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# Caribbean damselfish recolonize reefs following coral restoration

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Reef-building corals are foundation species that create habitats for themselves and other organisms.  For this reason, coral declines over the past 30 years (Gardner et al. 2003) have triggered widespread declines in fishes that occupy coral reefs (Paddack et al. 2009).  Coral restoration thus has the potential to both rebuild coral populations and recreate habitat for fishes (Rinkevich 2005), but few studies have tested whether fish populations respond to coral restoration (Caibatan 2008, Yap 2009).  In this study, we document the colonization of a degraded reef in the British Virgin Islands by a common reef fish (the 3-spot damsel, *Stegastes planifrons*) following the restoration of an important reef-building coral (the elkhorn coral, *Acropora palmata*) to the site.

Many reef fish use live coral as a habitat, with most preferring structurally complex corals such as *Acropora* (Clarke 1977).  *Acropora palmata* formerly dominated shallow-water reefs in the Caribbean, but has declined severely over the past 30 years (Vollmer and Kline 2008).  Three-spot damsels are territorial herbivorous fish that often associate with branching and foliose corals as adults, probably for shelter, and frequently occupied *Acropora* before it declined (Precht et al. 2010).  In contrast, when juvenile 3-spots first colonize reefs after a planktonic larval phase, they appear to select foliose and columnar corals like lettuce leaf corals (*Agaricia spp*). and boulder star corals (*Montastraea annularis*) (Lirman 1999, Tolimieri 1995, Gutierrez 1998, Precht et al. 2010).

The restoration site, White Bay, is near Guana Island in the British Virgin Islands (18.473°N, -64.575°W) (Forrester et al. 2011).  Elkhorn coral has been absent from the shallow (1-3 m depth) reefs in White Bay for at least 22 years but, based on skeletal remains and

anecdotal reports, was formerly common.  Other live corals are also rare at the site (1.6% cover in 2005; Forrester et al. 2011).  From 2005-2011, 832 fragments of elkhorn coral were transferred to White Bay from nearby source sites and attached to the reef.  All transplanted corals were tagged individually and their locations were mapped at the time of transplant.  Their growth and survival was monitored until 2012 (Table 1) (Forrester et al. 2011, 2012a, 2013a, 2013b, 2013c).

Tracking the response of 3-spot damsels to the transplanted corals was not originally a goal of the restoration project, but was investigated starting in 2010 when we noticed newly settled 3-spots occupying transplanted corals (Figure 1).  In August 2010, divers systematically searched the site by swimming in a zig-zag pattern over the reef's surface and using the tagged corals as reference points to ensure the entire reef was inspected.  This search revealed 19 juvenile 3-spots (7-20 mm standard length [SL]) on the White Bay reefs, all occupying transplanted elkhorn corals.  In August 2011, a similar search revealed 39 juvenile 3-spots.  All small juveniles (< 20 mm SL, < 1 month post-settlement, Levin et al. 2000) were associated with a transplanted coral, as were 14 of the 24 large juveniles (20-30 mm SL, 1-2 months post-settlement).  In July 2012, we found 93 juvenile 3-spots at the site.  Sixteen of the 59 small juveniles occupied transplanted corals, as did 8 of 34 larger juveniles.  One of us (G. Forrester) has visited the White Bay site ≈30 times per year since 1992 while working on other fish ecology projects.  No juvenile 3-spot damsels were observed from 1992-2009, so we are reasonably confident they were absent, or extremely rare, until 2010 (Table 1).  Adult 3-spots, however, were observed every year, and presumably immigrate from deeper reefs nearby.

We cannot demonstrate conclusively that the appearance of juvenile 3-spots was a direct response to coral transplanting, because the restoration project was not designed as a controlled

experiment (we restored only one site and there were no unrestored control sites). However, one of us (G. Forrester) monitored 3-spot populations on 8 other reefs around Guana Island from 1992-2012: Bigelow Beach, Crab Cove, Grand Ghut, Iguana Head, Long Point, Monkey Point, Pelican Ghut, White Bay. Fish at these site were counted within 30 x 1.5 m belt transects (n = 3-12 transects per site per year). Juvenile 3-spots (< 20 mm SL) did not increase in the 20 years at any of the 8 sites (Mann Kendall tests for a linear trend, $p > 0.05$), and adults (> 30 mm SL) consistently declined (Mann Kendall tests, $p < 0.05$). The sudden appearance of juvenile 3-spots on the restored reef thus stands in contrast to the general trend locally.

In 2011 and 2012, the number of juvenile 3-spots present was sufficient to analyze their choice of microhabitats quantitatively. All transplanted corals were tagged individually and mapped at the time of transplant, so. In August 2011, we used the maps of the reef to locate all transplanted corals present. We tested for size-selectivity by comparing the size (surface area of live tissue in $cm^2$) of occupied elkhorn corals (n = 29) to the size of all transplanted corals present (n = 411). On average, occupied corals were roughly twice as large as those present overall, indicating that juvenile 3-spots select larger corals (mean $\pm$ 95% CI: occupied corals = 464 $\pm$ 363-566 $cm^2$; all corals = 220 $\pm$ 171-268 $cm^2$). A possible explanation for the 5-year lag between starting the restoration and the appearance of 3-spots is that we transplanted small coral fragments (mean size $\pm$ 95% CI = 108 $\pm$ 98-117 $cm^2$), which took 3-4 years to reach 4-500 $cm^2$ (Forrester et al. 2013c).

In July 2012, we tested for microhabitat selectivity by comparing microhabitat features in the home range ($\approx 0.12$ $m^2$) of juvenile 3-spots (n = 176) to microhabitats in randomly selected sites (n = 129) of the same size. Each home range and random location was assigned to one of 3 categories, based on the dominant microhabitat: (1) *A. palmata*, (2) other live coral (*M.*

*annularis*, *Porites astreoides*, or *Agaricia agaricites*), or (3) other substratum (primarily *Millepora spp., Palythoa caribbaeorum* or algae-covered limestone). Three-spots were significantly more likely to occupy *A. palmata* than expected if sites were selected at random (Pearson $\chi^2$ = 39.7, df = 2, p < 0.0004; Fig. 2).

In July 2012, we tracked 95 juvenile 3-spots to test whether apparent survival differed based on the microhabitat within their home range. We marked each home range by tying small pieces of flagging tape to the reef so we could relocate them later. We then returned 2-3 times over the following 17-20 days to check if the fish was still present. A fish present throughout was assumed to have survived, whereas fish that disappeared were presumed dead (Tolimieri 1995, Levin et al. 2000). Three-spots on *A. palmata* survived slightly better (n = 25, 96% survived) than those on other substrata (n = 67, 82% survived), but the difference was not statistically significant (Pearson $\chi^2$ = 1.87, df = 1, p = 0.17). Too few 3-spots occupied other live corals for analysis (n =3).

Overall, our results suggest that that transplanting small fragments of elkhorn coral ($\approx$ 100 cm$^2$) to a degraded reef triggered colonization by juvenile 3-spot damsels settling from the plankton. Colonization began 5 years after restoration, perhaps because 3-spots only select larger colonies. Juvenile 3-spots have previously been reported to select other corals such as *Agaricia spp.*, and *Montastraea annularis* (Lirman 1999, Tolimieri 1995, Gutierrez 1998, Wilkes 2008), which suggests that several corals provide potential settlement habitat. Measured selectivity depends on the array of microhabitats available at a given place and time, and selection for *A. palmata* may not have been detected previously simply because this coral has been effectively absent from the Caribbean for over 25 years (Precht et al. 2010).

Replanting other marine foundation species, such as mangrove trees and eelgrass, has stimulated rapid increases in the abundance of fish and invertebrates (Chen et al. 2007, Evans and Short 2005). In the Pacific, two controlled coral transplanting experiments showed that fish abundance at restored sites increased relative to unrestored sites within a few months. Fish that colonized restored sites included adult immigrants and newly recruited juveniles, and were mostly species known to use live corals for shelter or food (Caibatan 2008, Yap 2009). Our results suggest that, in some cases, fishes may respond much more slowly to coral restoration and long-term monitoring may be required to assess community-wide benefits of coral restoration. Fish declines following coral die-offs display lags from months to years, depending on the nature of the interaction between fishes and corals, and fish increases after coral restoration may show equally variable timing (Munday 2004, Jones 2004, Feary 2007, Pratchett 2008, Paddack 2009).

## Acknowledgements

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Table 1.  History of *A. palmata* restoration at the study site and colonization by juvenile *S. planifrons*.  Displayed are the number of *A. palmata* transplanted each year and the total number present at the site (the new transplants plus survivors from previous years).  Also shown are the number of newly settled *S. planifrons* at the site and the percentage that were associated with an *A. palmata* coral colony.

| Year | # *A. palmata* transplanted | Total # *A. palmata* present | # *S. planifrons* recruits present | % of *S. planifrons* on *A. palmata* |
|---|---|---|---|---|
| 1992-2004 | 0 | 0 | 0 | 0 |
| 2005 | 35 | 35 | 0 | 0 |
| 2006 | 19 | 49 | 0 | 0 |
| 2007 | 88 | 130 | 0 | 0 |
| 2008 | 254 | 301 | 0 | 0 |
| 2009 | 44 | 189 | 0 | 0 |
| 2010 | 135 | 275 | 19 | 100% |
| 2011 | 257 | 411 | 39 | 74% |
| 2012 | 0 | 322 | 176 | 43% |

Figure 1.  A newly settled 3-spot damsel (shown close-up in the inset) occupying a transplanted elkhorn coral.


Figure 2.  Habitat selection by newly settled 3-spot damselfish in 2012.  A comparison of occupied home ranges (30-40 cm in diameter) to similarly sized areas selected at random to define available habitat.  Locations were classified into three habitat types:  *A. palmata (black bar)*, other live coral (grey bar) species, or other substrata (white bar).