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# Status of Lionfish (*Pterois volitans*) populations in Anguilla, British West Indies, with additional biometric and stomach content analysis results.

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## ABSTRACT

Following recommendations made by a brief ecological study of the invasive Lionfish (*Pterois volitans*) in Anguilla during 2014, the Department of Fisheries and Marine Resources (DFMR) undertook an extensive year-long population assessment for the species between July 2015 and July 2016. Biometric and stomach content analysis were also carried out for captured individuals, thus building upon the 2014 dataset. The present study found *P. volitans* could sustain themselves successfully on a mixed diet, or one even completely based on crustaceans, suggesting habitat flexibility and resource generality aids its invasion potential. The mean size of *P. volitans* in Anguilla appears to be increasing, a natural phenomenon expected while a species is establishing itself in an area. Despite this, populations are relatively low on most shallow reef areas. A number of 'hotspots' were however identified where *P. volitans* settlement appears more frequent than other areas, as even after eradication efforts they soon repopulate: Crocus Bay, Meads Bay, Anguillita and West Cay (Dog Island). Based on past habitat health mapping and other ecological survey work, *P. volitans* numbers in Anguilla appear to closely match areas with 'reasonably high' habitat health, thus their presence and/or abundance may serve as a habitat health indicator. Thus it is likely populations recorded are due to a combination of eradication efforts by DFMR and local dive operators; recreational spearfishing by residents; fishing activities by commercial fishers; and habitat suitability and/or quality. Populations on some of the wrecks were low, probably due to eradication efforts by dive operators, whereas other wrecks were also considered 'hotspots'. Reports suggest that *P. volitans* populations are increasing on offshore fishing grounds where eradication efforts are not possible. However, these populations are helping to sustain supplies for a growing demand from the restaurant industry. Even though it is recognized that *P. volitans* are here to stay and should to be recognized as a fishery in its own right, certain management recommendations can be made to give the ecosystem time to naturally acclimatize to this highly successful and adaptable invader: DFMR eradication efforts should continue at 'hotspots' and recreational swimming areas; dive operators should continue to be encouraged to remove *P. volitans* from wrecks and other dive sites; fishers should continue to be encouraged to target *P. volitans* for a growing restaurant driven market; outreach materials (i.e. informative posters) should continue to be distributed as necessary, with future design revision made as appropriate.

# Introduction

The invasive Red Lionfish (*Pterois volitans*) is a species of Scorpionfish (Scorpaenidae) native to the Indo-Pacific region (Whitfield *et al*., 2002). The first documented sighting in the tropical western Atlantic was made by a lobster fisherman off Dania in Florida during October 1985 (Morris & Akins, 2009). No further sightings were recorded until six individuals were reportedly released accidentally when a sea-side aquarium in Florida was damaged by Hurricane Andrew in August 1992 (Courtenay, 1995). Courtenay (1995) went on to state that lionfish had also been observed in Lake Worth, Palm Beach and Boca Raton in South Florida. Following this report, five years went past before more sightings were recorded in Palm Beach and both North and South Carolina. Semmens *et al*. (2004) attributes many of these sightings to releases by home aquarists, although subsequent genetic work suggests that there was only a small founding population (Freshwater *et al*., 2009). Sightings continued exponentially until, by 2002, lionfish were considered more or less continuously distributed from Miami, Florida to Cape Hatteras, North Carolina (Schofield, 2009). At this time they had also been reported in Bermuda, and by 2004 had arrived in the Bahamas and began rapidly spreading across the Caribbean: Cuba (2005); Turks and Caicos (2006); and Jamaica, Cayman Islands, Dominican Republic, Puerto Rico and as far east as the US Virgin Islands in 2008 (Schofield, 2009). Although two genetically distinct species of lionfish have been reported within their invaded range (Hamner *et al*., 2007), there is some discussion on this (Whitfield, 2007;) and thus only one species (*P.volitans*) is generally considered to have dominated the invasion across the wider Caribbean (Gonzáles, 2009), having initially accounted for 93% of the population (Hamner et al., 2007). By the end of 2008 the first reports from South/Central America came in from Columbia and Belize, and by early 2009 confirmation of their arrival on the continent had also been made by Mexico, Honduras and Costa Rica. Interestingly, probably due to prevailing currents, lionfish did not arrive in the Florida Keys until 2009, but between 2010 and 2011 alone underwent a three to six-fold increase (Ruttenberg *et al*., 2012). In August 2010, the first report of *P. volitans* in Anguilla was made by a local dive operator who sighted a juvenile on the reef close to Anguillita Island. This individual was subsequently captured by a Fisheries Officer from the Department of Fisheries and Marine Resources (DFMR). Since then lionfish have become widespread around the island (Ali & Bertoul, 2014).

The rapid spread of lionfish across the region is thought to have been facilitated by a lack of natural predators, high fecundity, and toxic spines but also due to their generalist nature in both terms of diet and habitat (Bayraktarov, 2014). The invasion is one of the most notorious cases of alien marine fishes in recent years (González, 2009), with studies suggesting their populations can exceed that from their native range (Green & Côté, 2008) and that they have the ability to reduce recruitment of native reef fish by almost 80% when in these high densities (Alblins & Hixon, 2008). For these reasons Anguilla had been bracing itself for the arrival of lionfish prior to its arrival, and thus engaged in such proactive initiatives as producing a lionfish response plan (Wynne, 2009) and an extensive public awareness campaign. After their arrival, DFMR kept a detailed record of sightings, and as laid out in the response plan, conducted eradications in order to try and slow the establishment of these invasive fish. Although it was recognized that it would not be possible to entirely eradicate them, the hope was that by slowing their population growth it may provide native fish populations time to adapt to their arrival. Eradication efforts initially focused on reefs close to popular swimming beaches and those within marine parks, in part to allow time for public awareness to establish. Dive operators were also encouraged to conduct eradication dives to keep dive sites minimally impacted. Aside from eradications, DFMR and the DOE also actively encouraged fishers to target lionfish, and restaurants to serve them as exotic delicacies. This latter endeavor proved highly successful with numerous restaurants now selling a wide range of lionfish dishes and fishers not able to keep up with demand (Wynne, pers. obs).

In 2012 a pilot study of the Lionfish invasion in Anguilla was conducted by a team of marine biologists. This study tested a methodology designed to rapidly assess populations around the island. During this time DFMR staff were also trained in lionfish dissection skills and stomach content analysis (a limited amount of dissections also took place in 2011 on collected specimens), and the results of this work, combined with a limited in-water study between 11th and 21st January 2014, were published as the first provisional research into lionfish populations in Anguilla (Ali & Bertoul, 2014). This study concluded that eradication efforts should continue, but that the most effective method for lionfish control was encouraging it as a fishery. It did however go on to state that further density surveys were necessary in order to cover a greater temporal and geographic range of study sites, and to assess how lionfish populations may be changing. Therefore this current research conducted by DFMR is a direct response to this recommendation.

## Methods

Following the arrival of *P. volitans* in August 2010, the DFMR began collecting biometric data for individuals captured during eradication dives and from those landed by fishers and brought into the office for analysis. In 2011 detailed records began being kept, with stomach content analysis and a suite of other variables collected. Logistical limitations meant at times all variables were not able to be collected. Variables included total length (TL), standard length (SL), width, sex and stomach contents. In 2015 mouth gape was also measured to explore its relationship with body size and therefore predator potential. The final sets of measurements were made in October 2015.

Population surveys were conducted using the Roving Diver Technique (RDT), where a diver swims at a constant speed of 5m $min^{-1}$ and counts all lionfish seen 2.5m to either side. This methodology was chosen as it follows one of the survey types conducted during the Anguilla Marine Monitoring Programme (Wynne, 2007), and hence allows this work to be incorporated into the present study. The methodology also allows surveys to be conducted by DFMR field staff during or after other in-water work and maximize productivity without the need for extra equipment. For example, after fixing a dive site mooring, staff can conduct a lionfish RDT with only a watch and dive slate. Depth, location and an estimated fish total length were recorded[1]. Sites too deep to snorkel were surveyed using SCUBA equipment, and every effort was used to search thoroughly under ledges and overhangs. Survey effort was used to standardize the results when more than one survey team we involved. This provided the following equation to calculate densities:

$$((\text{lionfish} / (\text{mins} * 5)) / \text{survey effort}) * 100 = \text{Density } 100m^{2\text{-}1}$$

In total surveys were conducted at 65 locations between July 2015 and July 2016 (see figure 1). As eradications were often conducted simultaneously replicate surveys would bias results, thus each site was only surveyed once. Replicates were however conducted within regions in a similar way to Ali & Bertoul (2014), where four treatments were allocated: offshore/cay site; wreck site; north coast site; south coast site. Logistical limitations meant certain areas were not surveyed as desired, especially those in harder to reach and/or more distant areas. For this reason no surveys were conducted at Sombrero Island or other offshore fishing grounds.

[1] Although this method varies slightly from that used by Ali & Bertoul (2014), it yields the same result (density $100m^{2\text{-}1}$).

# Results

*Stomach Contents and Biometric Measures*

The initial study by Ali and Bertoul (2014) analysed data from 163 *P. volitans* captured in Anguilla. The present study expands on this by including individuals captured up until the end of October 2015, and goes on to filter out older records that were not collected in the presence of DFMR staff. This latter step was an attempt to standardize results and remove anecdotal reports. Thus, the results presented here are for a total of 155 *P. volitans*. Of these, 74 underwent stomach content analysis where it was ascertained that 50% contained only fish, 13% only crustaceans, 18% mixed contents and 19% were empty.

Sizes of individuals caught ranged from 8 cm TL to 38 cm TL, with a mean value of 19 cm TL. Size frequency distribution for all 155 lionfish is illustrated below in Figure 1. Figure 2 illustrates the relationship between total length and mouth gape. Figure 3 presents a time series of captures.

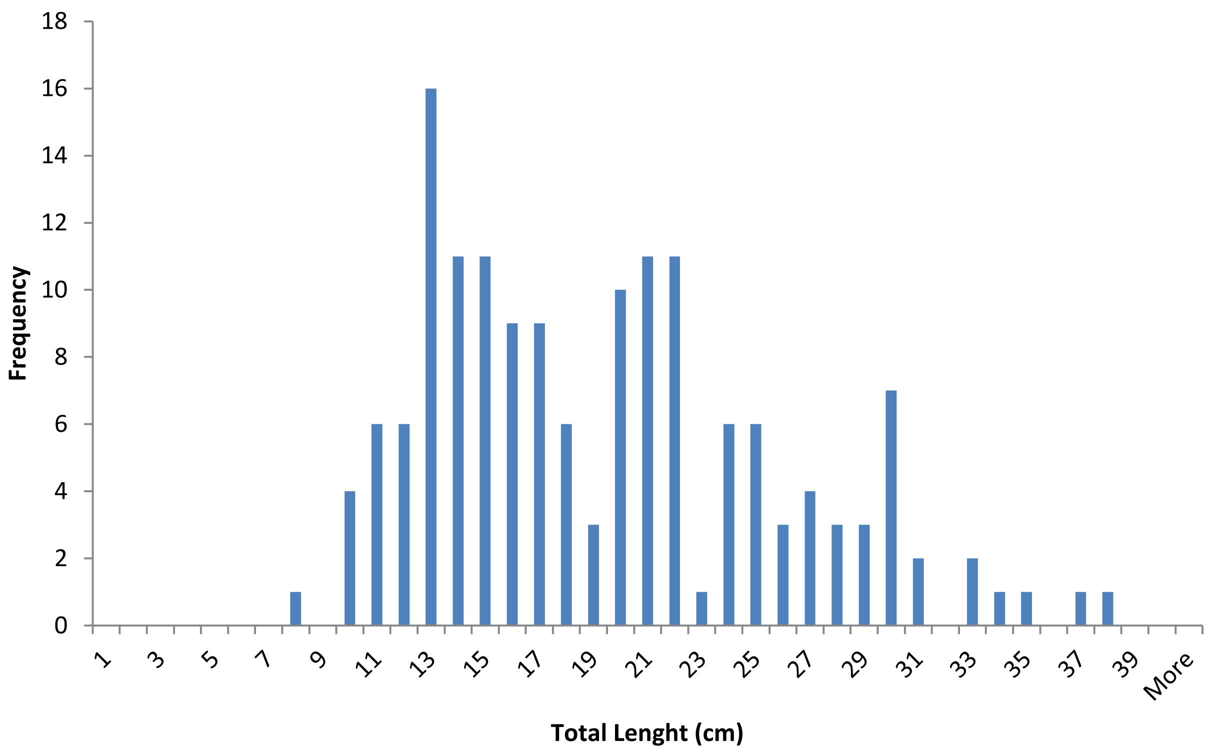


**Figure 1**: Size frequency distribution (n = 155) for lionfish in DFMR records captured and analysed during all eradication efforts between February 2011 and October 2015.

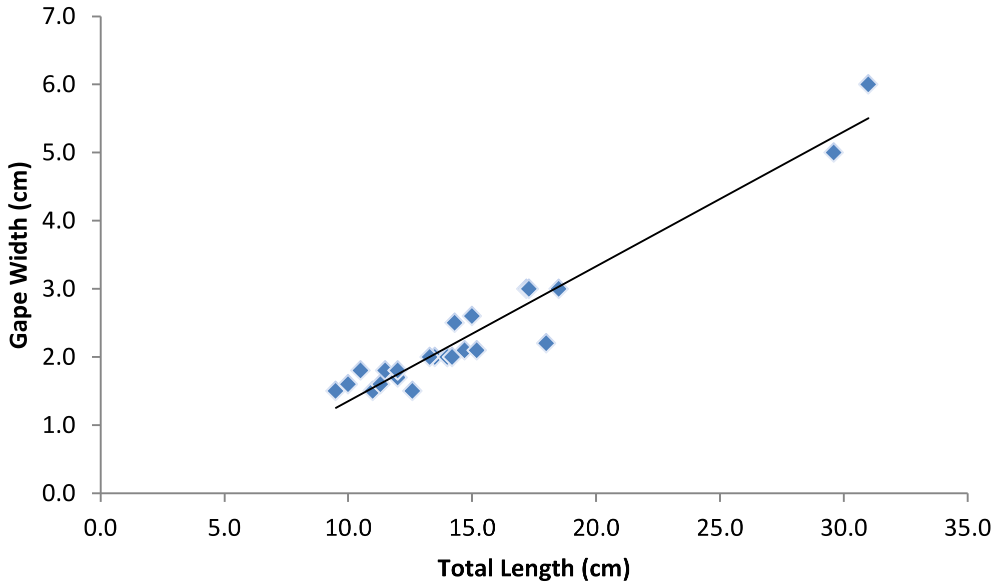


**Figure 2**: Relationship between total length and mouth gape size (n = 24), September to October 2015.

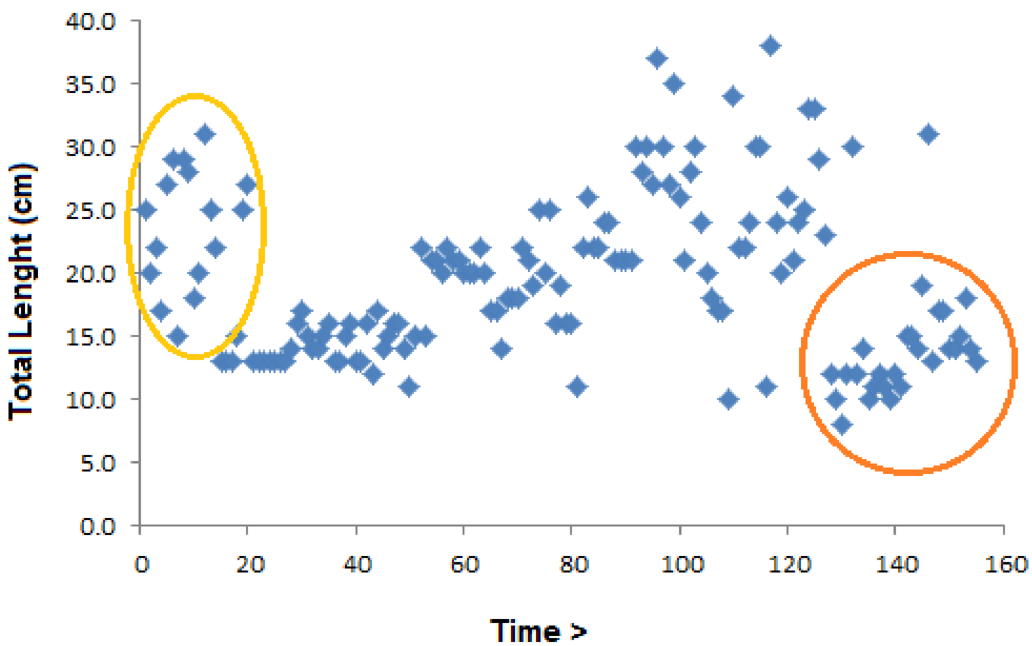


**Figure 3**: Ordered time series of lionfish captures based on total length of individuals captures across a sequential temporal axis (order of capture) illustrating three distinct groups. Those circled in yellow represent captures in the first twelve to fifteen months following first sighting, and those circled in orange represent those captured in 2015 at previously culled hotspots. The remaining points represent all other captures and illustrate a general trend of increasing capture size.

*Population Counts*

Numbers of individuals sighted at each location were put into five density categories based on calculated abundance per 100m$^2$ of representative habitat. Results from all sixty five study sites visited are presented in Figure 4 with colour coded abundance categories: None = No lionfish seen during survey; Low = Less than 1 per 100m$^2$; Medium = Greater than 1 but less than 2 per 100m$^2$; High = Greater than 2 but less than 3 per 100m$^2$; Hotspot = Greater than 3 per 100m$^2$.

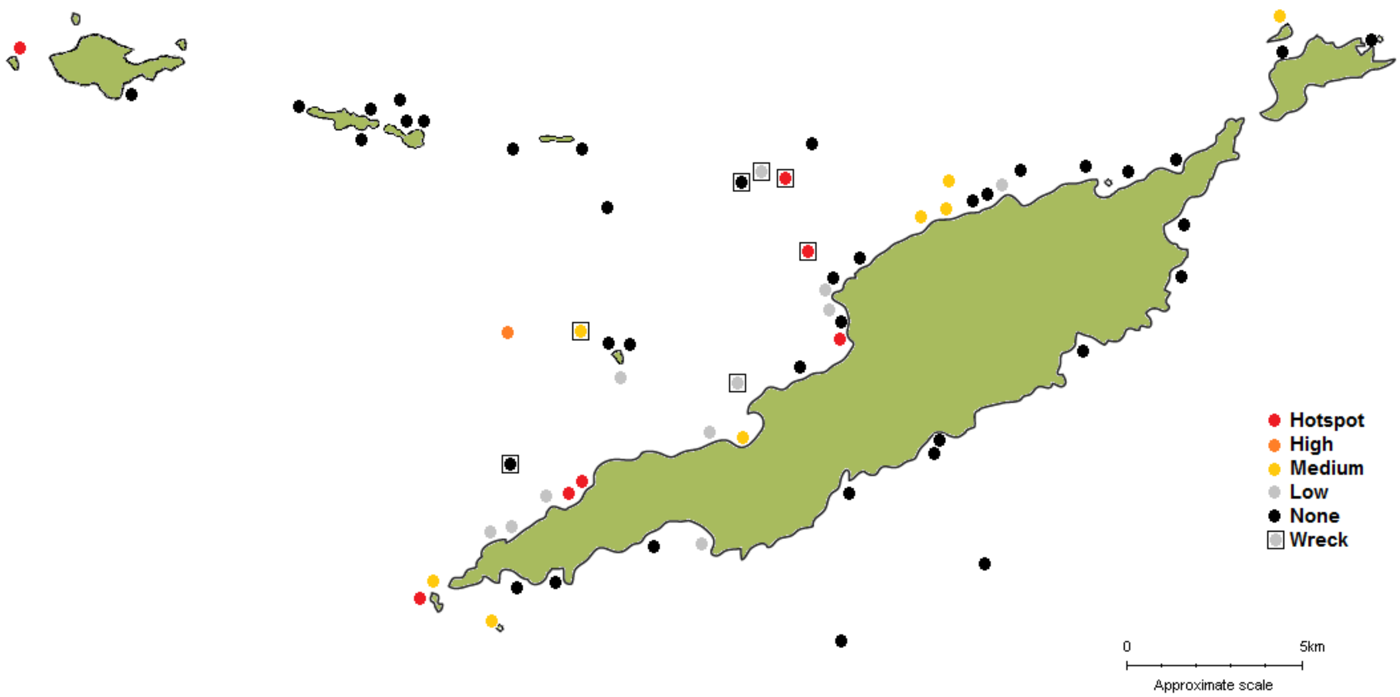


**Figure 4:** Map of study sites around the island with lionfish abundance categories illustrated.

## Discussion

*Stomach Contents and Biometric Measures*

As with past work in Anguilla (Ali & Bertoul, 2014), the stomach content analysis reveal that if needed, lionfish can sustain themselves on a diet of crustaceans only, which helps explain their ability to inhabit such a wide range of habitat types. Ali & Bertoul further reported a wide variety of fish families being present in their analysis, although the present work found that identification to this level was only possible when stomach contents were relatively fresh. For this reason identification was limited to 'fish' or 'crustaceans' only. Fish however were their favorite prey items, so although an opportunistic foraging strategy is likely used thus allowing them to utilize a range of habitat types, if present fish will be more probably targeted over crustaceans. This is likely driven by their corralling hunting strategy as free swimming fish will be more targetable than shrimps hiding in crevices. This also indicates that habitats will be able to support higher abundances of lionfish than small fish populations alone would indicate, and that if lionfish over-harvest these fish, they will be able to sustain themselves by switching to a crustacean dominated diet.

In terms of sizes captured, figure 1 illustrates an expected size frequency distribution where smaller individuals are uncommon due to cryptic habits, with a sudden peak during their ‘teenage’ phase when they begin to forage more openly. The peak then gradually slopes off towards the larger sizes as carrying capacity issues and mortality influences begin to impact populations. Interestingly, smaller lionfish were witnessed to exhibit a previously unknown behavior of burying themselves under the sand when threatened. During a number of eradication dives where smaller individuals were targeted, if narrowly missed by the spear gun the lionfish would dive into the sand and disappear. This habit was witnessed in sizes up to at least 20 cm TL, and demonstrates one benefit to the species when living on reef/rocky areas that are in close proximity to sand patches.

In terms of overall sizes, the mean value of 19 cm TL recorded is relatively high when considering the number of smaller individuals captured in certain locations. This is more clearly illustrated in figure 3, where far more individuals under 19 cm TL are recorded, and those over this value, although fewer, have a much greater size range. This further illustrates, especially when the two outlier groups of data are ‘removed’ from the analysis, that a general increase in size has been observed over time. Such an increase may signify a success in eradication efforts/fishing pressure removal as overtime one would expect such an increase while a population is establishing, but after six years many more of these larger individuals would be expected to be present.

Results from mouth gape size analysis show that this variable has a linear relationship with total length. The reason for conducting this analysis was a concern that mouth gape may have a more exponential relationship with total length, and so as lionfish get larger they can consume proportionally larger prey items and thus exponentially increase the amount of prey that is available to them for consumption. This may have had significant ecological implications if found true, but from the results presented here it doesn’t currently appear to be the case. Overall, this is good news for local ecology.

*Population Counts*

Generally speaking, lionfish numbers are low around Anguilla’s coastal regions. This is opposite to what was expected when they first arrived in Anguilla in 2010, as based on the scientific literature, especially from the Bahamas where they have been extensively studied. Fears were that by now they would have reached plague like proportions. This can only be for one of two reasons; either eradication efforts and other management measures proposed originally in the Lionfish Response Plan (Wynne, 2009a), that were later summarized and expanded upon by Ali & Bertoul (2014), have been successful; or lionfish are not able to proliferate in Anguilla as they have in other places. It is unlikely that Anguilla differs greatly from other neighboring islands, even those as distant as the Bahamas, although in terms of available habitat, shallow reef areas are not as abundant here as in some of these other places, with waters quickly becoming deep and less topographically complex. Having said this, reports from fishers are that lionfish are so prolific in offshore reef dominated fishing grounds (such as the Anguilla Bank), that their traps often laden with the invasive fish. Although removing them from their traps may not be a favorite activity, thanks to a growing restaurant demand for the species, the landed catch can be easily sold at a good price, with demand still greater than supply. In fact, this may well be the reason for *P. volitans* low numbers in coastal areas, as they are extremely easy to target with a spear gun, and can readily be sold, so they are a favorite target species for spear fishers.

Reported high densities in offshore fishing grounds is something that needs more investigation, as local spear fishers will not be able to control them in a similar way as it is suspected they do in coastal areas. Currently the Department of Fisheries and Marine Resources is putting together a proposal to conduct surveys of these fishing grounds using underwater video techniques, which once completed will yield data able to corroborate this. For the time being, it is telling maybe that the one deep reef site able to be surveyed as part of this current population study (Author Deep dive site) was recorded to have high lionfish numbers in comparison to other reef areas.

It should be  noted that since the invasion of this new marine species, no lionfish have yet been reported at Prickly Pear Cays or the Seal Island reef system. Interestingly, a lot of recreational snorkeling and some fishing activities take place near Prickly Pear East; this study undertook a number of surveys in the vicinity and has not seen any sign of the Lionfish. One would expect sighting to have been made. A similar situation has been observed along much of the south coast, with no lionfish yet reported between Rendezvous Bay and Windward Point. One theory behind this is that lionfish may act as an indicator species for overall habitat health. For example, Prickly Pear reef areas and much of the Seal Island reef system is known to be in a poor state of health or under a process of degradation (although some pockets of high coral cover do exist). Similarly, as reported in numerous DFMR studies, for example Wynne (2009b), the south coast is extremely degraded, again matching lionfish sightings. Indeed, habitat health maps produced for Anguilla (Wynne, 2016) match overall lionfish sightings quite closely. For example, both the present study and Ali & Bertoul (2014) found no lionfish along the eastern portion of Shoal Bay East and on towards Island Harbour, whereas both recorded sightings along the western end of Shoal Bay East passed Zemi Beach. A similar habitat health gradient was reported when mapping the area. The potential for lionfish to act as indicator species is important and warrants further research, and may also go on to explain lower than expected numbers in Anguilla (rather than eradication efforts alone) where much of the reef areas are considered to be in a poor state of health.

As reported in Ali & Bertoul (2014), hotspots of high lionfish densities were recorded at certain locations, although this former work only identified them at some of the offshore cays. The present study also identified some coastal hotspots (Meads Bay and Crocus Bay), although these predominantly only housed smaller juvenile individuals. This small size may be due to previous eradication efforts by DFMR, as illustrated by the orange circled data subset in figure 3. Thus, these areas appear to be hotpots of lionfish settlement, as even after eradication they reappear again a year or so later. There is also the possibility that certain areas are favourable for settlement of the *P. volitans* pelagic larval phase, which then migrate to surrounding areas once a certain size has been reached. Reasons for these areas being attractive to settling post-pelagic juveniles remain unclear, but in terms of general habitat characteristics some similarities can be noted. For example; the site at Meads Bay (near the rocks off from Malliouhana) is of relatively high complexity with numerous small ledges and overhangs, surrounded by sand; the site at Crocus Bay, although very different, offers the same opportunities as a pipeline originating from the desalination plant essentially forms one long ledge and overhang, also surrounded by sand. As discussed earlier, it is theorized that proximity to such sandy areas is beneficial for juvenile Lionfish as they appear to display a flight response that involves diving under the sand and hiding. Furthermore, both areas are considered relatively healthy, with higher than average biodiversity, high numbers of juvenile fish present and often clear waters. This again adds to the indicator theory.

Further fuel to this theory are the offshore cay hotspots identified, all of which are considered 'healthier than average'. The present study identified West Cay (Dog Island) and Anguillita as offshore cay hotspots for *P. volitans* . West Cay was also identified by Ali & Bertoul (2014), although Anguillta was not. They instead recorded Little Scrub as having high abundances of Lionfish. The present study did record elevated numbers at Little Scrub as compared to many other coastal areas, but it did not fall in the 'hotspot' category. The area around Little Scrub is very popular with fishers, and so it is possible that the relative abundance has decreased there. The term 'relative abundance' is used in this context as it is interesting to note that overall, the study by Ali & Bertoul (2014) recorded much lower abundances per $100m^2$ than the present study. This might be due to methodological differences as using transects inherently restricts survey area, and if surveying while reeling out the transect tape, it is difficult to search behind rocks within the whole transect strip. This might lead to proportionally lower numbers being recorded across the whole study, hence an abundance relative to the survey methodology was recorded. The present study used a controlled, timed, roving survey technique that allows the surveyor greater freedom to explore under complex topography, thus abundances may be recorded as higher.

Despite this methodological difference and its implications, relative abundances between studies did yield some similar results. As mentioned earlier, both recorded higher levels of Lionfish at the western end of Shoal Bay East, than at the eastern end for example, and both methods recorded high levels on some of the wrecks. The present study found two of the wrecks to be within the 'hotspot' category, although others had only low levels or no lionfish present. It is thought that this variation between wrecks is probably due to eradication efforts by dive operators and/or DFMR. The hotspots recorded at some of the offshore cay sites all share similar characteristics, being vertical walls with numerous small caves and/overhangs. As discussed earlier, although lionfish can inhabit a range of habitats, they seem to prefer these complex overhanging and/or vertical structures. It is also a consideration however that these offshore areas are less likely to be visited by either dive operators or spear fishers (Anguillita, although a dive site, has not had a mooring in place for a number of years and so isn't visited as frequently by dive operators as it used to be), and lionfish on vertical or overhanging structures are not able to be targeted by traps. Thus, with all these confounding variables, it is not possible to conclude at the present time as to why the hotspots are where they are, but it is likely some kind of trade-off between habitat suitability/quality and harvestability.

Whatever the case, one can surmise that lionfish are now fully established around Anguilla (although not as abundant or evenly distributed as expected), and that they are here to stay. Marine ecosystems are interconnected in such a way that it would never be feasible for expectations of eradication efforts to be total. DFMR have been conducting their eradicating efforts in collaboration with dive operators in the hope that Lionfish numbers can be controlled in such a way to allow time for a natural balance to be reached after such a rapid invasion. It seems clear that total eradication can be successful on limited areas such as shipwrecks, and this should continue to be encouraged, but eradications on huge areas of deep-water reef are simply not possible. Furthermore, as promotion of lionfish as a food item has been such a success, they should now be considered a fishery in their own right, and at least to a certain extent begin to be considered a new but 'normal' part of the reef fish community. This is not to say that at the present time DFMR eradication efforts should cease, just lowered in priority with the work focusing on identified hotspots and in response to reports made in recreational areas such as the marine parks (public safety). Indeed, these latter areas present an interesting conundrum. The current plan is for spearfishing to be restricted in these areas, whereas it is the preferable method to control numbers. If *P. volitans* numbers were to increase in the marine parks, DFMR would not have the man power and other resources to continually conduct eradication efforts and control numbers on its own. Thus, the protective efforts of banning spearfishing may have an unwanted knock-on effect. In essence, the marine parks will become an interesting study scenario if/when spearfishing is successfully restricted in these areas. It remains to be seen what happens when Lionfish populations are essentially left unchecked, and find out if Caribbean reef ecosystems are resilient to their presence here or not.

## Management Recommendations

- DFMR eradication efforts should now be labeled as a control measure and only continue at ‘hotspots’ (minimum annually), and in response to sightings at selected recreationally important swimming areas and Marine Parks.

- Continue the passive collection of lionfish sighting data from all sources to inform potential future adaptive management measures and aid their implementation.

- Dive operators should continue to be encouraged to remove lionfish from the wrecks and other dive sites.

- Fishers should continue to be encouraged to target lionfish for a growing restaurant driven market demand.

- DFMR/ANT/DOE posters informing the public of the lionfish should be revised, and redistributed as necessary.

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