LETTER

The Role of Citizens in Detecting and Responding to a Rapid Marine Invasion

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Abstract

Documenting and responding to species invasions requires innovative strategies that account for ecological and societal complexities. We used the recent expansion of Indo-Pacific lionfish (*Pterois volitans/miles*) throughout northern Gulf of Mexico coastal waters to evaluate the role of stakeholders in documenting and responding to a rapid marine invasion. We coupled an online survey of spearfishers and citizen science monitoring programs with traditional fishery-independent data sources and found that citizen observations documented lionfish 1–2 years earlier and more frequently than traditional reef fish monitoring programs. Citizen observations first documented lionfish in 2010 followed by rapid expansion and proliferation in 2011 (+367%). From the survey of spearfishers, we determined that diving experience and personal observations of lionfish strongly influenced perceived impacts, and these perceptions were powerful predictors of support for initiatives. Our study demonstrates the value of engaging citizens for assessing and responding to large-scale and time-sensitive conservation problems.

Introduction

The contributions of citizens in documenting, understanding, and responding to species invasions have been increasingly recognized by scientists, conservationists, and ecosystem managers (e.g., Delaney *et al.* 2008; Wolkovich & Cleland 2010; Shine & Doody 2011). Species invasions have traditionally been portrayed as exemplifying some of the most harmful impacts of humans on natural ecosystems, but more recently scientists have illustrated complex scenarios where benefits and consequences exist for both natural and human systems (Sax *et al.* 2007; Sax & Gaines 2008; Schlaepfer *et al.* 2011; Bertness & Coverdale 2013). Even for invasive species broadly regarded as harmful, such as many mobile predators that can cause high extinction rates and declines in native biodiversity (Sax & Gaines 2008; Green *et al.* 2012), disagreement often still occurs when establishing conservation goals and prioritizing societal and stakeholder investments (Schlaepfer *et al.* 2011; Shine & Doody 2011). One of the more recent and highly publicized marine invasions involves Indo-Pacific lionfish (*Pterois volitans/miles*) rapidly expanding throughout the northwest Atlantic Ocean, Caribbean Sea, and Gulf of Mexico during the past decade (Whitfield *et al.* 2002; Schofield 2009, 2010).

The invasion and continued expansion of lionfish is potentially the most well documented marine invasion in history (Côté *et al.* 2013), with the observations of recreational divers, fishers, and other citizens playing a major role by reporting sightings and participating in initiatives to control or reduce population levels (Schofield 2010; Akins 2012; Ruttenberg *et al.* 2012). Lionfish have been considered consummate invaders because of their high fecundity, generalist diet, and aggressive and specialized foraging strategies (Morris & Akins 2009; Albins & Hixon 2013; Côté *et al.* 2013). Although the invasion dynamics and potential impacts of lionfish have been most thoroughly described for coral reef ecosystems, lionfish have also been documented across a broad range of habitats spanning from offshore reef and hard bottom to other shallow, coastal and estuarine habitats such as seagrass meadows, mangroves, and oyster reefs (Claydon *et al.* 2012; Jud & Layman 2012). Despite observations of native predators consuming lionfish (Maljkovic *et al.* 2008) and population control or culling efforts often termed "lionfish derbies" (Barbour *et al.* 2011; Albins & Hixon 2013), the abundance and geographic footprint of lionfish have continued to rapidly expand (Schofield 2009; Green *et al.* 2012; Ruttenberg *et al.* 2012; Côté *et al.* 2013). Although extirpating lionfish is not a realistic goal for managers to pursue, the efficacy and ecological benefits of efforts to control lionfish densities on local scales seem increasingly positive in many settings (Akins 2012; Côté *et al.* 2013).

Like many other challenging conservation issues, the lionfish invasion is a scenario where the initial problem and many of the solutions require understanding and potentially changing the behavior of humans (Schultz 2011). Nearly all initiatives proposed or currently being employed to reduce lionfish densities involve citizen volunteers (Akins 2012); however, little attention has been focused on quantitatively comparing the observations of citizens to traditional reef fish monitoring programs (Ruttenberg *et al.* 2012), or understanding how the perceptions and motivations of key stakeholders can influence their willingness to support response initiatives (Moore 2012). The lack of information on these latter variables is surprising given the centrality of both factors to the success of initiatives. Here, we focus on resolving these two uncertainties related to the presence and expansion of lionfish in the northern Gulf of Mexico (nGOM). First, we quantitatively compared citizen observations and monitoring programs versus traditional reef fish monitoring. Substantial effort is allocated toward monitoring the region's more than 100 commercially fished species; however, the efficacy of these surveys for detecting invasive species, such as lionfish, is not known. Second, we assessed spearfishers' perceptions on potential ecological impacts of lionfish and willingness to harvest them under various contexts.

Methods

Lionfish abundance

We compared five different sources of lionfish abundance data generated by citizen observations and traditional reef fish monitoring from the earliest recorded sightings through 2012. Our study region encompassed coastal and shelf waters north of 28°0′N and between 90°0′W and 83°30′W. The first traditional reef fish data set involved stationary video camera data collected as part of the Southeast Area Monitoring and Assessment Program (SEAMAP; Rester 2011). A second set of reef fish monitoring data was collected by the Dauphin Island Sea Lab and involved remotely operated vehicle (ROV) surveys of artificial reef structures. The U.S. Geological Survey's Nonindigenous Aquatic Species (USGS-NAS) database and the Reef Environmental Education Foundation (REEF) Volunteer Survey Project database are two of the most frequently cited sources of data for tracking invasive species and monitoring reef fish communities, respectively. The USGS-NAS database is the national repository for sightings data for aquatic nonindigenous species and has played a central role in describing the lionfish invasion (Schofield 2009, 2010; Schofield *et al.* 2012). The REEF database contains fish sightings data collected by volunteer divers trained as citizen scientists (Pattengill-Semmens & Semmens 2003; REEF 2013). Finally, we assessed lionfish prevalence from the collective knowledge and experiences of a specialized group of stakeholders, licensed Alabama spearfishers, using an online survey in October 2011. The survey questionnaire was designed to quantitatively measure spatial and temporal patterns of recent spearfishing/diving effort and the frequency of encounter or relative abundance of lionfish. Participants who reported observations of lionfish were prompted to provide detailed qualitative accounts and any available photographs of their encounters. We used the open-ended responses to provide further context on the invasion timing, distribution, and habitat of lionfish, and photographs were used to verify species identifications. Further description of all data sources is provided in Supporting Information Appendix 1.

Perceived impacts and willingness to participate in initiatives

The second objective of our spearfisher survey focused on the perceived ecological impacts of lionfish in the nGOM and the willingness of spearfishers to harvest lionfish under four different contexts. For perceived ecological impacts, participants were offered five ordered response variables ranging from "very harmful" to "very beneficial." For willingness to participate in initiatives, participants were presented with five choice options ranging from "absolutely not" to "absolutely." The four potential contexts for harvest were personal consumption, trophy or sport, market demand, and encouragement from scientists and managers.

We used classification tree analyses to determine the demographical factors or experiences that were most powerful at predicting spearfishers' perceptions of lionfish and overall willingness to participate in lionfish harvest initiatives (Agresti 2002). Classification tree analysis for perceived impacts considered 10 independent variables: age, gender, state residency (Alabama or other), nGOM diving experience (years), mean annual dives (last 5 years), total dives in 2011, personally observed lionfish while diving (binary), total abundance of lionfish observed, abundance of lionfish observed in 2011, and perceived change in abundance. The classification tree analysis on overall willingness to participate, calculated as the mean of all four proposed contexts, considered participants' responses regarding the perceived impacts of lionfish as an independent variable in addition to all 10 variables from above. We used the results of classification tree analysis on overall willingness to participate to identify independent variables for Mann-Whitney U tests on each of the four proposed contexts. Further details on our survey and analyses are provided in Supporting Information Appendix 1.

Table 1 Yearly effort and observations of lionfish for each data source

	Pre-2011		2011		2012	
Data Source	Effort	Total Lionfish	Effort	Total Lionfish	Effort	Total Lionfish
Stationary camera	710[a]	0	247	0	189	4
ROV video	29[a]	0	144	1	92	50
USGS-NAS	n/a	15	n/a	76	n/a	244
REEF	86[a]	0	48	2	57	13
Spearfisher survey	14802[b]	230	3559	1073	n/a	n/a

[a]Total 2008–2010 camera deployments or dives.
[b]Total 2007–2010 trips.

Results

Lionfish abundance

Our analysis of traditional reef fish monitoring data included 1,411 stationary camera and ROV deployments broadly distributed across the coastal and shelf waters of our nGOM study region (Table 1, Figure S1). SEAMAP stationary camera surveys documented four different lionfish sightings from 189 deployments in 2012, and recorded no lionfish in 2011 or earlier (Table 1). The sightings occurred southwest of Venice, LA and south of Port St. Joe, FL and involved one to three lionfish (Figure 1). ROV surveys recorded one lionfish approximately 65 km south of Dauphin Island, AL in 144

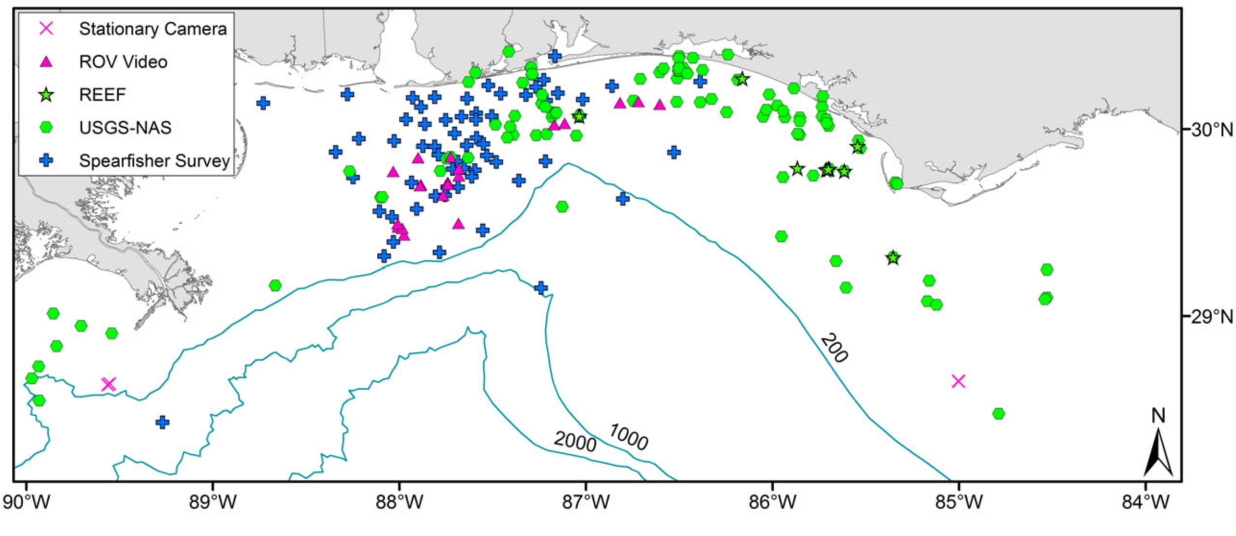

Figure 1 Map showing the spatial distribution of lionfish sightings within the study region. Sightings derived from traditional fisheries and ecological monitoring sources are shown in pink. Sightings from REEF and USGS databases are shown in green. Blue crosses represent spearfisher responses to a map-based question that asked them to identify a single location representing the majority of their lionfish sightings.

deployments in 2011 (Figure 1). In 2012, a total of 50 lionfish were documented in 92 deployments (Table 1).

Two databases that catalog the observations and reports of nonnative species and marine fish communities are the USGS-NAS database and the REEF volunteer survey database. According to the USGS-NAS database, lionfish were not detected in our study region prior to 2010 when a total of 15 were reported (Table 1). In 2011, confirmed reportings increased more than fivefold as 76 additional lionfish were reported, and again by more than threefold to 244 in 2012 (Table 1). Reported abundances typically ranged from one to four lionfish per sighting, although abundances as high as 50 were reported. Lionfish were observed ranging in size from 5 to 30 cm total length and at depths of less than 2 m in shallow seagrass habitats to more than 40 m in offshore natural and artificial reef habitats. The REEF database indicated that no lionfish were observed prior to 2011 when two were documented in 48 dives (Table 1). In 2012, a total of 13 lionfish were observed in 57 dives.

To quantify lionfish encounters by spearfishers, we conducted an online survey of 232 licensed Alabama spearfishers. The overall survey response rate was 24.6%, and demographics of respondents were largely reflective of the population of spearfishers in the database (Supporting Information Appendix 1). The spearfishers surveyed had collectively logged more than 14,800 dives from 2007 to 2011 and reported more than 3,500 dives in 2011 alone. On average, respondents had more than 13 years of experience and logged more than 17 dives in the nGOM annually. Diving effort was spatially distributed across the entire study region, although the most heavily targeted areas were between 88°30′W and 87°0′W (Figure S1). One-third of respondents reported directly observing lionfish while diving in the nGOM. More than 1,300 individual lionfish were reported, and 82% of these lionfish were observed in 2011 (Table 1). Several spearfishers noted observing upwards of 20 lionfish on a single dive, and two spearfishers stated they had observed more than 250 individual lionfish during 2011 (Table S1). Another respondent reported encountering lionfish on every dive in 2011 but only once in 2010, and several spearfishers suggested highest lionfish densities were observed at depths greater than 30 m near artificial and natural habitats. All photographs submitted were confirmed to be Indo-Pacific lionfish.

Perceived impacts and willingness to participate in initiatives

In addition to quantifying encounters with lionfish, our survey also measured spearfishers' perceptions of potential ecological impacts and their willingness to target lionfish under various contexts. Overall, 75% of respondents perceived lionfish to be harmful or very harmful for marine ecosystems, while 24% perceived no effect, and only 1% perceived lionfish as beneficial (Figure 2). Classification tree analysis showed that spearfishers who had logged more than six dives per year perceived lionfish to be more harmful than less avid respondents. Among the more avid spearfishers, a perceived harmfulness was ubiquitous among those who had personally observed more than ten lionfish or had more than 33 years of diving experience. Considering all proposed contexts, on average spearfishers were modestly willing to harvest lionfish (Figure 3). Classification tree analysis revealed spearfishers' perceptions regarding the ecological impacts of lionfish was the most powerful factor for predicting willingness to participate, with spearfishers who perceived lionfish to be harmful or very harmful more willing than those who perceived lionfish as beneficial or neutral. Using Mann-Whitney U tests, we found that the pattern of greater willingness among respondents who perceived lionfish as harmful was consistent for all four contexts (Table 2 and Figure 4).

Discussion

Spearfishers, divers, and other citizen volunteers have played a central role in documenting and responding to the invasion and expansion of lionfish. Our study reveals that these nontraditional data sources are effective at detecting a rapid marine invasion and could address critical information gaps or serve as an "early warning system" in certain scenarios. Although the targeted spearfisher survey, USGS-NAS, and REEF databases indicated a similar pattern of initial invasion in 2010 and increased prevalence through 2012, each approach has strengths and weaknesses. The USGS-NAS database relies upon volunteered observations from a variety of sources and has no measure of effort. Therefore, it is difficult to compare the prevalence of lionfish across regions or time periods. The REEF volunteer survey and database utilizes divers trained to employ a standardized citizen science approach and involves measured effort, but survey intensity in many nontropical regions, such as the nGOM, may be much lower than the southern Gulf of Mexico, Florida Keys, and Caribbean Sea. Our survey of spearfishers allowed for a synoptic assessment of effort and lionfish abundance, and it demonstrated that the spatial and temporal coverage of data sourced from a relatively small and local group of stakeholders can surpass or complement traditional, large-scale monitoring surveys.

Stakeholder and citizen observations have become increasingly popular and vetted resources for

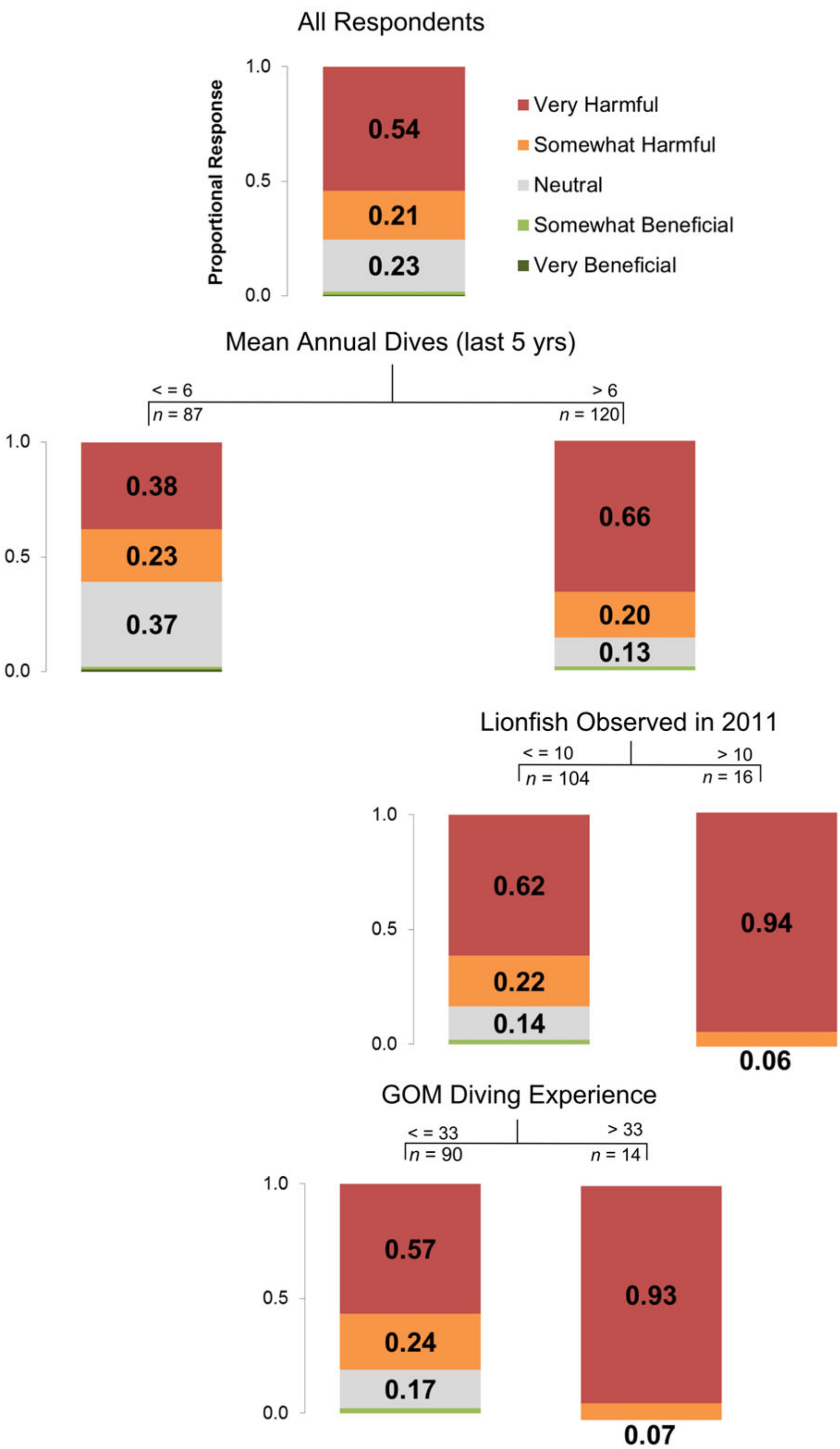

Figure 2 Classification tree showing the most powerful predictors of spearfishers' perceptions of lionfish. Separate branches within the tree indicate statistically significant differences at $P \leq 0.05$.

large-scale and rapid ecosystem studies (Pattengill-Semmens & Semmens 2003; Silvertown 2009; Wolkovich & Cleland 2010; Hassell *et al.* 2013). In marine ecosystems, the observations and collective knowledge of fishers and divers have been used to document species declines, shifts in community structure, and inform

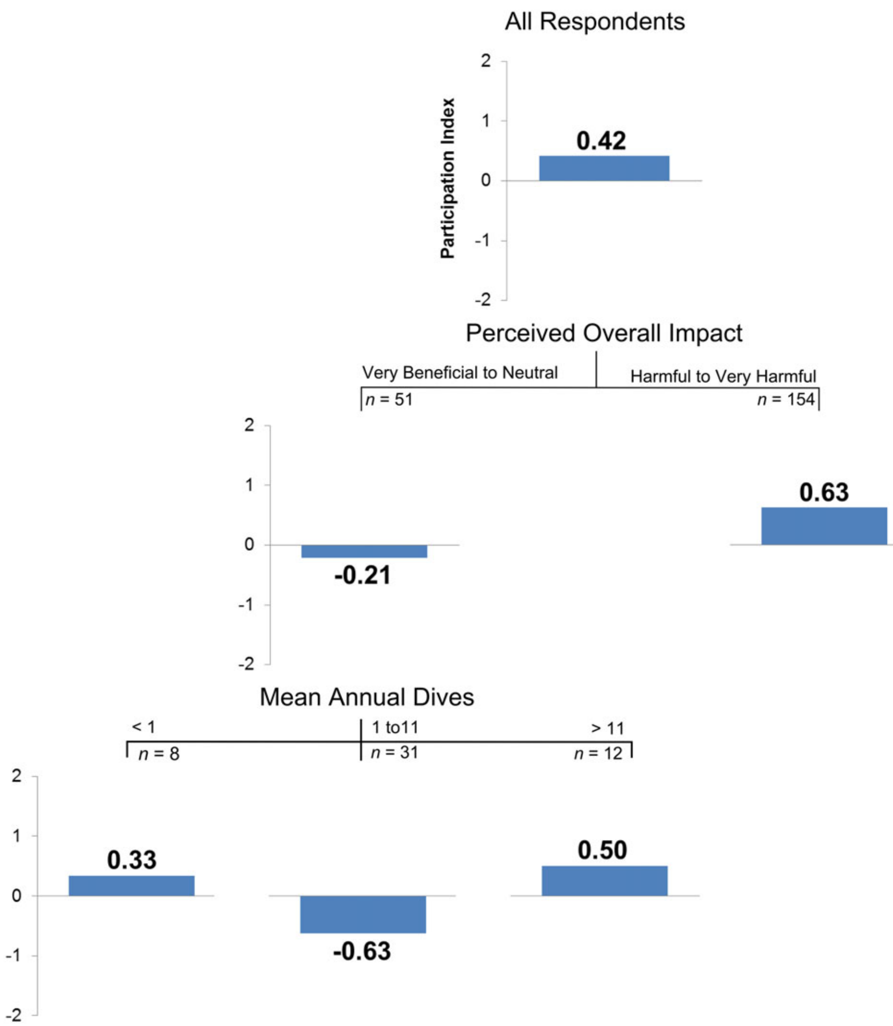

Figure 3 Tree-based model output showing the most powerful predictors of spearfishers' overall willingness to target lionfish. The participation scale ranges from absolutely not (−2) to absolutely (2). Overall willingness was calculated as the mean of all four proposed contexts. Separate branches within the tree indicate statistically significant differences at $P \leq 0.05$.

conservation initiatives (Scholz *et al.* 2004; Stallings 2009), but certain precautions must be taken to minimize potential biases and artifacts. For example, underwater visual surveys may overestimate the abundance of large, highly mobile species when noninstantaneous counts are not corrected to account for species entering and exiting the study area (Ward-Paige *et al.* 2010). Although this type of artifact is less likely to plague diver counts of lionfish, as lionfish are less mobile and exhibit high site fidelity (Jud & Layman 2012), it is plausible that some respondents were diving together and observed the same individual lionfish resulting in similar overestimation. Given that lionfish also have fairly distinctive and unique morphology, the probability of misidentification is likely lower than it could be for species of similar appearance to native fishes. It is also conceivable that individuals that had not encountered or were unfamiliar with lionfish were underrepresented in the survey sample. However, these biases would likely result in an

Table 2 Results of Mann-Whitney U tests on the relationship between spearfishers' perceptions of lionfish and willingness to participate in initiatives

	n	*Z*	*P*
Personal consumption	207	3.532	<0.001
Sport/trophy	206	4.206	<0.001
Market demand	206	5.037	<0.001
Encouraged by scientists or managers	207	5.248	<0.001

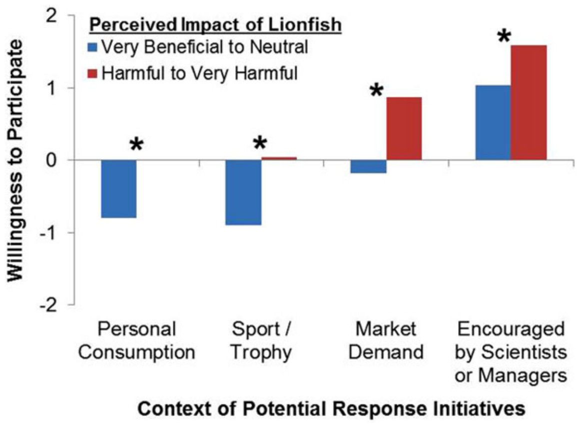

Figure 4 Willingness of spearfishers to target lionfish under four different contexts. Asterisks indicate significant differences at $P \leq 0.05$ using Mann-Whitney U test.

overestimation for all years, and thus would not explain the dramatic increase observed in 2011. Furthermore, the photographs and comments provided by respondents promote confidence in the overall patterns.

The willingness of stakeholders to "buy-in" on conservation initiatives can be influenced by their knowledge, perceptions, values, socioeconomic status, and social norms (Cinner 2007; Schultz 2011). In our study, we found that spearfishers' perceptions regarding the potential ecological consequences of lionfish were closely related to their experiences encountering lionfish while diving, and perceived harmfulness was an effective predictor of their stated willingness to participate in initiatives involving lionfish harvest. However, further studies are needed to determine if or when verbal support of initiatives ultimately translates to active participation in organized initiatives and harvesting or culling lionfish during regular activities. Numerous other uncertainties also still surround initiatives to reduce or control lionfish populations. For instance, modeling studies have suggested that high exploitation rates would be necessary to cause lionfish population declines, and population recovery may be rapid if exploitation levels were relaxed (Barbour *et al.* 2011; Morris *et al.* 2011). A broader criticism of initiatives to promote harvest or marketing of invasive species suggests that such initiatives could be counterproductive if societal desire for the resource becomes too high (Nuñez *et al.* 2012).

The lionfish invasion has prompted new policies for preventing and responding to marine invasions, as well as highlighted the importance of coordination among citizens, government agencies, and conservation groups. For instance, state-level response in Florida has involved new policies to ban the importation and aquaculture of lionfish, promote and facilitate culling by recreational fishers, and has involved the development of a mobile application ("app") for tracking lionfish observations (FFWCC 2014a, b). The policies also ease licensing requirements for individuals specifically targeting lionfish, permit the use of specialized gears (e.g., rebreathers, pole spears), and highlight the absence of size and bag limits for lionfish in fishing regulations. Nonetheless, similar and coordinated responses among nearby states and federal agencies will be important given the distribution of lionfish across geopolitical boundaries. Organized lionfish derbies have been well supported and facilitated partnerships among stakeholder groups (e.g., dive clubs, environmental organizations), state, and federal agencies throughout the Gulf of Mexico (Akins 2012; GCLC 2014), but our results indicate that education and outreach programs, particularly directed toward less experienced spearfishers, may be needed to garner support from the broader community.

Rapid species invasions are challenging conservation problems, in part, because of mismatched scales between social and ecological systems making it difficult to diagnose, understand, and respond to the issue (Cumming *et al.* 2006). Clearly, it is essential to understand the ecological and evolutionary processes involved with species invasions to effectively predict ecosystem consequences and develop conservation initiatives (Sax *et al.* 2007), but these studies should coincide with efforts to understand linked social systems (Cumming *et al.* 2006). The ability to detect invasive species early, effectively, expeditiously, and economically are desirable attributes of any citizen or traditional approach for monitoring. Our study demonstrated the value of spearfishers as citizen scientists and citizen conservation practitioners for responding to a rapid species invasion, but the collective observations and actions of citizens may also benefit response efforts for a much broader range of ecosystem disruptions (i.e., oil spills, posthurricane assessments), especially when large-scale and time-sensitive response is needed. Further, the increasing popularity of mobile apps and similar technologies offers potential pathways for coordinating these efforts and moving closer toward real-time monitoring and response (Newman *et al.* 2012). In conclusion, citizen involvement may provide many benefits for ecosystem monitoring and conservation efforts, including rapid information exchange and more effective adaptive management, but understanding the knowledge, beliefs, and behaviors of key stakeholders can be essential for maximizing success.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Figure S1: Map showing the distribution of effort for all data sources. Values within geographically defined cells indicate the total number of spearfisher respondents that had completed dives within the zone.

Table S1: Selected quotes from spearfisher respondents when asked to describe their lionfish observations.

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