Decadal Changes in Reef Fish Recruitment at Turneffe Atoll, Belize: Before and After Lionfish Invasion

Cambios Decenales en el Reclutamiento de Peces de Arrecife en el Atolón Turneffe, Belice: Antes y Después de la Invasión del Pez León

Décennales Changements dans le Recrutement des Poissons de Récif À Atoll Turneffe, Belize: Avant et Après L'invasion de la Poisson-lion

JASON SELWYN[1]*, ALAN DOWNEY-WALL[1], PAOLO USSEGELIO[2], and DEREK HOGAN[1]
[1]*Texas A&M University – Corpus Christi, Department of Life Sciences, 6300 Ocean Drive, Corpus Christi, Texas 78412 USA. *jselwyn@islander.tamucc.edu.*
[2]*University of Hawaii – Manoa, Department of Biology, 2500 Campus Road, Honolulu Hawaii 96822 USA.*

ABSTRACT

Invasive lionfish have been shown to have many deleterious effects on native reef fish populations in the western Atlantic, reducing recruitment by up to 80% and prey fish biomass by 65%. Few studies have been able to compare baseline fish recruit communities on natural reefs before and after the invasion. With historical data going back over a decade, we look at the differences in community structure before and after the lionfish invasion at seven sites around Turneffe Atoll, Belize. Significant differences in the abundance of some species were found across survey years, with 2002-2004 typically having similar abundances and 2013 being most different from the others. A nonmetric multidimensional scaling analysis was used to compare overall community structure. We found differences in the structure of recruit communities across this decadal time scale; with some species being more frequently observed post invasion while others were more common prior to the invasion. It is currently unclear if the lionfish invasion (ca. 2008) is the primary factor for the observed shift in community structure at Turneffe Atoll or if other factors are the primary driver (e.g. Hurricanes, coastal development, bleaching events etc.). Future manipulative studies need to be performed to determine the primary causes of the shifts in fish communities that are currently being observed at Turneffe Atoll.

KEY WORDS: Lionfish impacts, recruitment, coral reefs, community structure, invasive species

INTRODUCTION

Biological invasions are defined as the arrival, survival, and successful reproduction of a species in a habitat where it previously did not exist (Elton 1958). It has been estimated that invasive species cost the US economy more than $120 billion annually (Pimentel et al. 2005) with at least 42% of all threatened and endangered species at risk due to invasive species (Pimentel et al. 2005). With rates of species invasions rapidly increasing globally (Ruiz et al. 1997, Cohen and Carlton 1998, Mack et al. 2000, Semmens et al. 2004, Côté and Green 2012), it is becoming more important to understand how these invasions are shaping the invaded communities.

The invasion of the western Atlantic and Caribbean by two species of lionfish (*Pterois volitans/miles*) represents the first case of a marine fish becoming a major invasive threat to a local ecosystem (Albins and Hixon 2011) and is recognized as a global environmental problem (Sutherland et al. 2010). Lionfish are voracious predators in their invaded range consuming a wide variety of both economically and ecologically important species such as: grouper, snapper and parrotfish (Morris and Akins 2009, Côté et al. 2013). Lionfish have been shown to reduce recruitment of native species by up to 80% on artificial reefs and overall native fish biomass by 65% (Albins and Hixon 2008, Green et al. 2012). The consumption of the ecologically important herbivorous parrotfish has been suggested as the trigger of a trophic cascade in a mesophotic reef in the Bahamas, leading to overgrowth of corals by competitively dominant algae (Albins and Hixon 2011, Lesser and Slattery 2011).

Despite the growing awareness of the impact of lionfish on native fish species, few studies have looked at the how lionfish are changing the structure of native communities on natural reefs. Here we use surveys of recruitment over a decadal scale, spanning the lionfish invasion, to investigate the possible effects of lionfish predation on natural reef fish communities. Given that lionfish are known to drastically reduce native fish recruitment (Albins and Hixon 2008) we hypothesize that the community structure of native fish species has changed since the lionfish invasion.

METHODS

This study was conducted at seven sites around Turneffe Atoll in Belize (TA) spaced approximately 10 km apart around the circumference (Figure 1). The sites were censused for recruitment of 16 species of common species of reef fishes (Table 1) on a bi-weekly basis during the summer months (between May and September) of 2002 through 2004. One identical survey was performed in July/August 2013. Only individuals $\leq$ 2.5 cm total length were recorded as newly recruited juveniles. At each site recruitment was censused using 16 1 x 30 m transects, eight of which were located at a deep

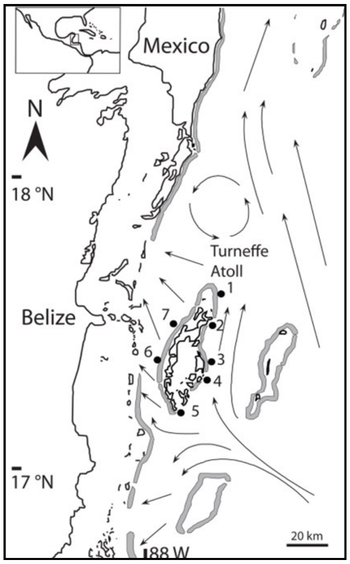

Figure 1. Map indicating sites surveyed around Turneffe Atoll, Belize. Arrows indicate prevailing current patterns.

Table 1. A list of the species surveyed during recruitment surveys at Turneffe Atoll, Belize. A total of 16 unexploited species from four families were surveyed.

Family	Species
Grammatidae	*Gramma loreto*
Labridae	*Halichoeres bivittatus*
Labridae	*Halichoeres garnoti*
Labridae	*Halichoeres maculipinna*
Labridae	*Halichoeres pictus*
Labridae	*Thalassoma bifasciatum*
Pomacentridae	*Chromis cyanea*
Pomacentridae	*Stegastes adustus*
Pomacentridae	*Stegastes diencaeus*
Pomacentridae	*Stegastes partitus*
Pomacentridae	*Stegastes planifrons*
Scaridae	*Scarus iserti*
Scaridae	*Scarus taeniopterus*
Scaridae	*Sparisoma atomarium*
Scaridae	*Sparisoma aurofernatum*
Scaridae	*Sparisoma viride*

position within a site (depth range 9 to 11 m), and eight of which were located at a shallow position within a site (depth range 6 to 7.5 m). Within each position transects were placed haphazardly, parallel to the reef crest, with a distance of 2 to 3 m between transects. Species densities were calculated by pooling all transects within sites at each independent survey period and dividing by the total area covered by the transects.

To determine if recruitment of each species varied across years, one-way bootstrap ANOVAs were performed for each species in R with 5,000 iterations to calculate 95% confidence intervals (Canty and Ripley 2013, Pinheiro et al. 2013, R Core Team 2013) using year as a factor and density as the response variable. To determine if overall recruit community structure had varied among years, a non-metric multidimensional scaling analysis using a Bray-Curtis distance matrix was performed using the R package vegan (Oksanen et al. 2013, R Core Team 2013) to look at community structure according to the interaction of year and site. We used a permutational ANOVA with 10,000 iterations to find significant differences in the treatments year, site, and the interaction of the two.

RESULTS

Three of the 16 species surveyed species showed a negative change in recruit density between 2013 and previous years, since the lionfish invasion (*Chromis cyanea*, *Sparisoma viride*, *Stegastes planifrons*; $p < 0.05$) (Figure 2). Seven species showed a positive change in recruit density since the lionfish invasion (*Halichoeres garnoti*, *Scarus iserti*, *Scarus taeniopterus*, *Sparisoma atomarium*, *Sparisoma aurofernatum*, *Stegastes partitus*, *Thalassoma bifasciatum*; $p < 0.05$). Six species did not show significant changes in density post lionfish invasion (*Gramma loreto*, *Halichoeres bivittatus*, *Halichoeres maculipinna*, *Halichoeres pictus*, *Stegastes diencaeus*, *Stegastes adustus*; $p > 0.05$).

We found clear differences in the community structure between 2013 and previous years surveyed (ANOSIM $R^2 = 0.11$, $p = 0.0001$, Figure 3). The 2D stress for this analysis was calculated to be 0.21 with a nonmetric R^2 of 0.96, indicating that this result was very robust. We also found clear differences in the community structure among sites (ANOSIM $R^2 = 0.06$, $p = 0.008$) and in the interaction of year and site (ANOSIM $R^2 = 0.15$, $p = 0.02$).

DISCUSSION

We investigated changes in reef fish recruitment after the invasion of lionfish to natural reefs in Belize. Our results indicate complex changes in native recruitment over the decadal time scale with some species declining in density as expected, while others increased or did not change since the lionfish invaded. We also demonstrated significant changes in community structure of native reef fish recruits since the lionfish invasion. However, given the complex changes in species densities, the direct role of lionfish in these changes is unclear from these observational results alone.

One potential explanation for the complex changes in recruit community structure we saw could be through the process of competitive release (Persson and Hansson 1999). Lionfish could be preferentially targeting specific species leading to a competitive release of other native species. For example we observed an increase in the *Stegastes partitus* and a corresponding decreasing trend in the *Stegastes planifrons*. These two damselfish compete for habitat on the reef which is used as nesting sites and to culture turf algae (Allen 1991). Further research is needed to determine if there is preferential consumption of specific species by lionfish (in this case *S. planifrons*) which could alter competitive interactions between species.

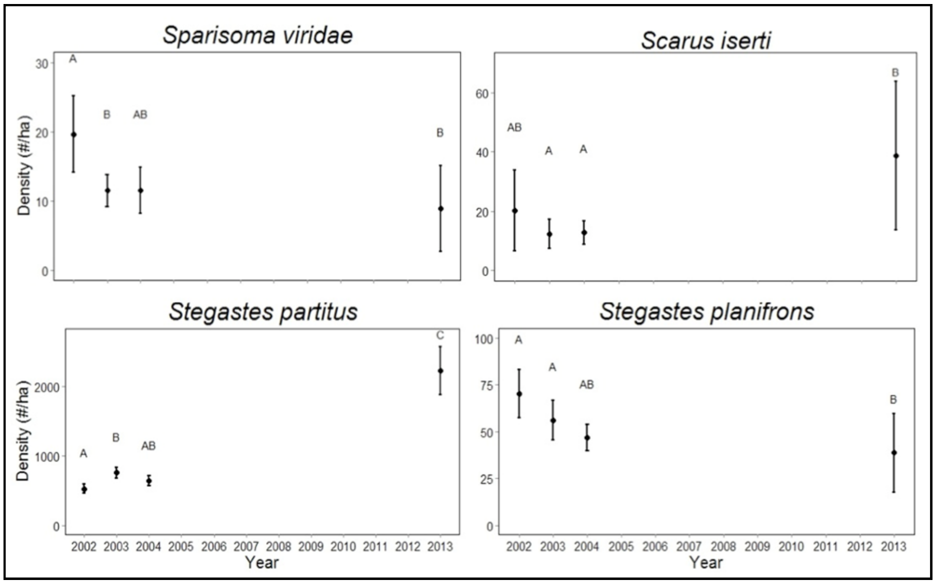

Figure 2. Decadal scale patterns of mean recruit density (#/ha) for four selected species from recruitment surveys (*Sparisoma viridae, Scarus iserti, Stegastes partitus, Stegastes planifrons*). All species show signficant changes in recruit density over the decadal time scale ($p < 0.05$). Significant differences were calculated using bootstrap ANOVAs with 5,000 iterations, error bars indicate 95% confidence intervals, letters indicate among treatment significant differences.

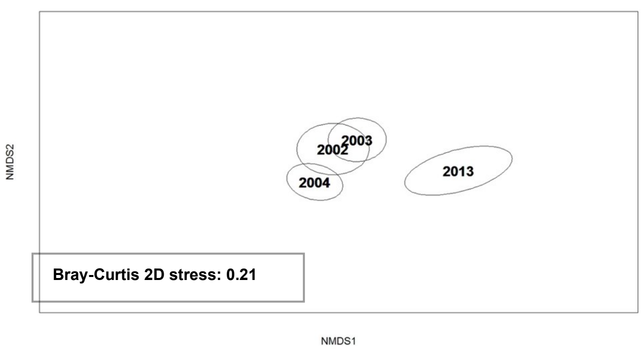

Figure 3. Changes in recruit community structure over the decadal time scale shown by nonmetric multidimensional scaling analysis (NMDS). ANOSIM indicates that changes in recruit densities were significant ($p < 0.05$).

Additionally, due to a lack of data in the years between 2004 and 2013 and our lack of current habitat data we are unable to say that the shifts which have occurred at Turneffe Atoll are solely the result of the lionfish invasion, or simply coincident with it. For example there have been five hurricanes and a number of tropical storms which have impacted the atoll in the intervening years (NOAA 2013).These hurricanes could potentially have reduced the habitat complexity of the reef system which in turn could alter the fish community in the area (Roberts and Ormond 1987, Diehl 1992, Beukers and Jones 1998).

Regardless of the mechanism, we observed changes in the community structure that can have further effects on the ecosystem functioning of these habitats (Larsen et al. 2005). One of the changes we observed in recruitment that could lead to changes in ecosystem functioning is a decrease in recruitment of large-bodied parrotfish (i.e. *Sparisoma viridae*) and a parallel increase in recruitment of small-bodied parrotfish species (i.e. *Scarus iserti*). This shift could have dramatic implications for coral growth and overall reef health. Parrotfish are established as the most important herbivore on coral reefs in the Caribbean for removing algal overgrowth and preventing a transition from coral-dominated to algae-dominated habitats (Hughes et al. 2007). Larger parrotfish are able to consume exponentially more algae than small bodied ones (Mumby et al. 2006) indicating that a reduction in the abundance of large-bodied parrotfish would not likely be compensated for by small bodied parrotfish increases. This shift away from large bodied parrotfish could be one of the factors driving shifts seen in The Bahamas to more algae-dominated reefs since the lionfish invasion (Lesser and Slattery 2011). Further experimental research will be critical for determining if this shift in parrotfish recruitment is specifically linked to the lionfish invasion.

More research is needed to look for a causal relationship between lionfish predation and shifts in the community of fish recruits that we have seen in the last 10 years in Belize. These studies need to account for any changes in habitat, and should also attempt to account for natural population shifts that may occur generally on this time scale. The observed changes in recruitment, if caused by lionfish, may indicate a complex effect of this predator on the diverse native fish communities of the Caribbean, a perspective that has not been seen yet in this invasion. The lack of information about the fish community and habitat in this area leading up to and immediately following the lionfish invasion indicate how important it is to collect this data on a continuing basis, which is especially relevant in areas that have only recently been invaded.

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