All boom and no bust as the lionfish invasion progresses in Bacalar Chico Marine Reserve, Belize

L'invasion des poissons lions s'agrandit sans fin dans le Réserve Marine Bacalar Chico, Belize

La invasión del pez león crece sin cesar en la Reserva Marina Bacalar Chico, Belice

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ABSTRACT

The first confirmed sighting of invasive lionfish (*Pterois volitans*) in Belize was in 2008, and the species is now well established throughout the country. Lionfish sighting frequency in Bacalar Chico Marine Reserve, northern Belize, increased from 2011 to 2012, coupled with a significant upward shift in size class frequency distribution. Lionfish dissections confirmed that lionfish in Belize reproduce throughout the year, and a change in diet from fish- to shrimp-dominated was observed between years. A similar change in lionfish diet has been observed in Port Honduras Marine Reserve, southern Belize, and may be indicative of fish recruit depletion. Given that consistent removal of more than one third of the population is required to prevent population growth and expansion, market development is heralded as the most feasible management solution. As protected areas may provide a refuge for lionfish, an open-minded approach to developing alternative management solutions within protected areas must be applied.

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INTRODUCTION

Invasive species have been highlighted as one of the greatest threats to global ecosystems (Mooney and Cleland, 2001; Wilcove *et al*., 1998); often leading to biodiversity loss, food web disruption and alterations in ecosystem structure (Jackson, 2008). The red lionfish, *Pterois volitans*, was introduced to the Atlantic in the 1980s (Morris and Whitfield, 2009). Its numerous venomous spines make it an unsavoury prey item, with few species recorded to successfully predate upon lionfish (Bernadsky and Goulet, 1991; Morris and Whitfield, 2009). This lack of predatory pressure, in combination with a generalist diet (Green *et al*., 2011; Green *et al*., 2012) and high annual fecundity in their non-native ranges (Morris and Whitfield, 2009), have enabled the establishment of rapidly growing populations of lionfish throughout the Caribbean (HRI, 2010; Ruttenberg *et al*., 2012; Schofield, 2009).

The first lionfish officially recorded in Belize was at Turneffe Atoll in 2008 (Searle *et al*., 2012); the population expanded throughout the coastal waters of northern Belize in 2009 finally reaching Port Honduras Marine Reserve, in the far south of Belize, in 2010 (James Foley, TIDE, pers. comm.). Blue Ventures, observing an increase in opportunistic lionfish sighting frequency throughout 2010 during reef monitoring expeditions in Bacalar Chico Marine Reserve (BCMR), began systematically monitoring the lionfish invasion in August 2010.

BCMR is one of seven marine protected areas (MPAs) that together form the Belize Barrier Reef Reserve System, a UNESCO World Heritage Site (UNESCO, 1996). Threats to reef health from coastal development, oil exploration, overfishing, climate change, and introduced species have led to its inclusion on the List of World Heritage Sites in Danger (UNESCO World Heritage Committee - Decision - 33 COM 7B.33).

Located at the north of Ambergris Caye, BCMR borders the Mexican MPA, Arrecife de Xcalak. Covering 15,529 acres of coastal waters, BCMR encompasses coral reefs, seagrass beds, mangroves and lagoons.

Using the Simplified Integrated Reef Health Index (SIRHI), overall reef health within BCMR is ‘Poor’. Mean hard coral cover has decreased dramatically in the past decade, from 18% in 2004 (Garcia-Salgado *et al*., 2008) to 9% in 2013 (Blue Ventures, unpublished). Fleshy macroalgae dominates the reef benthos (23% in 2013), and has placed BCMR in alert status since 2004 (Garcia-Salgado *et al*., 2008). Corresponding herbivorous fish biomass is ‘Fair’, though lacks diversity, and *Diadema* populations are critically low.

Anecdotally, fishers consider BCMR to be “fished out”, blaming unsustainable and intensive historic fishing pressure prior to reserve designation in 1996. The biomass of commercially significant fish on reefs is poor, and large-bodied grouper sightings are rare. Nevertheless, it is still used by some Sartenejan fishers, targeting primarily conch and lobster, and residential trap fishers, targeting finfish. The majority of visitors to BCMR utilise it for tourism, including sport fishing, snorkelling and diving.

Blue Ventures’ on-going lionfish monitoring programme seeks to determine and document invasive lionfish population status, growth, and expansion in BCMR, with the overall aim to contribute to regional research objectives and local management of this devastating invasion.

METHODS

<u>Lionfish Population Density</u>

Research Divers conducted eight haphazardly located fish belts (30m x 2m) across 13 sites annually between 2010 and 2012. Survey sites represented both forereef and backreef sites within each management zone of BCMR. The number and size category of priority fish species, including lionfish, were recorded, with a 6-8 minute time limit per transect.

<u>Lionfish Sighting Frequency</u>

An opportunistic sighting record for lionfish began in August 2010. During each individual dive, the size (Total Length, TL), depth and abundance for each lionfish observation was recorded. All divers were trained and tested for in-water size estimation.

Lionfish sightings were standardised per hour of diving time and segregated for backreef and forereef habitats. Size estimates were placed into size categories of 6 cm intervals. 2011 data was used as the expected distribution to test the null hypothesis that there was no change in size class frequency from 2011 to 2012, and results were compared using chi-squared.

<u>Lionfish Dissections</u>

In 2011, lionfish dissections recorded body size (TL) and stomach contents, identifying stomach contents to the highest taxonomic level possible, and measuring the length of whole prey items. In 2012, lionfish dissections additionally recorded the presence or absence of “developed” or “spawning capable” ovaries. In 2013, lionfish dissections follow GCFI guidelines, recording a digestion score for prey items as well as sex of individuals with a total length greater than 18cm.

To further investigate and test changes in size class frequency distribution, length measurements of dissected lionfish were placed into the same 6cm size categories as used for in-situ size estimates, and the same analysis was performed.

RESULTS AND DISCUSSION

Lionfish detection rates were low along traditional fish belts, likely due to their cryptic colouration and tendency to hide within crevices during non-crepuscular periods (Green *et al*., 2011; Green *et al*., 2013). The results of these fish belts are considered to be underestimates of true lionfish population density and were not used to inform population density status. Dedicated lionfish population density surveys were implemented in 2013, following recommendations in Green (2012).

The majority (89%) of sightings were on the forereef, where both maximum and mean sighting frequencies increased annually (Figure 1, Table 1), to a maximum of 49.5 fish hr^{-1} in 2012. This upward trend in lionfish sighting frequency indicates the potential carrying capacity of reefs in BCMR is large.

Lionfish TL was estimated for in-water sightings and measured for culled individuals. There was a significant upward shift in size class frequency distribution between years (Figure 2), with 15% of lionfish observed in 2012 greater than 30cm, compared with just 5% one year earlier (χ^2=333.74, d.f.=5, P<0.01 – sightings data; χ^2=49.28, d.f.=5, P<0.01 – dissections data). The largest lionfish encountered during dissections was 38.0cm,in 2011 and 37 cm in 2012, while the largest individual observed in-water was estimated to be 40cm total length in 2011 and 45cm in 2012.

This three-fold increase in the proportion of largest size categories indicates the population stage structure is not stable. It can be confidently assumed that all individuals within size class 24-30cm, the modal score for populations in BCMR, are sexually mature (Morris, 2009): compatible with population modelling for a rapidly expanding population (Lebreton *et al*., 1992). It is expected that the trend for increased frequency of large individuals will continue, increasing total biomass. Given that larger fish are generally more fecund and produce better quality larvae (Fenberg and Roy, 2008; Kjesbu *et al*., 1996; Vallin and Nissling, 2000; Whiteman *et al*., 2005), the rate of lionfish reproduction and recruitment is likely to increase as the population stage structure stabilizes. Proportion of smallest individuals was similar for both years, suggesting lionfish recruitment rate is stable. Developed or spawning capable ovaries were observed in lionfish dissected throughout 2012, confirming that lionfish within BCMR reproduce year-round.

The mean number of prey items observed within culled individuals was unchanged between 2011 and 2012 (2.16 ± 0.13 in both years), and the highest number of prey items observed within a single lionfish was 19 in 2011 and 17 in 2012.

A change in diet was observed between years: in 2011, the majority of prey items were fish (68%), including parrotfish, wrasse, damselfish and grouper. However, in 2012 invertebrates, predominantly shrimp, comprised the majority of the diet (56%) (Figure 3). A similar shift has been observed in southern Belize (James Foley, TIDE, pers. comm.). Such a change in feeding behaviour to more cryptic or hidden prey such as shrimp may be suggestive of fish recruit depletion.

Given the Outstanding Universal Value of BCMR, and the ecological and social vulnerability of its resources, invasive lionfish could trigger terminal decline. Therefore, there is a critical need to develop systems for the effective management of this potentially devastating threat.

As the most effective tool for managing invasive lionfish is market development, there is an urgent need to develop effective methods for managing lionfish within MPAs, which provide a haven for lionfish as well as native species. Management of lionfish within MPAs may combine recreational diver removals, tournaments, and special commercial fishing licenses.

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FIGURES AND TABLES

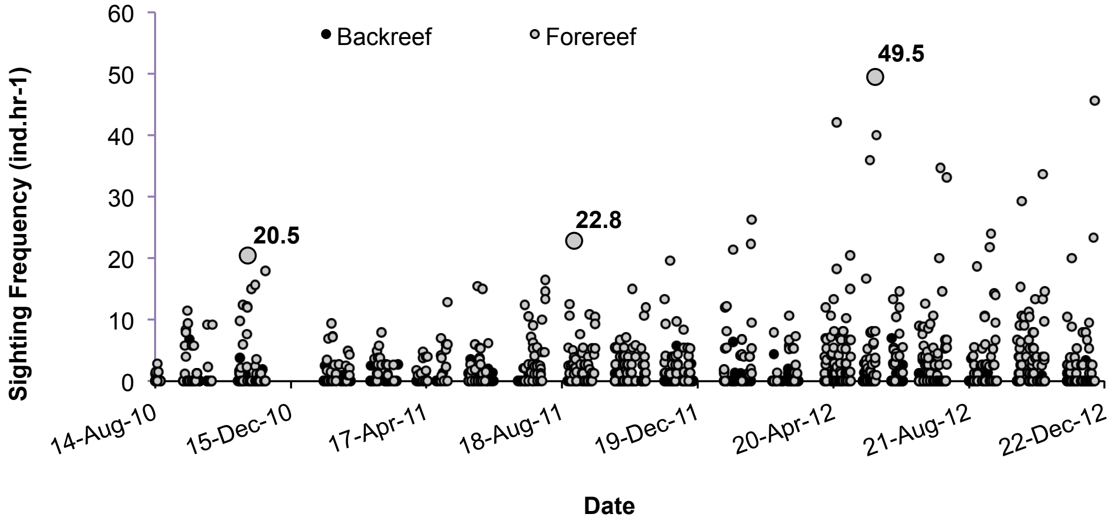

***Figure 1**: Lionfish sighting frequency on dives in BCMR. Annual maxima are enlarged and labeled.*

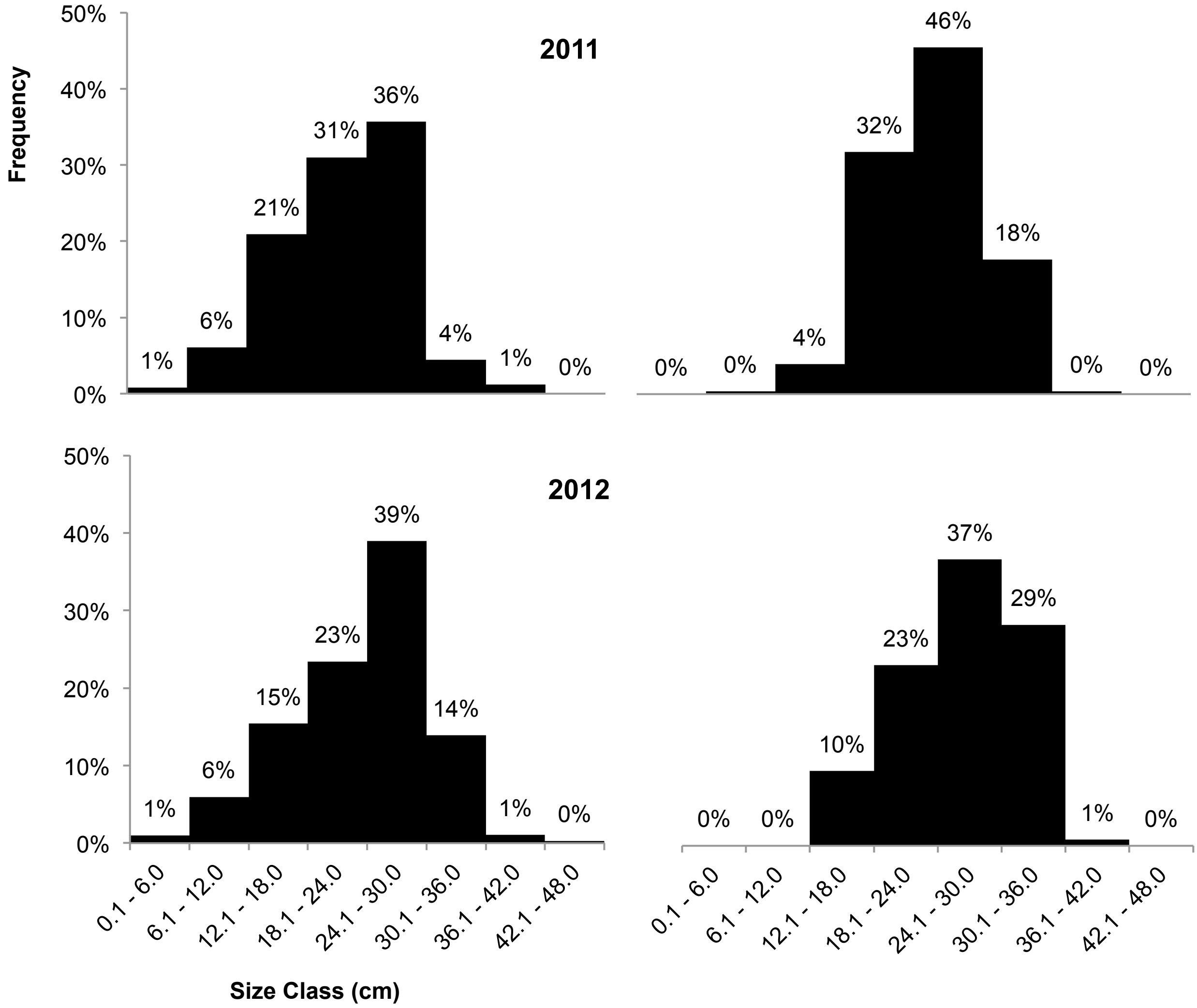

***Figure 2**: Lionfish size class distribution in 2011 and 2012 for (L) estimated TL from opportunistic sightings (2011 n=861, 2012 n=1389) and (R) measured TL of culled and dissected individuals (2011 n=254, 2012 n= 247).*

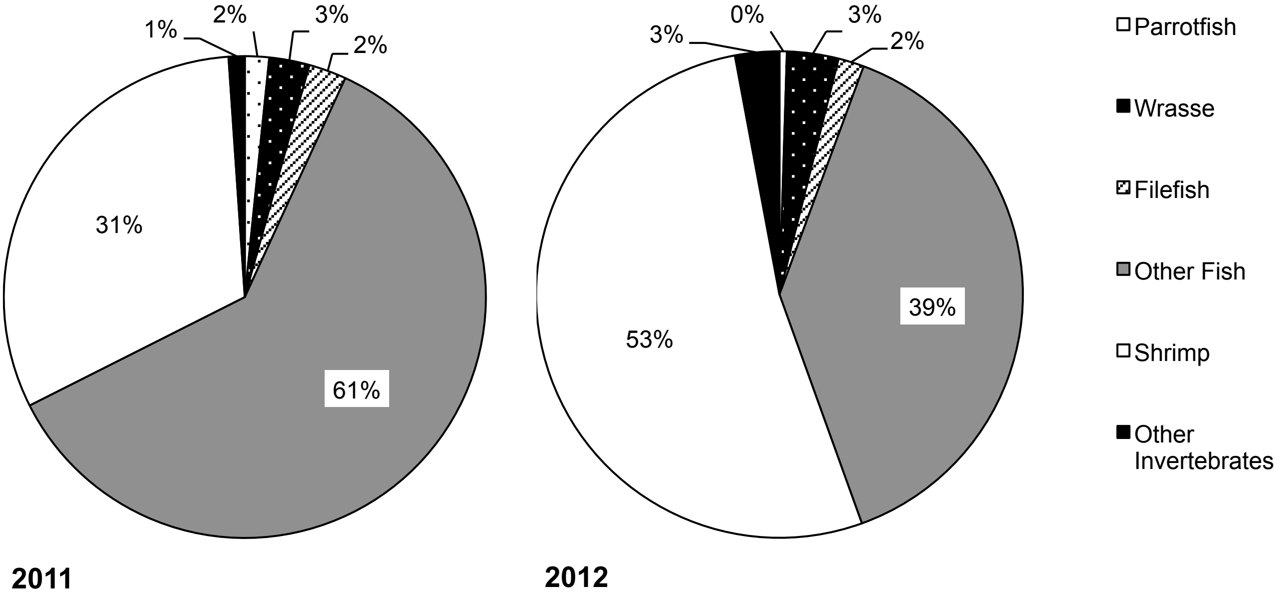

Figure 3*: Lionfish stomach contents in 2011 (n=254) and 2012 (n=189).*

Table 1*: Lionfish sighting frequency on forereef dives in BCMR.*

Year	Maximum (ind.hr^{-1})	Mean ± SE (ind.hr^{-1})
2010	20.5	2.7 ± 0.5
2011	22.8	3.1 ± 0.2
2012	49.5	4.1 ± 0.3

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