Supporting Text

Additional Details on Methodology

Measuring Goby Settlement on Entire Reefs. We measured settlement at each site over several consecutive weeks during the summer of each year. Within each year, all sites were sampled over the same time period, but the duration and precise timing of the sampling period varied from year to year (duration: 7–12 weeks; start dates: June 7–July 9; end dates: Aug. 23–Sept. 7). We measured settlement during summer because year-round monitoring showed that little settlement occurs at other times of year. Settlement was measured in five 1.5 × 1.5 m plots of natural habitat at each reef. The habitat on these plots was unaltered, except that it was caged to protect the recently settled gobies from predators, which are the primary cause of death of young gobies and can rapidly distort goby settlement patterns (1). Cages were built of plastic netting on poly(vinyl chloride) pipe frames. The mesh size (5 mm) was large enough to allow settling gobies to pass through but small enough to exclude virtually all predators. In previous work, we found no evidence that the cages themselves influenced settlement rates of the gobies (1). The settlement plots were located in a stratified random fashion. They were placed at random within 10-m-long sections of reef, which were themselves spaced by 40–50 m.

Scuba divers used hand nets to collect settling gobies that accumulated on the plots each week. Earlier work showed that weekly collections of recent settlers from caged areas accurately captured cumulative daily patterns of settlement (1). After collection, gobies were measured in the lab, and recent settlers (fish that had settled in the preceding week) were distinguished from older residents by their size, using known size–age relationships (ref. 1 and M.A.S., unpublished data).

Measuring Goby Mortality on Entire Reefs. To test whether mortality after settlement was density-dependent, we censused the reefs in late October to see how many of the summer’s settlers had survived to this date. By late October, gobies that had settled during the summer had reached 20–40 mm in length. Many of the gobies were already sexually mature by this time, because maturity is reached at about 25 mm (M.A.S., unpublished data, and refs. 2 and 3). To estimate goby density, divers counted gobies within quadrats that were distributed at each site by using a stratified, random design. From 1998 to 2001, we sampled 25 1.5 × 1.5 m quadrats per site. Quadrats were located by placing five 50-m-long transects so that they were roughly equally spaced within the goby habitat at the site. Each transect was divided into five 10-m-long segments, and a quadrat was placed at a random distance from the start of each segment. In 2003, we sampled 4 × 4 m quadrats at each site. Quadrats were placed by dividing the site into segments and placing one quadrat at a randomly located position within each segment. Sixteen quadrats were sampled at Goby Spot, Rainbow, and Windsock, and 8 quadrats were sampled at Square Rock and Tug and Barge. In each quadrat, all gobies were counted and assigned to one of seven size classes, each of which was 5 mm wide. Counts were made by a single diver throughout the entire study (M.A.S.), and visual estimates of size were typically within 2 mm of actual sizes, based on field tests in which gobies were captured and measured after their length had been estimated visually (M.A.S., unpublished data).

We converted the measured size structure to age structure by using statistical relationships between size and age. We measured age by using rings that form daily in the otoliths. We verified that these rings form daily by performing a field mark–recapture study of recent settlers whose otoliths had been chemically labeled (M.A.S., unpublished data and ref. 4). Using collections of at least 60 gobies per site, we developed statistical relationships between body size (length in millimeters) and age in days for each site, based on counts of daily growth rings in the otoliths (M.A.S., unpublished data). Using these otolith-based relationships between size and age, we converted the size classes from the autumn censuses into age classes. We were then able to determine, based on their estimated age, which of the fish present in late October had settled during the preceding summer’s settlement monitoring.

We estimated goby mortality from the day of settlement to the date of the October census, making separate estimates for each year at each site. The calculation focused on cohorts or groups of individuals that arrived at a given site as settlers during the same week (x = the number of settlers in a cohort). For simplicity, all settlers were assumed to have arrived exactly at the midpoint of the week (so t_i is the time in days on which the ith cohort settled, and t_0 is the beginning of summer). The number of cohorts (i_{max}) is the number of weekly collections. To estimate the instantaneous per capita mortality rate (m) from our data, we assume that individuals of all ages experienced the same mortality rate during the entire time interval from the date on which settler collection began until the final autumn population count (X = the number of surviving individuals and T = the day of the autumn census).

Under the assumption of constant mortality, the number of individuals that settled on day t_i and also remained alive on day T is

$$x_{t_i} e^{-(T-t_i)m},$$

and consequently

$$X_T = \sum_{i=1}^{i_{max}} x_{t_i} e^{-(T-t_i)m}.$$

The preceding equation was solved iteratively to estimate m.

Measuring an Index of Refuge Density on Entire Reefs. Because density dependence in bridled gobies is caused by a shortage of refuges, each year a diver estimated an index of refuge availability for bridled gobies within a set of 25 plots (each 1.5 × 1.5 m) that were located in a stratified random fashion at each site. The diver hovered above each plot, and made a visual estimate of the fraction of area covered by different types of substratum: live coral, sand, sea grass, limestone pavement, rubble (pieces of rock <25 cm in diameter), rocks and dead coral (>25 cm in diameter), and other substrata. The combined percent cover of live coral, rock/dead coral, and rubble was used as a measure of the density of crevices used by gobies to shelter from predators (5).

Density Dependence on Small Habitat Patches. We used four separate small-scale studies to compare the strength of spatially density-dependent mortality on entire reefs to that on small habitat patches (6). Two of these studies were done at Rainbow and Windsock reefs in the Bahamas. For both of these studies, we collected recently settled gobies on a set of paired plots (2.25 m^2) for 3 weeks by using methods described in ref. 1. Settlers were collected from both types of plot weekly. One plot of each pair was caged to exclude predators, so the number of recently settled gobies collected per week (S) is thus an estimate of the actual settlement rate. The second plot in each pair was uncaged, and so the number of settlers collected each week (R) reflects the number that settled minus the number killed by predators before collection. Assuming that actual settlement to both plots in a pair was identical, we estimated the daily instantaneous per capita mortality rate (m) of the gobies on each pair of plots during each week as:

$$m = \frac{(\ln(S) - \ln(R))}{7}.$$

For each pair of plots, goby density and mortality were then averaged across the 3 weeks sampled. For all four small-scale studies, we then calculated linear regressions relating mean goby density (number per 2.25 m^2) to instantaneous per-capita mortality. The strength of density dependence (the slope of the regression line) in each of the small-scale studies was thus directly comparable to strengths calculated for entire reefs.

1. Steele, M. A. & Forrester, G. E. (2002) *Ecology* **83,** 1076–1091.

2. Cole, K. S. & Robertson, D. R. (1988) *Bull. Mar. Sci.* **42,** 317–333.

3. Cole, K. S. & Shapiro, D. Y. (1992) *Mar. Biol. (Berlin)* **113,** 1–9.

4. Campana, S. E. & Thorrold, S. R. (2001) *Can. J. Fish. Aquat. Sci.* **58,** 30–38.

5. Forrester, G. E. & Steele, M. A. (2004) *Ecology* **85,** 1332–1342.

6. Forrester, G. E. (1995) *Oecologia* **103,** 275–282.