Controlling Lionfish:
Survey Data and a Preliminary "Sustainable" Fishery Model for Aruba

El Control de Pez Leon:
Datos de la Encuestayun Modelo Preliminar de la Pesqueria "Sustentable" para Aruba

Controle Lionfish:
Les Donnees de L'enquete et un Modele Preliminaire "Durable" de la Peche pour Aruba

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ABSTRACT

Introduced in the 1980s, Indo-Pacific Lionfish (*Pterois volitans* and *P. miles*) are the first established marine invasive fish species off the Atlantic Coast, Caribbean, and Gulf of Mexico. In 2010, lionfish were ranked among the top fifteen greatest threats to global biodiversity, capable of removing over 90% of native reef fishes. Once established, an invasive marine species is nearly impossible to eradicate; however, we can aim to suppress the population through organized control efforts. Here we present results from preliminary pilot-surveys from stakeholder groups influential in developing a lionfish fishery in Aruba. In 2014, individuals (n = 117) were surveyed about their awareness of lionfish and willingness to utilize it as a food resource. In addition, 734 lionfish were removed to obtain length-weight relationships – the first to be reported for the island. Our preliminary approach uses results from pilot-surveys to determine the interest and feasibility of creating a lionfish fishery, while we use catch-per-unit-effort estimates to determine if commercial divers can contribute to a viable seafood market. Fifty-six percent of government officials viewed lionfish positively providing they can be utilized as a food resource. Eighty percent of individuals surveyed (locals and tourists) were willing to eat lionfish, with 61% of them never having tried it. Sixty-two percent of fishermen were willing to participate in a lionfish fishery. Preliminary survey results suggest Aruba is willing to support dedicated lionfish removal teams. We acknowledge that creating a lionfish fishery is beyond traditional fisheries management goals; however, employing a long-term, ecologically and economically sustainable removal effort will be necessary to effectively combat lionfish in their invaded region.

KEYWORDS**:** Lionfish, Aruba, surveys, sustainable fishery

INTRODUCTION

Biological invasions occur when an organism is introduced into a new range where the population proliferates, expands, and persists (Mack et al. 2000). These invasions can dramatically alter the balance of natural habitats through replacement of community keystone species, and by altering the environment physical features, nutrient cycles, and productivity (Mack et al. 2000, Molnar et al. 2008, Betancur-R et al. 2011). No marine fish invasion has proliferated as greatly as the Indo-Pacific lionfish (*Pterois volitans* and *P. miles*); the two species have overlapping morphological characteristics and therefore, require genetic analyses to differentiate (Hamner et al. 2007). Because of this, the two species will be collectively referred to as lionfish for the entirety of this study. First sighted off the coast of Florida in the 1980s, lionfish have become the first established non-indigenous marine fish species along the Atlantic Coast, Gulf of Mexico and Caribbean Sea (Morris & Akins 2009). Introduced through the aquarium trade (Morris and Whitfield 2009), their high fecundity rate, recurrent dispersal capabilities (Schofield 2009, Betancur-R et al. 2011), lack of local predators (Hackerott et al. 2013), and replacement as a mesopredator (Cote et al. 2013) have contributed to their successful expansion.

Lionfish are reported to remove up to 94% of small native reef fish, a rate nearly triple that of local predatory fish (Albins 2013). Because of this, in 2010 they were ranked as one of the top fifteen greatest global threats to biological diversity (Sutherland et al. 2010). Once established, a non-native marine fish is nearly impossible to eradicate (Mack et al. 2000, Thresher and Kuris 2004, Molnar et al. 2008); thus, effective management strategies for suppressing lionfish populations are needed in order to successfully combat the invasion (Cote and Maljkovic 2010, Green et al. 2012). Various methods to control their numbers have been proposed on an ad-hoc basis including: lionfish culling, incidental bycatch, state and federal bounties, biologic control, and human consumption (Morris 2012). Utilizing human consumption for reduction of invasive species populations offers the potential to create a sustainable resource out of an otherwise destructive organism (Gherardi et al. 2011, Nunez et al. 2012, Varble and Secchi 2013). For this study we posed the question: can the deleterious impacts of the lionfish invasion be reversed by developing a positive, economically and ecologically "sustainable" fishery? Here we present the first study of lionfish in Aruba that analyzes 1) results from preliminary pilot-consumer preference and awareness surveys in order to identify important stakeholders and evaluate the response of creating a commercial lionfish fishery; and 2) utilizes information collected during the November 2014 lionfish tournament to determine a virtual catch per unit effort (CPUE) for divers, as well as, present biologic data (length-weight relationships).

Aruba is a small southern Caribbean island nation (Figure 1) approximately 180 km^2 with a population of 104,000 (World Bank 2016). We chose Aruba for our study because:

i) There is no existing literature on lionfish in Aruba,
ii) It represents one of the last and southern-most Caribbean nations to be impacted by the invasion (USGS 2016), and
iii) There is no current regulation or management plan in place for dealing with lionfish establishment.

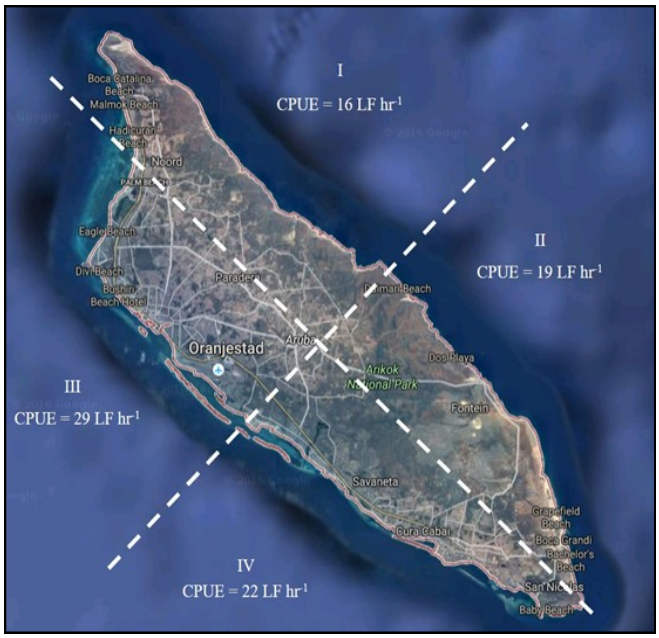

Figure 1. *Map of Aruba with regional division for 2014 Lionfish tournament.* The map has dashed lines that indicate where the island was divided during the 2014 lionfish tournament. Each Roman numeral (I – IV) indicates a regional number that was required when diver teams submitted their lionfish at the tournament. This was used to determine where hunters most prevalently visited and the total number of lionfish removed from each region. We calculated a catch per unit effort (CPUE) for each region from the diver team removals.

Lionfish were predicted to have reached the southernmost Caribbean by 2009 (Schofield 2009), affording nearly five years of invasion prior to our study. In Aruba, lionfish are opportunistically removed by local divers and researchers; however, there were no systematic control efforts prior to 2014 (this study). In 2014, we hosted the first lionfish tournament and conducted the first pilot-surveys to identify potential stakeholders for a lionfish fishery, to assess participant's awareness of the lionfish issue, and their willingness to contribute to an established fishery. Since the initial organized tournament in 2014, Aruba annually hosts this event in November.

When determining the market potential for a new fish species, it is important to survey several factors simultaneously to determine awareness of the health benefits or potential harm associated with fish consumption, psychological aversion to new products, potential effects to local fish population abundances, and willingness of governmental support (Pliner and Pelchat 1991, Varble and Secchi 2013). These variables may be shared among stakeholders, or identified as a sole responsibility under individual stakeholder groups, therefore, we conducted pilot-surveys among six different groups of individuals that we determined would be influential in the development of a lionfish fishery in Aruba.

METHODS

The sample framework for this project was identified as stakeholder groups in Aruba that are currently being affected by lionfish and/or are likely to be impacted and, therefore, have a vested interest in the establishment of a fishery. We conducted a series of oral-surveys (n = 117) with fishermen (n = 21), divers (n = 16), restaurant owners (n = 8), government officials (n = 13), locals (n = 36), and tourists (n = 23) in Aruba during June – August 2014. Each participant was identified to one of these groups by the following definitions:

i) Fishermen – any person whom captures and sells fish recreationally or commercially,
ii) Divers – dive shop owners and employees of dive shops whose livelihood relied upon this profession,
iii) Restaurant owners – any person whom owned or managed a local restaurant; government official – any person who worked for the government,
iv) Local – any person who were not included in one of the previous groups but lived in Aruba, and
v) Tourists – any non-native person visiting Aruba.

Individuals were sampled during different times of the day in varied locations over the course of the sample period to eliminate any time bias during sampling. Surveying occurred during low tourist season (Hudman and Jackson 2003); however, locations that tourists frequently visited were surveyed in order to generate the targeted number of responses. A variety of resorts around the island were visited periodically during the survey period targeting varying economic strata so as to eliminate monetary bias. During the survey period there was one rater and interview script, which was read to each participant. All individuals within each group were asked the same questions in the same order. On rare occasions, if translation was needed, co-author Boekhoudt read the questions directly from the survey to the individual participants (e.g. local fishermen). These surveys received pre-approval by Texas A&M University's Internal Review Board for Human Subjects Research and all of those surveyed provided informed consent to participate.

There were six individual surveys (i.e. fishermen, divers, restaurant owners, government officials, locals, and tourists) that ranged in the number of questions from nine to thirteen with the median being twelve. Surveys were unique to each group of individuals, as their knowledge, experience, and contribution to creating a lionfish fishery varied. Each were asked a series of questions to identify their familiarity and perceptions of the invasive species, as well as, their willingness to eat lionfish. All participants were shown a photograph of a lionfish and prompted whether they had seen the fish before, if they could identify the fish by name, and where they had exposure – we did this to avoid bias results towards project goals. The number of participants for each group varied dependent on the available pool to survey (Figure 2), with the largest number of surveys completed by locals and tourists.

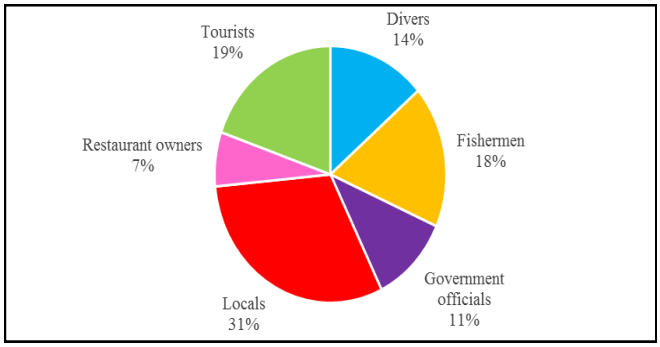

Figure 2. *Percentage of surveyed individuals in each of the participant categories.* The total number of individuals surveyed (n = 117) is divided among six identified stakeholder groups: fishermen (n = 21), divers (n = 16), restaurant owners (n = 8), government officials (n = 13), locals (n = 36), and tourists (n = 23), shown as percentages of the total in the figure. The largest numbers represented in our stakeholder groups were locals and tourists as they had a larger pool of individuals to survey.

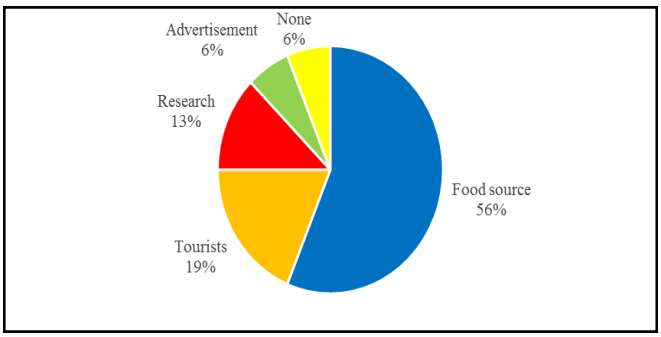

Figure 3. *Percentage of government official responses to prompted question on benefits lionfish may bring to Aruba.* These were responses from open-ended questions regarding potential benefits of lionfish in Aruba. More than half of the government officials (n = 13) interviewed considered using lionfish as a food source to be a beneficial solution for Aruba.

Government officials were an important survey entity as they would be the ones to create and mandate any regulations for the fishery, manage the health of the ecosystem and fishery, and work collaboratively with scientists to determine the most effective strategies. Officials' questions differed in that they were open-ended, so as to not bias their answers towards project goals. These individuals were questioned on their familiarity with lionfish, current concerns (if any), current regulations (if any), and perceptions on how lionfish can be used to benefit Aruba (if applicable) (Figure 3). Locals were surveyed in businesses along the coastline and inland to account for potential differences in exposure to the marine environment. Three locals identified that they did not participate in marine activities, with a single individual who did not recognize lionfish.

We hosted the first lionfish tournament collaboratively with the Department of Agriculture, Husbandry and Fisheries Aruba in November 2014 to assess basic lionfish biologic data and participation of local divers in an organized lionfish removal effort. Divers were required to provide information including: the number of divers on each team, the total time spent removing lionfish, depth from which lionfish were removed and the region (Figure 1) in which they hunted. We used this information to calculate a virtual catch per unit effort (CPUE) for each team. The summary of tournament results are provided in Table 1**.** The total number of lionfish removed (n = 532) were counted for each team, as well as, total tail-length and weight data (Figure 4) for basic biological information. Additional lionfish (n = 206) were collected during field studies in summer 2014, thus, the total number of lionfish removed during 2014 (n = 738) are reported in Figure 4.

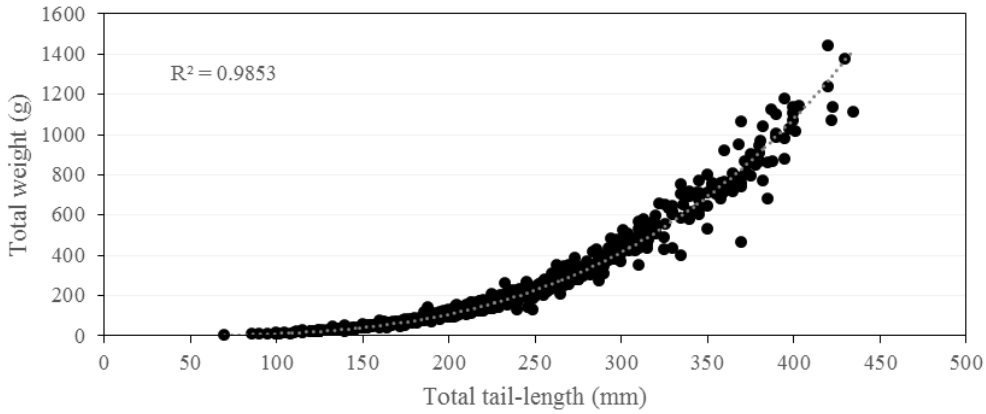

Figure 4. *Total Tail-length and weight data for lionfish collected during the 2014 Aruba lionfish tournament.* All lionfish (n = 532) were measured to the nearest millimeter using a standard fish measuring board and weighed on a digital scale to the nearest tenth of a gram (R^2 = 0.98).

Table 1. *Summary of dive team removals at the 2014 Lionfish Derby in Aruba*. There were nine dive teams entered at the derby, with a total of 29 divers. The table outlines the number assigned to each dive team, maximum number of divers that participated, total dive time (minutes) reported by the divers, average dive time for each diver, region(s) hunted, total number of lionfish removed (n=532), and a virtual catch per unit effort (CPUE).

Dive Team Number	Number of Divers	Total dive time (min)	Ave. dive time/diver (min)	Region(s)	Total Lionfish removed	CPUE (LF/hr)	CPUE (kg/hr
1	4	140	35	II	43	19	4.6
2	3	190	63	IV	107	34	8.7
3	2	160	80	I, II, IV	22	8	2
4	2	78	39	II, IV	41	32	8.2
5	5	212	42	I, III	133	38	9.7
6	3	153	51	I, III	30	12	3
7	4	195	49	I	42	13	3.3
8	3	83	28	III	26	19	4.9
9	3	180	60	III	88	29	7.4
TOTAL	29	1,391	48		532	23	5.8

RESULTS

Basic demographic data was collected for individuals surveyed, ages were categorized 20 - 40 (n = 57), 41 - 60 (n = 50), and > 61 (n = 9) – one individual did not provide this information, and participants were identified as male (n = 73) or female (n = 43). All 117 individuals surveyed (Figure 2) were shown a photo of a lionfish and asked if they had seen the fish before, if so, then prompted to identify the fish by name. Approximately 89% (n = 104) of the participants had seen lionfish before, while 79% (n = 82) of those individuals were able to identify the fish by name. Individuals were asked to identify where they have been exposed to lionfish from a series of available options (i.e. news/media, scientific journals, personal research/interest, water activities, documentaries, menu/market, or other/ specify) in order to identify the critical outlets for outreach and education efforts. They were able to choose more than one outlet; therefore, results presented for each category may have overlap from a single participant. Of the seven categories, the highest response rates were in water activities (n = 50), while the lowest number of responses were in news (n = 6) and documentaries (n = 6), respectively; Figure 5 shows the total number of responses of each category.

Seventy-five individuals were asked if they had consumed lionfish or if they were willing to consume it from the stakeholder groups: divers, locals, and tourists (Figure 6). Eighty percent were willing to try lionfish, of which only three individuals that did not eat seafood were willing to try the fish if it was deemed eco-friendly to do so. Approximately 61% of those surveyed had not tried lionfish

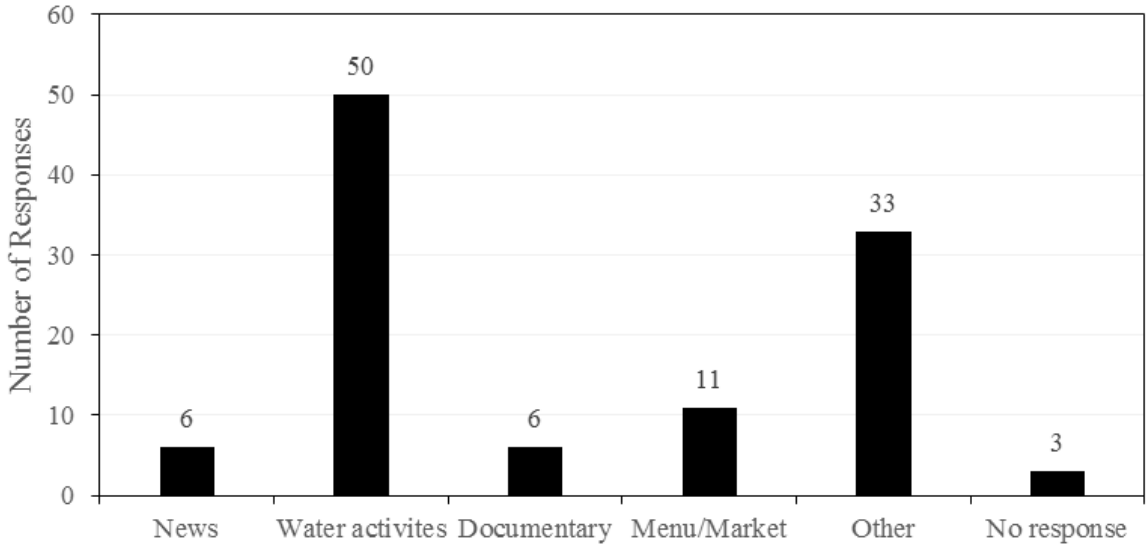

Figure 5. *Number of responses for each outlet of exposure to lionfish of participants who identified they have seen lionfish before*. All groups surveyed were allowed to choose more than one response, therefore, individuals may be represented in more than one category. The greatest exposure was during water activities (i.e. diving, snorkeling, swimming, fishing), while the lowest exposure occurred with documentaries (n=6) or the news (n=6). Of the individuals that have seen lionfish before, three individuals did not identify where they were exposed. Participants who identified other (n=33) were asked to specify: divers brought to shore (n=22); aquariums (n=4); videos (n=3); pictures (n=2); school project (n=1); book (n=1). *Note: government officials were excluded from this question.

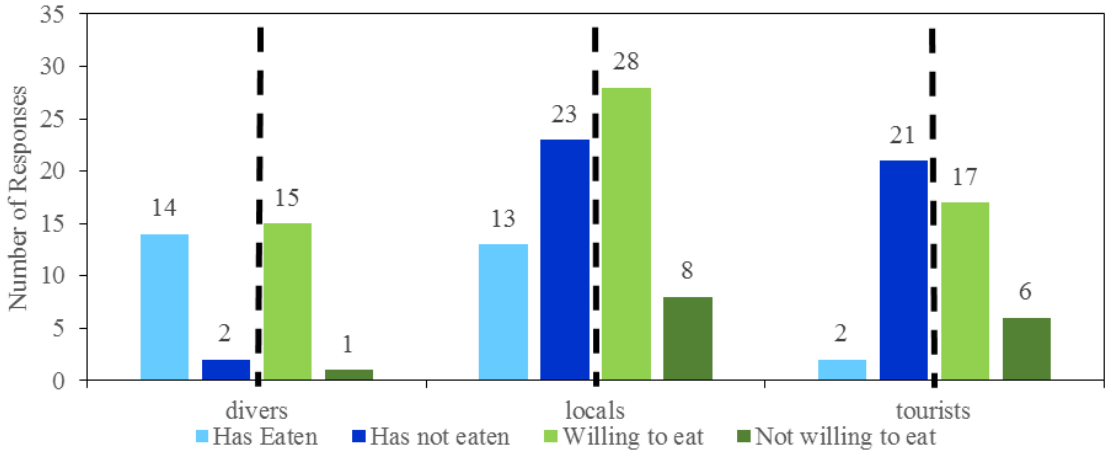

Figure 6. *Participant survey results for those who have tried lionfish or are willing to try it.* These are results of 75 individuals surveyed in the groups of divers, locals, and tourists on two different questions: whether they had already eaten lionfish (Yes or No); and whether they were willing to eat lionfish (Yes or No). We have included the dashed line to separate the results of the two questions to show the results. The numbers above the blue columns will add to be the same number as those shown over the green columns. For example, people that have already eaten lionfish will be included in the "willing to eat" column.

(50% locals, 46% tourists). Only two divers had not tried lionfish, one of which was willing to try, while the other was not willing to try it. Of locals surveyed, one identified they do not eat fish, but would try lionfish if it were deemed eco-friendly to do so. Two locals identified that they eat fish, but would not try lionfish. A local that does not eat fish was not willing to eat lionfish. Two tourists that do not eat seafood were willing to try lionfish, while five tourists that eat seafood were not willing to try lionfish. One tourist only eats shellfish, and therefore, would not try lionfish. In total, eight participants identified they would not eat lionfish, regardless of their current desire to eat seafood; however, did not specify why they were not willing to eat the fish.

Twenty-one fishermen were surveyed on their willingness to catch and sell lionfish for commercial purposes – 62% (n = 13) of these individuals were willing to participate in a lionfish fishery. Fishermen were prompted to identify the categorical weight (e.g. < 11.5 kg, 11.5 - 22.5 kg, > 44.5 kg) of fish caught per week to determine level of dependence on fishing. From this, two individuals identified < 11.5 kg/wk (9%); one 11.5 - 22.25 kg/wk (4%); five in 22.25 - 33.5 kg/wk (23%); two in 33.5 - 44.5 kg/wk (9%); nine identified > 44.5 kg/wk (42%), and three (13%) did not respond when prompted. Fishermen were also asked if they felt impacted by lionfish (Yes or No) and, if so, then how. Fourteen individuals claimed they were not impacted by lionfish (67%); five responded they had been impacted by lionfish (23%); two individuals did not respond (9%). When prompted on how they have been impacted by lionfish, respondents provided: reduction in target-fish capture (n = 1), fewer fish available (n = 3), negative aesthetic change in marine environment (n = 1), and negative behavioral response to divers – aggression, hiding (n = 1).

Government officials were surveyed with open-ended questions as to not create bias towards project goals. All officials were prompted on whether they considered lionfish to be a concern for the island, 100% responded yes. Of the questions, the most important to our study was the notion of "how" or "if" lionfish could be beneficial for Aruba. Responses from officials included food source, tourist attraction, research, advertisement, or none. Of these responses, 56% of government officials suggested lionfish can be used for a food source (Figure 3).

We collected basic biologic data for lionfish removed during the tournament in November 2014 and during Summer 2014 fieldwork (Figure 4). The mean length of lionfish removed was 237 mm, with a range 70 – 435 mm (median = 227 mm). The removed sub-population's mean weight was 256 g, with a range 3 – 1440 g (median = 165 g). In Aruba, lionfish are marketable as small as 150 mm (this study), which is the average size for juvenile lionfish as females and males sexually mature at 175 mm and 100 mm, respectively (Morris et al. 2011). This suggests a demand for juveniles is present on the island with restaurant officials and, therefore, these individuals can still be targeted for a commercial lionfish fishery. Wholesale costs for lionfish averaged US$11.00 per kilogram in Aruba in 2014 (this study); results of the lionfish derby yielded a CPUE of 5.8 kg/hr suggesting the island can conceivably sustain dedicated commercial lionfish harvesters.

DISCUSSION

Thus far, the most common approach for combating lionfish involves ad-hoc removals by recreational divers in derby events (Morris and Whitfield 2009, Barbour et al. 2011). Development of a commercial or recreational fishery has been proposed as a long-term management strategy, but has yet to be well quantified or defined. Here we have evaluated the interest of stakeholders to participate in a

commercial lionfish fishery with preliminary pilot-survey results from Aruba. It is evident from these preliminary survey results that the varied stakeholder groups are willing to contribute to utilizing lionfish as a food source, as well as identify an available consumer demand to develop an economically sustainable market.

While conducting the pilot-surveys we determined the future surveys must distinguish between fisherman and recreational versus commercial diver for the purposes of identifying those stakeholders most involved in establishing the fishery. Although we have support from local fishermen to participate in a commercial lionfish fishery, it is unlikely that these individuals would discontinue their current fishing endeavors to strictly target lionfish. It is beneficial if they contribute to the removal on an *ad-hoc* basis; however, participation in a solely dedicated lionfish fishery is unlikely. Recreational divers are those who work for and/or own dive charters that are primarily working with tourists. These divers do occasionally remove lionfish on an ad-hoc basis, some of which participated in our 2014 lionfish tournament; however, these divers are also not likely to quit their current profession to solely hunt lionfish. For the fishery we propose, we need a separate category of "commercial" diver whose sole purpose and income is obtained from harvested lionfish. Management for this will be complex and is beyond the scope of this preliminary study.

Conceivably, commercial divers could reduce the number of lionfish needed to be caught to maintain economic sustainability if consumer demand increases and lionfish afford a higher dollar value per kilogram sold ($/kg). Although an increase $/kg may reduce the number of fish needed to be caught in order for these divers to sustain a livelihood, they must still remove lionfish annually to retain an ecologically "healthy" ecosystem. If the $/kg were increased by changes in Aruban consumer demand for lionfish, this would afford an increase in the number of divers that can be supported or an increase in income per diver. If harvesting were restricted to local stakeholders responsible for the lionfish hunting grounds, a position we support, a common property-based management policy could be effectively employed (Ko et al. 2010).

Utilizing human consumption to reduce invasive species populations distinguishes a removal effort that constitutes both environmental and socio-economic benefits (e.g. Nunez et al. 2012, Varble and Secchi 2013). In this preliminary study we posed the question as to whether a "sustainable" lionfish fishery is feasible in Aruba to be covered in greater detail elsewhere. We have found that the awareness of lionfish and participation willingness among individuals is present, and therefore the development of a lionfish fishery would be supported. Our approach is both ecologic (i.e. allowing native reef fish populations to rebound which will benefit the overall health of the reef) and economic (i.e. the value of creating a "sustainable" lionfish fishery with its attendant employment and economic benefits). Difficulties arise with quantifying the economic impacts of lionfish, whereas ecological impacts are easier to quantify because it is directly reflected in the resident fish populations. Prevention and control of the lionfish invasion will require a long-term, ecosystem-based strategy rather than a focused tactical approach.

Eradication of lionfish is not likely, however, suppressing the population to a manageable level is obtainable. Controlling invasive species varies immensely in effort, therefore, employing a long-term, ecosystem-based management strategy is the most effective approach. Success of such approaches will depend more on commitment and continuation than efficiency of the specific strategy. Failing to address issues of biotic invasions can result in severe global consequences, including wholesale loss of fishery resources, disruption of the ecological processes that supply natural services to human enterprise, and creation of homogenous, impoverished ecosystems composed of cosmopolitan species (Mack et al. 2000).

Greater public and governmental awareness of chronic and global effects of lionfish (Morris 2009) must be addressed as many remain unaware of the severity of the issue. Arousal of public and government concern for invasive species has proved difficult; gaining support for prevention and control often fails because of a lack of understanding of the inevitable link between nature and the economy. The threats posed to biodiversity and ecosystem-level processes directly translates into economic consequences through the loss of fisheries and consequent imbalance in ecosystem structure (Pimentel et al. 2000). The ensuing potential economic consequences of lionfish has yet to be quantified, though it is evident that their invasion directly competes with native, commercially valuable species and, in turn, affects the economic viability of such fisheries. It is to the benefit of communities to consider harvesting lionfish for economic gain through a sustained consumer-driven fishery rather than solely as a negative ecologic and economic cost.

Choosing the species of a new fishery is complicated by factors such as: the intended location, development and employment of management efforts, collection of fishery resources, necessary removal efforts, development and implementation of regulations, etc. Many fish species have experienced dwindled stocks as fishermen remove fish prior to maturity, resulting in smaller fish sizes, causing the natural state of the ecosystem to shift due to an ecological imbalance (Pauly and Watson 2003, Pauly et al. 2005, Worm et al. 2006,). Fish species (e.g. Chilean seabass, Atlantic cod, Orange roughy, red snapper,) have long been heavily targeted by consumers and subsequently suffered in significant population decreases (Pauly et al. 2002, Varble and Secchi 2013). Development of a fishery that offers food security, economic sustainability, and promotes ecological benefits will be preferred for future viability.

Our survey sample size of 117 individuals is small to be used to evaluate market potential of a new fishery; however, it was designed as a preliminary analysis for Aruba, which will be followed by a repeat analyses in future years. Creating a consumer-driven fishery for lionfish could be a sustainable market-based solution for an otherwise inescapable problem with an invasive species. Lionfish originally appeared in the United States as an ornamental fish for the aquarium trade, and through their release, have now proliferated through the Atlantic, Gulf of Mexico, and Caribbean Sea (Morris and Akins 2009). It is obvious that their current distribution and, more shockingly, their anticipated expansion will undoubtedly have cascading ecological,

economical, and social consequences in affected countries. As lionfish compete for food and habitat resources with commercially viable fish, it will become a negative externality of these industries that are developed to meet consumable fish demand. Employing commercial divers in the removal of lionfish will meet the consumer demand, provide ecological stability, and sustainably provide additional employment resources.

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