A critique of Mumby et al. 2011 "Grouper as a natural biocontrol of invasive lionfish"

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Abstract: Mumby et al. (2011) tested the biotic resistance hypothesis by comparing the biomass of invasive lionfish (introduced from the Indo-Pacific) and native grouper (Serranidae) at 12 sites within and adjacent to the Exuma Cays Land and Sea Park, The Bahamas. They reported that there was a negative relationship between the biomass of lionfish and grouper and concluded that grouper can potentially control invasive lionfish. However, their study has a number of limitations and does not constitute sufficient evidence of a level of biotic resistance that would be ecologically meaningful. For example, the study design was pseudoreplicated and the biomass of lionfish was extremely low: 10% and 1% of the mean and maximum, respectively, of values reported across the Caribbean. Furthermore, the measured reduction in lionfish biomass that Mumby attributed to grouper was very small compared to the natural range of lionfish biomass. Given the problems with Mumby et al. (2011) and contradictory evidence indicating the biomass of lionfish and grouper is unrelated (e.g., Hackerott et al. 2013), managers should not rely on native grouper populations to control the lionfish invasion.

Introduction

The introduction of Indo-Pacific lionfishes (*Pterois volitans* and *Pterois miles*, hereafter termed "lionfish") to the Caribbean added yet another threat for local managers to address. As generalist predators that consume small fishes, crustaceans, and other invertebrates, lionfish have the potential to alter coral reef ecosystems via predation of native fishes and invertebrates (Lesser and Slattery 2011, Green et al. 2012, Côté et al. 2013). Fortunately, lionfish are uniquely easy to catch or spear, and culling by managers, sport diving operations, and organized lionfish "derbies" appears to be surprisingly effective at reducing lionfish densities (Barbour et al. 2011, Frazer et al. 2012, Côté et al. 2013).

Another potential "solution" to the lionfish problem is to restore native predators to reefs. The notion is that, if present, groupers, sharks, and other large predators would consume, intimidate, or reduce the fitness of lionfish, thereby minimizing their impact. Mumby et al. (2011) purported to test this idea by asking whether lionfish biomass is lower within the Exuma Cays Land and Sea Park (ECLSP), The Bahamas, where the grouper biomass is reportedly greater than on adjacent sites. Unfortunately, their study is flawed and their inference – native grouper are a biocontrol of invasive lionfish – is not supported by the balance of evidence. Here I outline the main limitations of their study.

First, there are two errors in the key study figure (reproduced below in Fig. 1) that makes an objective evaluation of their finding challenging; 1) The legend says lionfish density is plotted, but the figure axis label says biomass, 2) there are no "open squares" so it is unclear which data points are from within the ECLSP. (P. Mumby clarified that biomass is plotted on the y axis, but it is still unclear what sites are inside the marine reserve).

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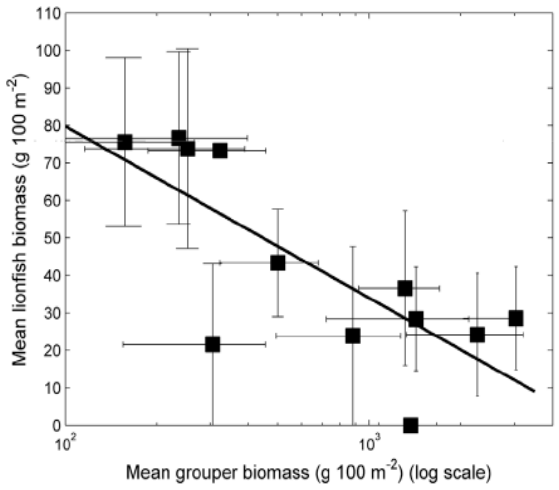

Figure 1. Relationship between grouper and lionfish biomass in and around Exuma Cays Land and Sea Park. From Mumby et al. 2011. Note that sites in and out the reserve are not labeled.

Second, the design is pseudoreplicated (Hurlbert 1984). Like all their previous work in the ECLSP (e.g., Mumby et al. 2007, Mumby and Harborne 2010), Mumby et al. (2011) surveyed sites inside (five) and adjacent to (seven) the no-take reserve, yet treated all sites as being independent replicates for an artificially inflated sample size (n) of 12. In reality the sample size is 1 given the hypothesis being tested is whether local protection of grouper effectively reduces lionfish (i.e., the subsamples are part of a nested design yet are being treated otherwise). This reality was masked by analyzing the data derived from a nested design using regression analysis (as has been done in previous work by Mumby et al. regarding the effectiveness of the ECLSP). This analysis assumes independence of the component replicates – an assumption that was clearly violated.

The "case study" approach frequently employed by Mumby et al. has limited application beyond a violation of basic statistical assumptions and good practices: without replication, it is impossible to determine whether the treatment (excluding fishing) is the cause of observed patterns. It is valid to statistically compare the two locations (reserve treatment and control), but not to assert a particular biological difference (i.e., high versus low grouper abundance) as being the sole cause of the observed pattern of lionfish abundance. To do so would require replication of the treatments, i.e., multiple protected locations (and not just subsampling within a single location). The limitations of this "case study" approach to testing the effectiveness of local management, e.g., the implementation of Marine Protected Areas, are well known. Mumby et al. 2011 is based on a *Control-Impact (CI)* design as described by Osenberg et al. (2006):

> *Control-Impact (CI) Designs*
>
> In this common design, multiple samples are typically taken from plots within an Impact site and at least one Control site. These two sets of samples are compared statistically to determine if the two sites differ. If they do, then we conclude that there was an effect of the restoration activity. Of course, because no two sites are identical (although Control and Impact sites may be *similar*), there will likely be statistically significant differences between the two sites. This will be true even before the restoration project begins. Thus, the Control-Impact design confounds the effect of the restoration project with other processes that produce spatial variation in parameters (e.g., Figure 13.1a).

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Mumby et al. (2007, 2011, 2013) stated there were no differences in biotic and abiotic factors between sites inside and outside of the ECLSP. Such complete homogeneity dictates the inferences they are able to make. If their sites were truly homogeneous, their study measured whether biotic resistance *could* control lionfish, not whether it actually does. By holding all other known factors and processes that control fish biomass constant (e.g., habitat quality, recruitment, prey availability, parasite load, etc.), they were able to detect a very small effect size (see below). But this tells us nothing about the effectiveness of grouper biocontrol in the real world where countless other factors do vary from place to place. Thus, the question and answer are not management-relevant.

Third, mean and maximum lionfish biomass for the Exuma cays is only 1/10 and 1/100, respectively, of values reported for the broader Caribbean (Fig. 2). Apparently, some environmental factor was greatly limiting lionfish abundance at all sites surveyed by Mumby et al. 2011, including the fished sites with low native predator biomass. This also limits the application of any inferences from Mumby et al. (2011), i.e., the inferences are not applicable to most the Caribbean, where lionfish are far more abundant.

Fourth, the effect size (i.e., the difference in lionfish biomass between the high and low grouper biomass sites in Mumby et al. [2011]) is less than 1% the range of lionfish biomass reported by Hackerott et al. (2013), which surveyed lionfish and grouper biomass at 71 sites in Belize, Mexico, The Bahamas, and Cuba (Fig 2). Clearly, such a small reduction in lionfish biomass is not ecologically relevant or meaningful to managers.

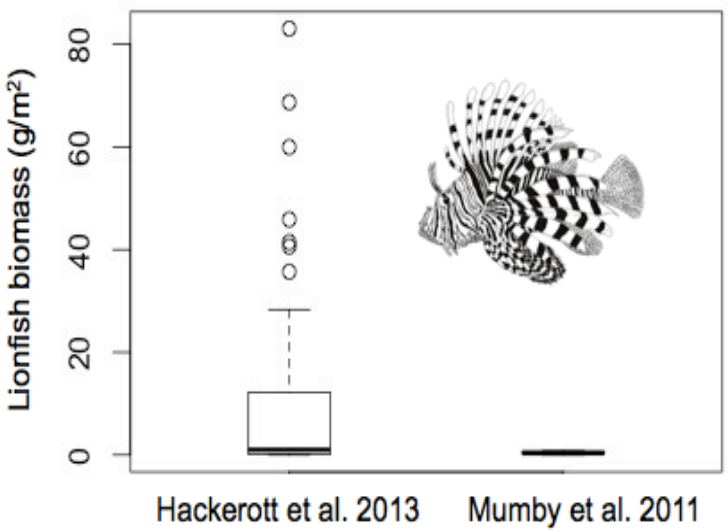

Figure 2. Box plots of lionfish biomass recorded by two studies. For the Mumby et al. data, the control and marine reserve sites were pooled and plotted, yet the difference is so small the entire range appears as a single horizontal line.

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The minimal difference between the reserve and control sites can also be seen when the data from Mumby et al. 2011 are included in a scatter plot of the data from Hackerott et al. (2013)(Fig. 3). This also illustrates the lack of any obvious relationship between lionfish and grouper biomass, when a greater range (of lionfish and grouper biomass) is included in the analysis. Also note the far greater lionfish biomass range recorded by Hackerott et al. (2013) at levels of grouper biomass comparable to the values recorded in Mumby et al. (2011)

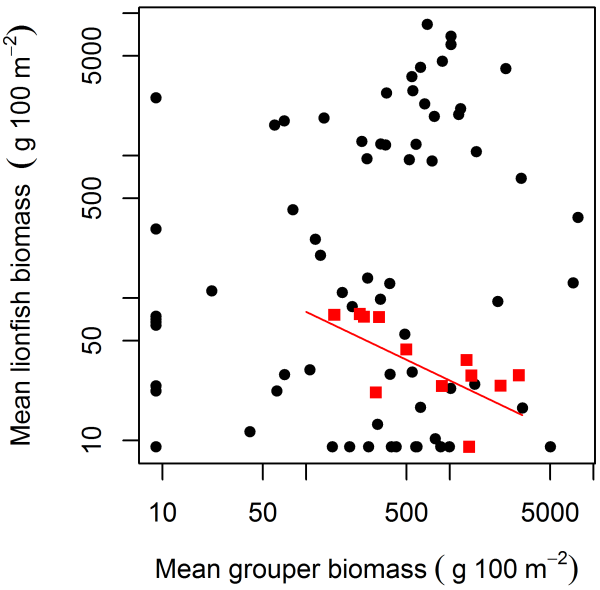

Figure 3 Relationship between the biomass of large grouper and invasive lionfish on Caribbean reefs. Black circles are data from Hackerott et al. 2013. Red squares and line (model regression fit) are from Mumby et al. 2011. Axes are in log scale. See Hackerott et al. 2013 and Bruno et al. 2013 for analyses.

Fifth, Mumby et al. (2011) did not include any evidence that grouper consume live lionfish within the ECLSP. In fact, no such evidence exists for any reef in the invaded range of lionfish. There is a single published "Reef Site" (Maljkovic et al. 2008) that describes the observation that two Nassau grouper (*Epinephelus striatus*) were caught with lionfish in their gut, however, it could not be determined whether the lionfish were dead or alive when consumed (divers commonly feed grouper and sharks dead lionfish).

In conclusion, there are a number of limitations of the study by Mumby et al. (2011) that undermine their inferences and advice for managers. A more recent and rigorous study (Hackerott et al. 2013) surveyed the abundance (density and biomass) of lionfish and large grouper (as well as other native predatory fishes) on 71 reefs in three biogeographic regions of the Caribbean. Hackerott et al. (2013) found no evidence of a relationship between the biomass of lionfish and native predators. Therefore, based on the available evidence, there is no support for the notion that native predators can control the populations of invasive lionfish, at least in most conditions and locations across the Caribbean.

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