge was significantly greater at shallow depths than at deep depths (ANOVA, F = 4.80, df = 1, 62, P = 0.032; Fig. 2).

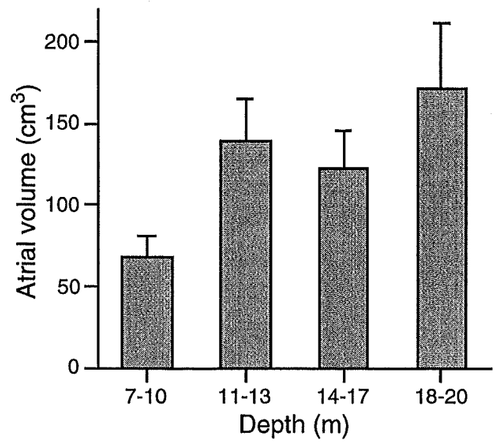

Fig. 1. Mean *A. fistularis* atrial volume (± 1 SE) in 4 depth ranges at Mooring 1, Discovery Bay, Jamaica (7-10 m: n = 45; 11-13 m: n = 52; 14-17 m: n = 52 18-20 m: n = 7).

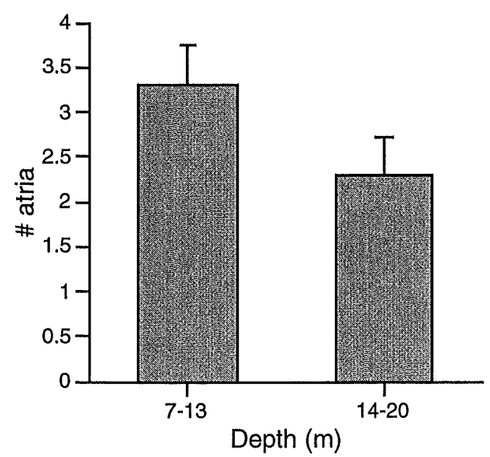

Fig. 2. Mean number of *A. fistularis* sponge atria (± 1 SE) per sponge cluster in two depth ranges at Mooring 1, Discovery Bay, Jamiaca (7-13 m: n = 33; 14-20 m: n = 31).

Gobies found at deep depths were significantly larger than individuals found at shallow depths (χ^2 = 8.52, df = 2, 83, P = 0.01; Fig. 3). Specifically, at deep depths, medium and large *G. horsti* were found more often than expected, while small *G. horsti* were found less often than expected. Irrespective of size, *G. horsti* was also more likely to be found in deep sponges than in shallow sponges (χ^2 = 12.81, df = 3, 168, P = 0.0051; Fig. 4). Specifically, *G. horsti* was found more often than expected in sponges in the 18-20 m range and less often than expected in sponges in the 7 - 10 m range.

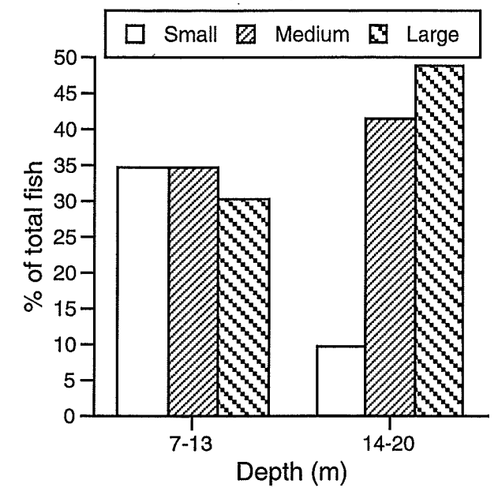

Fig. 3. Distribution of *G. horsti* sizes in *A. fistularis* sponges in two depth ranges at Mooring 1, Discovery Bay, Jamaica (7-13 m: n = 46; 14-20 m: n = 41).

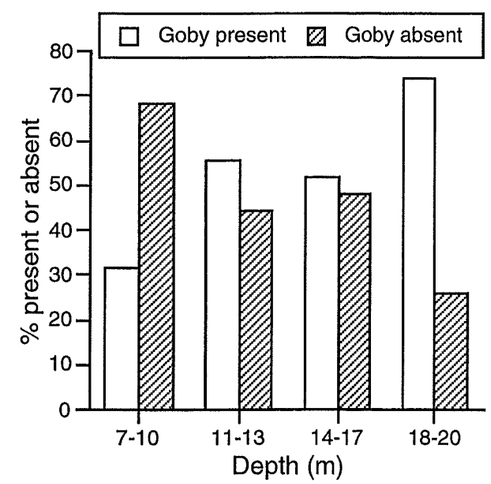

Fig. 4. Percentages of presence or absence of *G. horsti* in *A. fistularis* sponge atria in four depth ranges at Mooring 1, Discovery Bay, Jamaica (see Fig. 1 for sample sizes).

Experimental manipulations

Of the six *G. horsti* that were fin-clipped and left in the same sponge atrium from which they were taken, five were found again the next morning in the same atria and one was missing completely. Of the four *G. horsti* that were fin-clipped and transferred to different atria of the same sponge, three were found again the next morning in the original atria from which they were taken and one remained in the atrium to which it was transferred.

Gut contents

The gut contents of the single *G. horsti* that we dissected were composed primarily of sponge spicules. We also observed unidentifiable clumps of brown matter in the gut.

Discussion

Sponge survey

Our finding that *A. fistularis* sponge atria have the greatest volume at deeper depths supports our prediction that larger sponges will be found at deeper depths. During days of sampling with rough seas, we observed the greatest effect of turbulence in shallow water. Thus, we suggest that the difference in sponge atrial volume may be an adaptive response to a gradient of turbulence across depths. Alternatively, the size difference may reflect differences in mortality or growth rate with increasing turbulence. Further research could subject sponges of varying sizes to turbulence (either artificially or by transplanting them to different depths) in order to test this turbulence hypothesis.

Unexpectedly, shallow-water *A. fistularis* had more atria per sponge than deep-water *A. fistularis*. This difference in growth form may again be the result of turbulence. We observed that the multiple-tube shallow-

water sponges were generally wider (due to the many tubes per sponge), while the deep-water sponges were generally taller and narrower due to fewer tubes per sponge. The wider, multiple-tube sponges may have greater structural integrity, thereby making them better able to withstand the effects of turbulence in shallow water. Alternatively, this growth form may simply be the result of tube-regeneration following breakage caused by turbulence. When one tube is broken off, several new tubes may grow in its place from the sponge base. In this way, frequent breakage could result in dense clusters of tubes growing from a single sponge.

Brady and Levesque (1995) found that larger *G. horsti* generally are found in larger *A. fistularis* atria, and that larger gobies consistently dominated over smaller gobies in claiming sponge atria. Similarly, we found that larger, deeper sponges generally contained large and medium-sized fish, while smaller, shallower sponges generally contained small fish. Given that *G. horsti* eats polychaete worms that parasitize *A. fistularis* (Thresher 1980), Brady and Levesque (1995) suggested that larger sponge atria (with presumably more polychaete worms) are a more valuable resource to *G. horsti*, and that larger gobies are competitively dominant in territorial claims. Thus, our results suggest that depth, by directly affecting sponge atrial volume, may indirectly affect *G. horsti* size. Deeper *A. fistularis* atria were also more likely than shallow sponges to contain *G. horsti* individuals, irrespective of fish size. Again, this difference is likely the result of sponge size and goby preference for larger (and deeper) sponges. Future study could control for sponge size across depths to test for an independent effect of depth on goby presence or absence and size.

Experimental manipulations

Our finding that nine of ten fin-clipped *G. horsti* remained in the same *A. fistularis* tube clusters in which they were originally found suggests that these fish remain associated with the same sponges for at least 24 hours, rather than moving to different sponges during the day or overnight. The fact that three of four gobies moved back to the original sponge atria from which they were taken also suggests that *G. horsti* has strong associations with individual sponge atria. Furthermore, this finding suggests that anesthetization and fin-clipping had no ill effects, though we cannot rule out an effect of our manipulations (i.e. physical trauma or behavioral alteration) on our results.

Our goby dissection found that sponge spicules constituted a majority of gut content. However, we cannot conclusively say whether these spicules were directly consumed from the sponge tissue or if they were in the guts of parasitic polychaete worms consumed by the goby from the sponge tissue. Regardless, if *G. horsti* does indeed obtain all its food from the sponge, then remaining associated with the same sponge atrium over time eliminates unnecessary risk and energy expenditure in moving between sponges. However, Tyler and Böhlke (1972), in addition to the authors, observed that *G. horsti* is an able swimmer when removed from its sponge, suggesting that at some point in its life swimming skills are needed. There is as yet no documentation of the nighttime behavior of *G. horsti*, so it is possible that the gobies leave the sponge to forage or mate in the relative safety of darkness.

Clearly, larger sample sizes of both manipulations and dissections are needed to make stronger conclusions regarding individual goby/sponge associations. Additionally, sponge dissections may also be valuable to quantify polychaete worm parasite loads in *A. fistularis* of different sizes and/or depths and to better understand the effect of *G. horsti* on the sponges they occupy.

Literature Cited

Brady, J. H., and V. R. Levesque. 1995. Territoriality of the yellowline goby (*Gobiosoma horsti*) in yellow tube sponges (*Aplysina fistularis*). Pp. 187-190 *in* C. D. Wray, editor. Dartmouth Studies in Tropical Ecology 1995. Dartmouth College, Hanover, NH, USA.

Thresher, R. E. 1980. Neon gobies. Reef Fish: Behavior and Ecology on the Reef and in the Aquarium. The Palmetto Publishing Company, St. Petersburg, FL, USA.

Tyler, J. C., and J. E. Böhlke. 1972. Records of sponge-dwelling fishes, primarily of the Caribbean. Bulletin of Marine Science 22: 601-641.