Habitat Preference in the Invasive Lionfish (*Pterois volitans/miles*) in Discovery Bay, Jamaica: Use of GIS in Management Strategies

Preferencia de Hábitat en Lionfish invasivo (Pterois volitans/miles) en Discovery Bay, Jamaica: Uso de GIS en Estrategias deManejo

Préférence d'Habitat dans le Lionfish Envahissantes (*Pterois volitans/ miles*) à Discovery Bay, Jamaica: Utilisation des GIS dans les Stratégies de Gestion

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ABSTRACT

The invasive Indo-Pacific lionfish (*Pterois volitans* (Bennet, 1828) and *P. miles* (Linnaeus, 1758)) has been a source of concern due to its potential ecological, social, public health and economic impacts in Jamaica as in other Caribbean locations. The ecology of the lionfish, both in its native and introduced range, has been studied to a lesser degree than studies on its distribution and impact but not previously in Jamaica. Increased knowledge of the ecology of this invasive species is an important step to identify and improve management and control strategies. Habitat preference was studied in Discovery Bay, St. Ann, Jamaica in mid-2011 using the habitat characteristics of depth, substrate type, reef profile and reef health at five (5) different sites. Surveys were completed for lionfish and prey abundance as well as photo-transect surveys for reef health. Results showed a preference for deeper, hard-bottom, sloping or wall profiles, (Kruskal-Wallis test, $p = 0.002$, $p = 0.081$, and $p = 0.048$, respectively). Reef health was found to have no significant impact on habitat choice however this may be due to the overall poor condition of the reefs in the area. This study demonstrated how increased knowledge of ecology and GIS technology could be used to improve current management strategies by identifying potential lionfish refuges island-wide, based on habitat preference.

KEY WORDS: Exotic species, Caribbean, lionfish, reef structure, niche allotment, prey abundance

INTRODUCTION

The popularly discussed invasive Indo-Pacific Lionfish, *Pterois volitans* (Bennet, 1828) and *Pterois miles* (Linnaeus, 1758) was first reported in Runaway Bay, Jamaica in March 2008, and has since spread island-wide (Schofield 2009, United States National Lionfish Program). As an invasive species, the lionfish poses a threat to fish stock, biodiversity, coral reef ecosystems, and to society and health, which translate directly into threats to the economy (Mack et al. 2000).

They are prolific breeders, spawning every four days throughout the entire year, releasing an estimated 2 million eggs per year in a free-floating larval stage that is subject to transportation by the circulating oceanic currents (Morris 2009, Synagjeweski and Forman-Orth 2004, Kojis 2009, Freshwater et al. 2009). Their voracious appetite ranges from teleosts in adults to mostly crustaceans in younger specimens, and threatens native populations via direct predation as well as competition (Albins and Hixon 2008, Morris 2009, Synagjeweski and Forman-Orth 2004). Approximately 50 different species have been identified as lionfish prey based on gut content analysis with a number of them being from commercial fish families (Green and Cote in P. Schofield 2009, Whitfield et al. 2002, Morris 2009). Based on studied consumption rates, Cerino (2010) predict that a density of 393 lionfish/ha could remove 2.186 kg of prey per day and Fishelson (1997) suggest that a population of 80 adult lionfish along a 1-km reef could consume over 50,000 prey/year. Albins and Hixon (2008) report a 79% reduction in forage fish recruitment in their 5-week experimental study. Lionfish also have little recorded predators, though groupers, octopi, moray eels and sharks have infrequently been known to consume lionfish, sometimes after introducing lionfish as potential prey (Kojis 2009, Hamner et al. 2007, Maljkovic et al. (2008), Albins and Hixon 2008, Gulf and Caribbean Fisheries Institute, GCFI 2011).

The majority of research on lionfish regionally focuses on the biology, range expansion and feeding behaviour with a few basic studies on the ecology of lionfish – a gap in the knowledge base which needs filling if management strategies are to be applied effectively (Biggs and Olden 2011, Molnar et al. 2008). So far it appears that lionfish occupy most habitats in its introduced range with only a temperature-based limitation identified, however as with most species habitat preferences based on structure or prey availability can exist (Kimball et al. 2004, Biggs and Olden 2011). These habitat preferences can account for the differences in distribution pattern seen both regionally and locally. The islands of Bahamas established an approximate density of 300 lionfish individuals per hectare in the space of seven years (Morris 2009). Jamaica roughly has a population of 100 individuals per hectare in the space of four years. Preliminary results from the National Lionfish Project show that the north coast of the island has more abundance of lionfish than the south coast (Buddo, Personal communication). Research areas falling under this project include island range and distribution studies, gut content analysis, and research into developing lionfish specific traps to increase management strategies which include public education, and an "Eat it to Beat it" campaign promoting consumption of the fish (Buddo, Personal communication).

Since "Factors controlling lionfish in native range" and "Identification of lionfish refuges" are two of the many listed research areas aimed at targeting the lionfish invasion regionally, increasing knowledge on these ecological areas is an important component to justify and improve management plans (Morris et al. 2009, Sealey et al. 2008). The overall aim of this study is to determine the influence of habitat characteristics on the abundance and distribution of lionfish throughout the Discovery Bay area. The results will provide implications for management strategies locally and nationally using the data obtained and Geographical Information Systems (GIS) technology – a predictive environmental tool growing in popularity in conservation fields (ESRI 2011). It was hypothesized that sloping and wall type reef profiles will have higher lionfish densities as this profile allows for better movement during ambush hunting, and that sites providing higher prey abundance will have a greater abundance of lionfish. It was also hypothesized that a healthier reef would support larger prey abundance and thus attract a higher density of lionfish.

MATERIALS AND METHODOLOGY

Study Area

The University of the West Indies (UWI) Discovery Bay Marine Lab, located on the north coast of Jamaica in the Caribbean Sea, is surrounded by rocky shores with protection from high energy waves by a small emergent barrier reef and has presence of mangroves, seagrass beds and coral reefs nearby. The lab is located within close proximity of the town whose main activities involve fishing and bauxite transfer.

Five (5) sites were located within the area based on a combination of the habitat characteristics depth, reef profile, substrate and site health. The first (1st) site, M1 Deep represents a deep sloping reef, composed mostly of coral reef structures and sand. Site 2, M1 Shallow represents a shallow coral reef flat and is the shallow plateau of site M1 Deep. The edges of the third (3rd) site Lagoon have some mangrove and coral cover, and isinterspersed with emergent reef, while sand and seagrass account for the majority of space in between, forming a basin-like profile with presence of a freshwater source. The fourth (4th) site Rio Bueno represents a typical coral reef wall, with a shallower flat closer to shore that falls away at a vertical cut off to deep water (over 50 m). The fifth (5th) and final site, Back Reef, is bordered by an emergent reef and is a mixture of sand, seagrass and interspersed coral heads.

Field Survey Methodology

The use of SCUBA equipment (for sites M1 Shallow, M1 Deep and Rio Bueno) and snorkelling gear (for Lagoon and Back Reef) were involved to perform site surveys between 07:00 am and 01:00 pm during the period June 14 to July 15. The first diver laid down a 30m transect using an attached reel while performing lionfish and prey abundance surveys. A marked T-Bar AGGRA Fish Survey Stick was used to extend the observation belt 0.5 m on either side of the bar, effectively making a 30 x 2 m belt. Lionfish spotted were recorded for location depth, size and behaviour and removed by another diver, while abundance of potential prey (≥ 20 cm or known prey species) was tallied. The 3rd diver responsible for removing lionfish captured roving video footage which was used to supplement prey abundance data. Reef health was assessed by a 2nd diver who laid 1 m^2 quadrats every 3 m along the transect, and who conducted photosurveys with a digital underwater camera. The images were analyzed using CPCe software (Coral Point Count with Excel extensions version 4.0) using 20 randomly assigned identification points. Five to six transects were laid per site. Salinity was measured in the Lagoon site (and Back Reef and Rio Bueno for comparison) using a hand-held refractometer.

Statistical Analysis

Lionfish abundance was assessed using both a categorical 'presence/absence' method (Chi Square test) as well as numerical method using Kruskal-Wallis test (K Independent samples). Density was calculated using the total amount of lionfish found at the site divided by the area surveyed. Mean (± S.D.) length (cm) of lionfish recorded at each site was also calculated using Kruskal-Wallis test. Lionfish densities were calculated for each site. Each habitat characteristic (depth, profile, substrate, health) was assessed for significance using a Kruskal-Wallis test to infer habitat preference (See Table 1). Linear regressions were also run to test correlation between depth and lionfish abundance and length. The CPCe software performed descriptive statistical analysis of reef characteristics which were then used to determine reef health. Prey abundances for each transect were summed and the mean (± S.D.) determined and compared using a Kruskal-Wallis test to analyze if lionfish habitat preference is affected by prey abundance.

GIS Methodology

GIS analysis was performed using ESRI® ArcGIS version 9.3 and datasets were altered to suit data obtained in this study. All reefs island-wide were ranked for lionfish preference according to the results of the study, and the top choice of reef types highlighted. These reefs were considered to be hard bottom surfaces and were analysed for any that adjoined soft bottom areas (nursery areas of seagrass and mangroves). These reefs were considered to be lionfish refuges, with the primary refuges being on the north coast and the secondary on the south coast.

RESULTS

The Lagoon site's salinity was 32 ‰, whereas Back Reef and Rio Bueno were 34 ‰ each. A total of 1,740 m^2 was surveyed for the presence of lionfish at sites M1 Deep (300 m^2), and M1 Shallow, Lagoon, Rio Bueno and Back

Table 1. Classification of habitat characteristics

Habitat Characteristic		Classification Description
Depth	Deep	Over 13 m
	Shallow	13 m and under
Reef profile	Slope	Aggregate reef structures with a definitive shallow end that gradually inclines toward a deeper end (M1 Deep)
	Reef flat	Aggregate reef structures together with a plateau profile (M1 Shallow)
	Basin	Shallow area surrounded by small reef banks on majority of sides, with sand and seagrass in the middle (Lagoon)
	Vertical wall	Aggregate reef structures with a vertical drop and significant change in depth (Rio Bueno)
Substrate	Patch Reef	Isolated coral mounds surrounded by sand and seagrass (Back Reef)
	Soft bottom	Predominantly sand, seagrass or mangrove
	Hard bottom	Predominantly coral or rock based
Reef health*	Degraded	< 15% live coral cover; > 50% macroalgal cover
	Recovered	15 - 20% live coral cover; > 50% macroalgal cover
	Not degraded	> 20% live coral cover; < 50% macroalgal cover

Reef (360 m^2 each). Lionfish were found at M1 Deep (n = 4), Lagoon (n = 1) and Rio Bueno (n = 7) amounting to a total of 12 lionfish over the entire study area. A total of 41% of the transects were observed to have lionfish present on them, while 59% of the transects had no lionfish (See Figure 1). Estimates for lionfish densities were calculated for M1 Deep (13 lionfish/km^2), for Lagoon (3 lionfish/$km^{2)}$ and for Rio Bueno (19 lionfish/km^2).

Significant difference was found in the number of lionfish present at each of the five study sites using a Chi Square test (X^2 = 26.61, $p < 0.05$) (See Figure 2). Of all transects in the study that were observed to have lionfish (43% of all transects done), the deep wall site, Rio Bueno had the most (53.8%) transects with lionfish, and the seagrass and mangrove Lagoon (7.7%) had the least. The deep sloping reef, M1 Deep had 38.5% of the transects with lionfish. The remaining 57% of the transects that had no lionfish recorded were divided up between the shallow flat, M1 Shallow, the sea grass and mangrove Lagoon and the patch reef Back Reef (35.3%, 29.4% and 35.3%, respectively) (Figure 2).

A significant difference (Kruskal Wallis test, $p < 0.05$) was found between the mean length of lionfish found at all five study sites (Figure 3). The mean length of lionfish found at the deep slope, M1 Deep was the largest (23 ± 2.45 cm), while the deep wall, Rio Bueno had a mean size fish of 19 ± 2.58 cm. The length of the lionfish found in the seagrass and mangrove Lagoon was 5 cm. The length of lionfishes recorded were found to be significantly higher (Kruskal Wallis test, $p < 0.05$) at Rio Bueno and M1 Deep than at the remaining three sites – Lagoon, M1 Shallow and Back Reef, although the variation at M1 Deep was higher than at Rio Bueno (Figure 3). 20 ± 1.46 cm was the

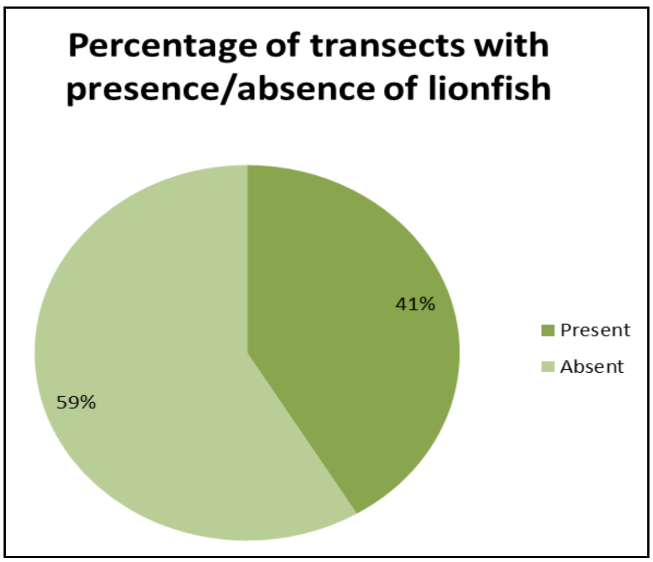

Figure 1. The lionfish surveys consisted of a total of 29 transects over five sites, covering 1,740 m^2. The majority of the transects surveyed had no lionfish (59%) while lionfish were observed on the remaining 41%.

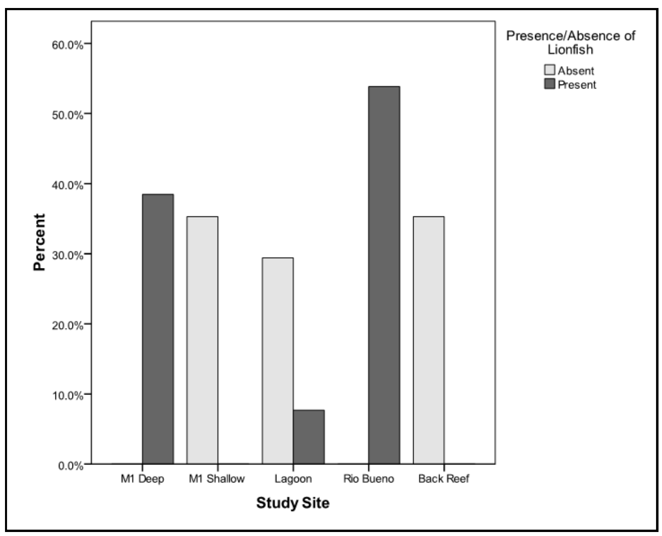

Figure 2. Distribution of Lionfish at various study sites. A total of 53.8% transects with lionfish were at the deep wall Rio Bueno, 38.5% at the deep slope, M1 Deep and 7.7% at seagrass and mangrove Lagoon (a total of 43% of all the transects done). Of all the transects without lionfish, 35.3% at the shallow flat, M1 Shallow and the patch reef Back Reef and 29.4% at the seagrass and mangrove Lagoon (a total of 57% of all the transects done).

most commonly found size of lionfish found at Rio Bueno, while 23.5 ± 1.46 cm was the most commonly found sized fish at M1 Deep. The largest lionfish recorded was 25 ± 1.46 cm at M1 Deep and the smallest was 5 ± 1.46 cm at the Lagoon.

A total of 33 species (in 17 families) of prey fish (including potential prey and reported prey) were identified in the study area. M1 Deep recorded the highest prey abundances with over 347 individuals while M1 Shallow and the Back Reef both recorded the lowest abundances of 166. The mean abundance in the Lagoon fell in between the previous two sites with 138 individuals recorded.

With regard to mean abundance, 69 ± 15.18 prey were found per study transect (60 m^2) at M1 Deep 28 ± 14.95 at M1 Shallow 23 ± 8.47 at Lagoon, 36 ± 5.95 at Rio Bueno and 26±7.97 at the Back Reef. The abundance of prey at M1 Deep was significantly higher than the rest of the sites (Kruskal-Wallis, $p < 0.05$). The other four sites showed no significant difference between their prey abundances (Figure 4).

Habitat Characteristic Preferences

A total of 35% of the transects studied were classified as deep (> 13 m) with the remaining 65% done at shallow site (< 13 m). 75% of the lionfish recorded were at deep sites, which was significantly higher than those recorded at shallow sites (Kruskal-Wallis test, $p = 0.05$) (Figure 5). Linear regression analysis showed a positive correlation between depth and number of lionfish with an R^2 value of 0.842 (Figure 6). The maximum depth of recorded lionfish in this study was 20 m (n = 5), and the shallowest depth 2 m (n = 1). The mean depth for lionfish sightings was 16 ± 5.29 m. Linear regression analysis also showed an even more positive correlation between depth and length of lionfish with an R^2 value of 0.932 (Figure 7).

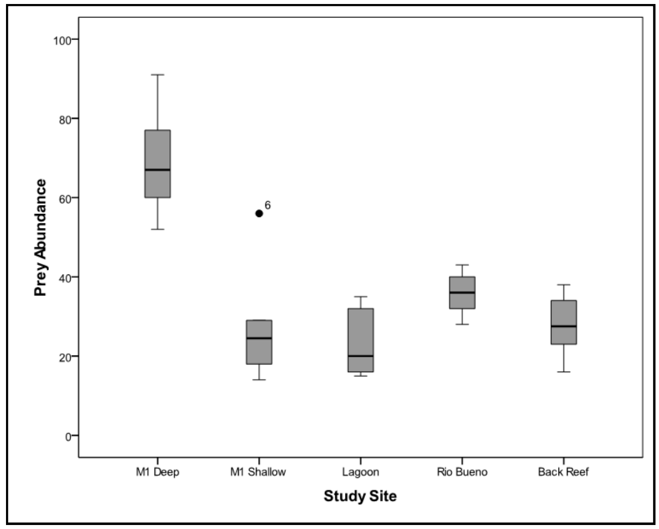

Figure 4. The deep sloping reef - M1 Deep – had significantly higher prey abundance than M1 Shallow, Lagoon, Rio Bueno and the Back Reef, with total abundances of 347, 166, 138, 215, and 166, respectively. Regarding mean abundance, 69,±,15.18 prey were found per study transect (60,m^2) at M1 Deep 28,±,14.95 at M1 Shallow 23,±,8.47 at Lagoon, 36,±,5.95 at Rio Bueno and 26,±,7.97 at the Back Reef.

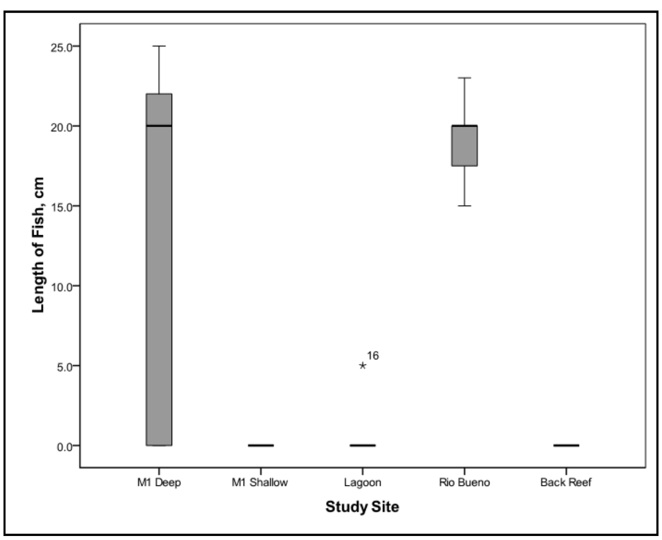

Figure 3. Significant difference was found between the lengths of the lionfish caught at the five sites (Kruskal-Wallis test, $p < 0.05$). M1 Deep had the largest mean size of fish (23 ± 2.45 cm), Rio Bueno had the second largest (19 ± 2.58 cm), and the size of the fish caught in the Lagoon was 5 cm.

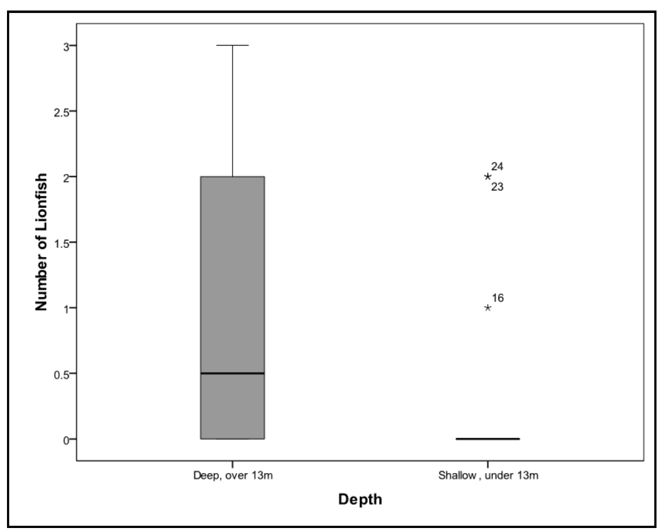

Figure 5. Lionfish were found to be more abundant at deep depths (over 13 m) than shallow depths, with a mean depth of 16 ± 5.29 m.

Of the lionfish recorded, 33.3% were found on a sloping profile (M1 Deep), and 58.3% were found on a wall profile (Rio Bueno). 8.3% were found in the seagrass and mangrove basin (Lagoon), while none were found on the shallow flats, or the patch reefs (M1 Shallow and Back Reef respectively). The abundance of lionfish at the wall and sloping reef profile were significantly higher than all other profiles (Kruskal-Wallis test, $p < 0.05$) (See Figure 8).

The wall and sloping reef profile had significantly higher abundance of lionfish than the other profiles (Kruskal-Wallis, $p < 0.05$) (Figure 8), as well as higher presence of lionfish out of all the transects completed ($X^2 = 26.61$, $p < 0.05$), with 23.3% of the transects containing lionfish found on the wall 16.67% on the reef slope and 3.3% in the basin (Figure 9).

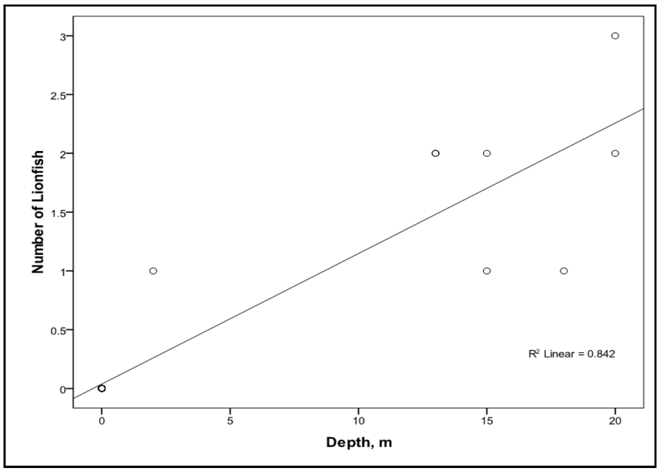

Figure 6. Regression analysis showing a positive correlation between depth and number of lionfish with an R^2 value of 0.842. The maximum depth of recorded lionfish in this study was 20 m (n = 5), and the shallowest depth 2 m (n = 1). The mean depth for lionfish sightings was 16 ± 5.29 m.

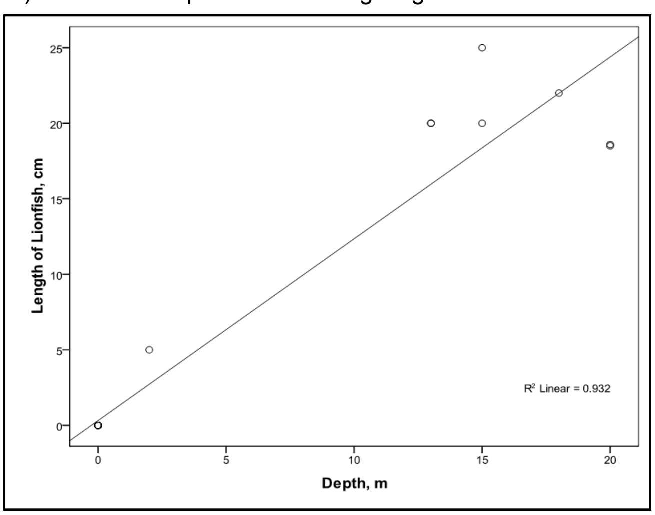

Figure 7. Linear regression analysis showing a positive correlation between length of lionfish (cm) and depth lionfish (m) was recorded ($R^2 = 0.932$).

No significant difference was found at the p = 0.05 level - for lionfish preference of substrate, however significant difference was found at the $\alpha = 0.10$ level (Kruskal-Wallis test), with a higher abundance of lionfish being found on hard bottom substrates than soft bottom substrates. A significant difference was also found to exist using a Chi Sq test between the presence/absence of lionfish on each transect and the type of substrate, with significantly more lionfish being found on hard bottom surfaces than on soft bottom surfaces (Chi Square test, $p <$

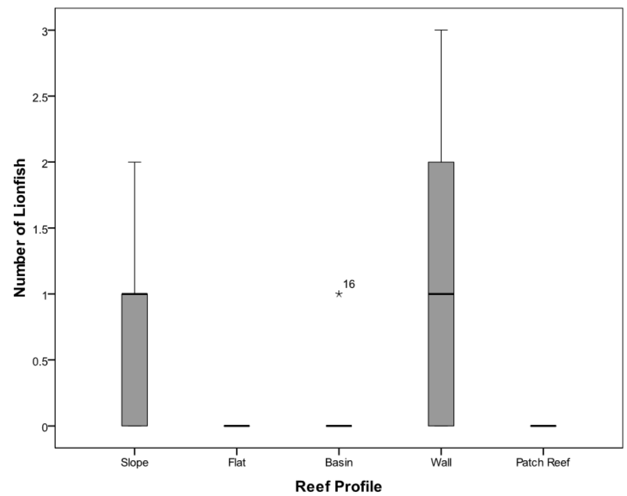

Figure 8. Reef profiles of the vertical wall (Site Rio Bueno) and the sloping reef (Site M1 Deep) had significantly higher presence of lionfish than the flat, basin and patch reef profiles (M1 Shallow, Lagoon and Back Reef, respectively) ($p < 0.05$).

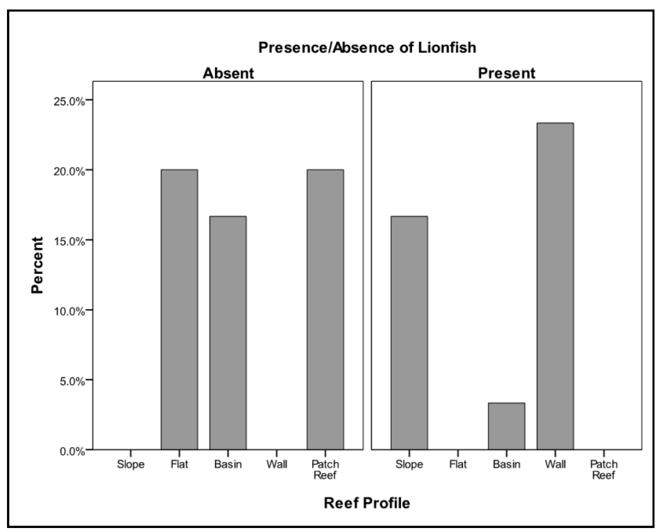

Figure 9. The wall and sloping reef profile had significantly higher presence of lionfish out of all the transects completed than the other profiles ($X^2 = 26.61$, $p < 0.05$), with 23.3% of the transects containing lionfish found on the wall 16.67% on the reef slope and 3.3% in the basin.

0.05). Lionfish were found on 8.3% of soft bottom surfaces studied, while 66.7% on hard bottom surfaces studied (Figure 10).

Live coral cover was found to be highest at Rio Bueno (26.28%), followed by M1 Shallow (11.7%), M1 Deep (3.39%), Back Reef (2.58%), and then Lagoon (0.15%). Dead coral accounted for 7.16% of Rio Bueno 20.61% of M1 Shallow 1.85% of M1 Deep, 3.26% of Back Reef and 1.71% of Lagoon. Macro-algae accounted for 59.35% of Rio Bueno, 41.76% of M1 Shallow, 85.67% of M1 Deep, 38.74% of Back Reef and 52.93% of Lagoon (Figure 11). No correlation existed between any of these habitat characteristics and the amount of lionfish recorded in each transect (Linear regression, $R^2 < 0.5$). There was no significant correlation between the amount of live coral and algae on a reef and the amount of prey recorded (Linear regression, $R^2 < 0.5$).

55.17% of the transects studied were found to be degraded 24.14% were designated as semi-degraded and the remaining 17.24% were designated as past the degraded status. Although 83% of the lionfish recorded were found on degraded reefs, this was not found to be significantly different (Kruskal-Wallis Test, $\alpha = 0.05$).

Back Reef exhibited the highest biodiversity index (Shannon-Weaver) of 1.23, followed by M1 Shallow (1.15), Rio Bueno (1), Lagoon (0.98) and then M1 Deep (0.58). No correlation was found between biodiversity and presence of lionfish (Linear regression, $R^2 < 0.5$).

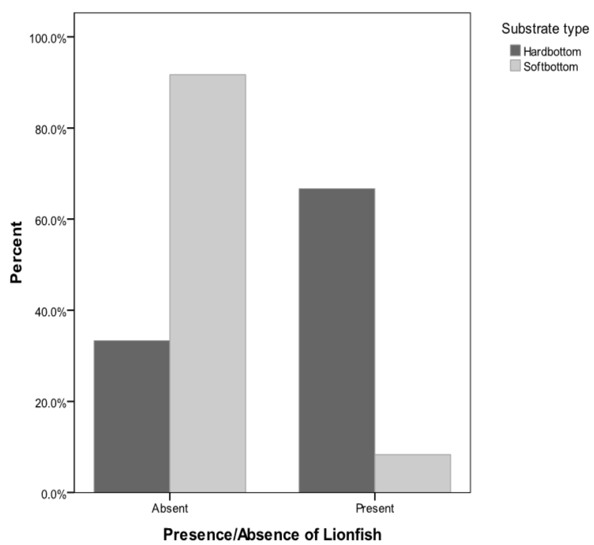

Figure 10. This shows that lionfish were more abundant on transects over hard bottom substrates than soft bottom ones ($X^2 = 9.98$, $p < 0.05$; Kruskal-Wallis test, $p < 0.10$). Lionfish were found on 8.3% of soft bottom surfaces studied, but 66.7% were found on hard bottom surfaces.

DISCUSSION

Shelter, food and mate availability, competition and predation tend to drive niche allotment in ecosystems including coral reefs (Hixon and Jones 2005). In studies by Darling et al. 2009, lionfish (*Pterois volitans/miles*) were at a lower density in their native range than their introduced one, suggesting a limiting factor or factors that are absent in their introduced range (Green and Cote 2009, Grubich et al. 2009). The native range, however, is home to five species of lionfish versus two species in the introduced range. In the introduced range, *P. volitans/miles* are released from the constraints of resource partitioning and are free to expand into niches, a situation also seen with the introduced species the peacock grouper, *Cephalopholis argus*, in its new Hawaiian range (Morris et al. 2009). This similarity supports the theory that lionfish occupy a top predator niche in an ecosystem similar to groupers (Family: Serranidae).

Due to lack of predators, lionfish distribution in the native range could be limited by competition between individuals (of all five species); however Darling et al. (2011) suggest that the difference in densities is simply a result of the population not reaching its maximum as yet. Another difference seen between ranges is that although lionfish make up a significant proportion of the fish biomass in the introduced range, this is not the case in the native range, possibly accounting for its lack of discussion as an ecological concern until its invasion (Darling et al. 2011, Schofield 2009).

Opportunistic invasive species tend to flourish in new environments (due to constraint release) and in altered habitats; in comparison of impacts between the native and introduced range of lionfish, heavily stressed areas are observed to have more negative and a greater magnitude of impacts (Morris et al. 2009, Ruiz et al. 1997). For instance, Smith (2006) report lionfish presence in seagrass, but primarily on artificial structures. Synergistic effects with other stressors such as global warming, habitat destruction and degradation, and depleting fish stock are likely to also affect a species' invasion (Morris et al. 2009, Darling et al. 2011, Molnar et al. 2011).

No reefs in this study were found to be 'healthy' though a few sections were considered 'recovering' according to Reef Check standards (Reef Check 2011); an observation typical of degraded Caribbean Reefs (Hughes 1994). Although no studies were found directly assessing the effects of reef health on lionfish abundance, comparisons can be made using characteristics of healthy reefs such as high coral cover (Reef Check 2011). Studies by Biggs and Olden (2011) show that lionfish abundance was higher in areas with high coral cover, which directly contrast the results of the present study showing little influence of live coral on lionfish abundance. Possible explanations for this incongruity include such low coral cover in Discovery Bay as to make it insignificant in lionfish habitat preference, or the overriding influence of

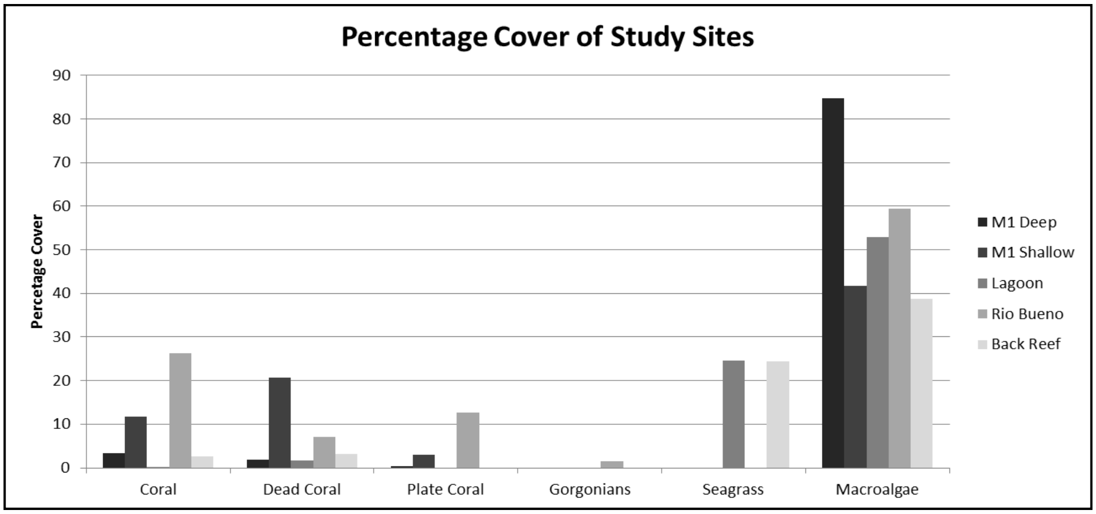

Figure 11. Mean percentage reef substrate or bottom cover types found at each site. Percentage cover at M1 Deep sites where lionfish abundance was highest, for mean coral cover, dead coral, plate coral, gorgonians, seagrass and macro-algae were, 39 ± 2.6%, 1.85 ± 1.39%, 0.3 ± 0.67%, 0%, 0%, and 84.67 ± 5.0%, respectively.

physical characteristics of the reef base – profile, crevices, hiding places – rather than reef health. Macro-algal dominance isalso used as an indicator for poor reef health. Studies by Eggleston (1995) on groupers, - which share similar ecological behaviours as lionfish, - showed a preference for macro-algal beds during juvenile stages. Although it is possible that the lionfish exhibit a similar preference, observations in this particular study do not support this theory.

If prey abundance plays a role in lionfish habitat preference then so would habitat characteristics since these characteristics, such as substrate which provide shelter and food, shape the abundance and distribution of fish and crustaceans (Friedlander and Parrish 1997, Gardiner and Jones 2005). The shift from nursery to coral reefs often occurs with maturity, resulting in higher fish diversity, biomass and density in reef rich areas than soft bottom ones, however there was no significant difference between lionfish prey availability between soft- and hard-bottom substrates in this study, and even less so when considering the presence of invertebrates in soft bottom habitats which were not measured (Eggleston 1995, Beets et al. 2010, Friedlander and Parrish 1997). Loss of crustaceans, a known prey for especially younger lionfish, which are harder to measure for impact, are affected by lionfish not only by direct predation, but also cause a competition for other fish species that rely on invertebrates for food (Albins and Hixon 2008, Fishelson 1997, Morris and Akins 2009, McCleery 2011); most of which, possibly including lionfish are found in soft bottom habitats such as mangroves and seagrass (Nagelkerken et al. 2002, Parrish 1989, Buddo Unpublished manuscript). Studies on feeding behaviour and ecology of lionfish in the evening or night may show previous data on abundance and predation rates to be skewed since crustaceans and larval fish which are the prey for lionfish, especially juvenile, are more active in the evening hours.

According to studies by Friedlander and Parrish (1997) on distribution of fish species across reef types, reef profiles of M1 Shallow and Back Reef are sites that should be favoured the most by species known as lionfish prey and thus attract more lionfish. However these sites were the only two in the present study that did not have any present. It should be noted in this comparison across studies however, that Friedlander and Parrish (1997) did not include species abundance in their study. Small sample sizes and restrictions such as omission of any fish over 20cm as 'prey' in this present study affect prey abundance - especially at Rio Bueno which had a considerable amount of prey species that could not be considered due to size.

Although a complex 3-D habitat is usually associated with high biomass, density and diversity of fish due to the presence of shelter, lionfish who have few predators and an effective defence system need not base habitat preference on this (Beets et al. 2010, Willis and Anderson 2003, Friedlander and Parrish 2007, Harter et al. 2008). Yet, their abundance often increases with habitat complexity – an observation seen in this present study though not measured – and a definite preference for overhangs has been noted by many authors (Harter and Ribera 2008, Morris et al. 2009, Mumby et al. 2011). This trend can be explained by either the increased prey availability associated with complex habitats or by the lionfish's ambush method of hunting. These patterns, including a positive correlation between depth and size were observed in studies on habitat partitioning based on feeding strategy of groupers by Gibran (2007). Results obtained in this study, showing increased lionfish abundance at deeper sites near reef edges, supported Friedlander & Parrish's (1997) findings that depth and distance to reef edge are important determining factors for fish distribution (not specific to lionfish, but relates to prey availability), and contradicted Johnston and Purkiss (2011) who concluded that depth had no significant influence on the distribution of lionfish.

Auster (2005) showed that morphology and landscape affect feeding behaviours of predators. Habitats that provide more horizontal than vertical shelters and over-hangs would be more ideal for a fish with the lionfish's hunting style and morphology (suitable for hovering with rapid bursts of speed and not for intricate manouvering through vertical spaces) (Gibran 2007, Sfakiotakis et al. 1999, Humann and Deloach 2003). The results of this present study supported this hypothesis, as lionfish were found on sites that provided horizontal movement and shelters (such as sloping reef M1 Deep and vertical wall, Rio Bueno). The results of Claydon et al. (2008) showing lionfish inhabiting "blow out" ledges of sea grass beds may also support this hypothesis.

This might also be a plausible explanation for the preliminary observations of the National Lionfish Management Plan showing higher abundances of lionfish on the northern coast than the southern coast of Jamaica. The bathymetry of Jamaica's north coast is much steeper (higher probability of providing wall type profiles) that the shallow gentle slope of the south coast. There is a possibility that the offshore drop off on the south coast may have comparable lionfish densities, but this is unproven at the present time, and should be included in future studies.

A number of studies observed higher lionfish abundance on coral reef habitats than other soft bottom areas (Barbour et al. 2010, in Biggs and Olden 2011, Personal observation, Biggs and Olden 2011, Morris and Akins 2009, Schofield 2009, Claydon et al. 2008). Biggs and Olden (2011) conducted habitat preference studies in lionfish in Honduras, using both field studies and lionfish reporting. Results, similar to this present study, showed a higher abundance on aggregate reefs over patch reefs and sea grass habitats. Biggs and Olden (2011), Smith (2006) and Eggleston (1995) (studies on grouper) showed higher abundance for patch reefs over seagrass beds, a result not observed in this present study. Studies by Biggs and Olden (2011) included reports from recreational divers in order to increase the sample size. Although a database is presently being developed for Jamaica, data on macro habitat rather than micro habitat is its present focus and should be altered to include as much ecological data as possible.

Biggs and Olden (2011), Barbour et al. (2010), and Weis and Weis (2005) and Claydon et al. (2008) report a higher abundance of lionfish in soft bottom areas than in this study. This difference might be accounted for by lower salinity – causing osmotic stress - or by the lack of suitable micro-habitats such as seagrass blow out ledges in the Lagoon site. All studies above however, support the results of this study showing a significant increase in lionfish abundance from nurseries to deeper reef habitats.

Lionfish presence in mangroves have been observed and studied by Barbour et al. (2008) and reported by Morris and Akins (2009), Claydon et al. (2008) and Schofield (2009), though none were found in this study. Lionfish found in seagrass communities by Smith (2006) was limited to an artificial structure made from concrete blocks reef grid, similar to observations by Johnson and Purkiss (2008). No significant artificial structures were studied in the present study, and should and Albins and Hixon (2008) be included in future studies.

A small degree of error is expected in comparisons of lionfish abundance around the region, with respect to habitat preference, due to different categorizations and lack of focus on habitat. Green and Cote (2009) and Fishelson (1997) reported only presence of lionfish on coral reefs, while Morris and Whitfield (2009) and Whitfield et al. (2009) included lionfish abundances on artificial structures and rocky surfaces. Knowledge of microhabitat structure can be used to develop a lionfish targeted artificial reef or trap, that can be used to focus hunting methods.

Management strategies are mainly composed of active hunting (for human consumption or otherwise) though bio-control using parasites or aquaculture to replenish stocks of potential predators like grouper have been suggested with varying degrees of scepticism, especially in Jamaica where predators such as groupers are constantly overfished (Poole 2011, Mumby et al. 2011). Additionally hunting (using a spear gun), may not be an effective control measure as one study by White (2011) indicated no difference between hunted and non-hunted areas in Bonaire, while Barbour et al. (2011) predicted that even with 35 - 65% removal of lionfish populations annually, 90% of the original population would recover after six years (in a 50-year model). Increasing knowledge of the ecology of lionfish, as in this study with habitat preference include the identification of lionfish refuges to target hunting efforts, and design of an ideal lionfish micro-habitat for trap purposes. Traps can either capture lionfish or provide an area that lionfish will inhabit to make hunting more efficient (although this runs the risk of aiding population rather than depleting if not properly managed). Due to the frequency and availability of dives, the presence of trained lionfish hunters as well as a desire to catch specimens for the National Lionfish Programme, the population of lionfish at the sites around Discovery Bay may not truly represent populations as they are constantly fished. Habitat studies should also be conducted on areas not known to be heavily fished for lionfish – at perhaps some of the identified refuges for comparison. These studies can be combined to also assess the effectiveness of constant lionfish removal by spear fishing at Discovery Bay versus another location.

For the GIS analysis in this study, reefs in close proximity to nursery areas were given priority due to the role of nurseries in prey species, while reefs in close proximity to freshwater sources were eliminated. The final identified refuges – using results from this study of a preference for hard bottom habitats, sloping reef and wall profiles - can be used to target lionfish hunting in order to increase the effectiveness of management efforts (Figure 12). Reef health though not found to be significant in this study should be included in future studies in areas known to have healthy reefs. Although there is a definite preference for north coast reefs this can be due to the bathymetry of the area or the fact that more coral reefs are found on the north coast. Obtaining more detailed and accurate datasets for GIS analysis, and new technologies such as satellite imagery would go a long way to make the results of the analysis accurate.

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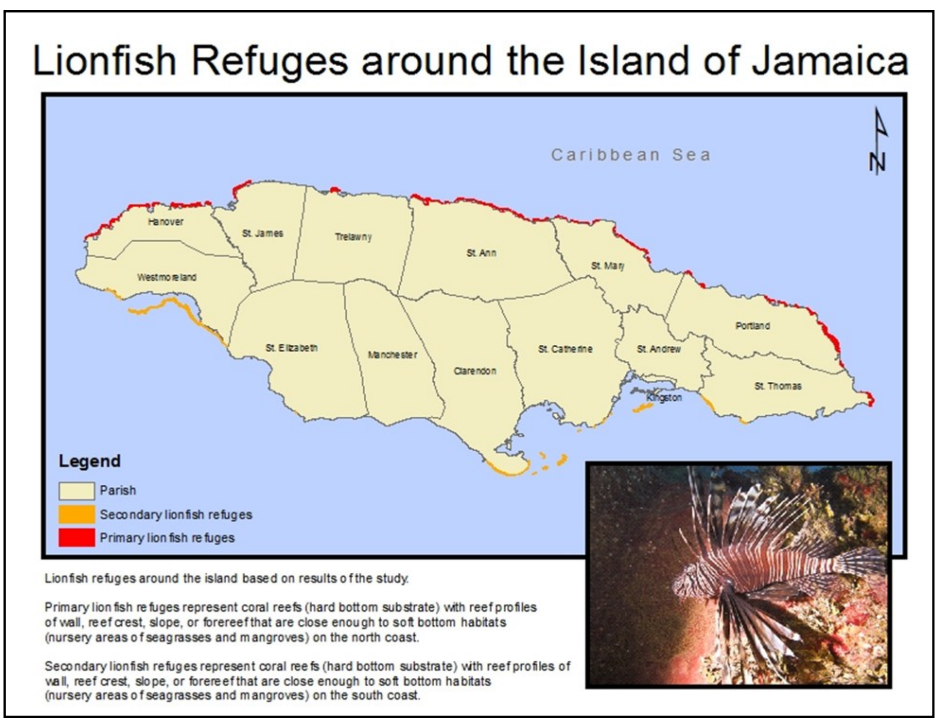

Figure 12. Map showing lionfish refuges around the island of Jamaica.

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