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Research Article

Use of social-media networking to facilitate a grass-roots lionfish removal program in the British Virgin Islands

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Abstract

Volunteers are extensively involved in monitoring and controlling invasive species. Most research has examined volunteer activity in groups organized "top-down", but we examined a local community-based group removing lionfish in the British Virgin Islands (BVI) with a specific focus on the use of social media by the group. Indo-Pacific lionfish (*Pterois miles*, *P. lunulate* and *P. russelii*) are invasive in the Western Atlantic Ocean and can impact the composition and function of coral reef communities. In response, resource managers and scientists have organized programs using divers and snorkelers to remove lionfish. In the volunteer-led BVI program, participants searched for and culled lionfish in their spare time and used a public Facebook group to record their activity. We compiled all lionfish-related posts from 2012 to 2014 (n = 654). Lionfish were reported at 147 sites, and 1451 lionfish were culled from 117 sites, but activity was concentrated at 35 established dive/snorkeling sites. We also performed SCUBA surveys (n = 27 sites). Survey results were consistent with Facebook reports in suggesting that culling made lionfish wary but did not consistently reduce lionfish abundance or size-distributions. Most removals were conducted by a core group of locals whereas a much larger group of locals and visitors, some of whom apparently participated after seeing the Facebook page, contributed mainly by reporting the location of sightings. Those removing lionfish frequently followed-up on posted sightings, suggesting that social networking facilitated information sharing by guiding the selection of hunting sites. Posts were also used by participants to encourage one another and share negative attitudes about lionfish. Community-based groups are challenged by limited resources, however social-media networks may facilitate communication among participants in ways that help motivate, coordinate and direct group activity.

Key words: communication, coordination, Facebook, non-profit group, participation, *Pterois,* volunteer

Introduction

Volunteers are extensively involved in conservation efforts, including the monitoring and control of invasive species (McCurley and Lynch 2011; Pyšek and Richardson 2010). Groups of volunteers are most often organized "top-down" by task-oriented government agencies (Checkoway 1995) or non-governmental organizations (Butcher 2007), and implement plans derived from expert recommendations (Rabb and Sullivan 1995). Less frequently, groups are organized by the participants themselves (e.g. Staples 2012). The operation of non-profit groups that involve volunteers has been well-studied (Arnstein 1969; Carroll 1992; Margerum 2008; McCurley and Lynch 2011), but relatively few studies have focused on local volunteer-led groups (Freeman and Ray 2001).

Volunteer-led groups tend to operate in active roles, characterized by performing on-the-ground activities like monitoring, education, and restoration as well as invasive species control (Lewis 2003; Margerum 2008; Reed 2008). Because invasive species eradication and suppression programs are usually expensive and labour-intensive (Simberloff et al. 2013), the successful incorporation of volunteers into these programs can potentially expand their scope and likelihood of success (Simberloff 2009). It is thus valuable to identify factors that influence the number of volunteers who participate in small community-led groups, and to understand the nature of their experiences and ecological effectiveness of their actions (Donlan et al. 2003; Ford-Thompson et al. 2012).

Volunteer-led groups tend to be relatively small, act locally, operate with limited funding and often deemphasize formal internal organization and management (Arnstein 1969; Lewis 2003; Margerum 2008; Reed 2008). For such groups, the rapid expansion of internet access, coupled with the ubiquity of computers and cellular telephones has created new opportunities for volunteers to collect and report ecological data. It has also allowed for volunteers to receive personalized feedback, or view broader expert summaries and interpretations of project data (Newman et al. 2012; Silvertown 2009; Stafford et al. 2010). Social media platforms can also facilitate interactions and information exchange among participants and provide new avenues for communication by groups with limited resources (e.g. Daume and Galaz 2016). Our focus was thus to explore how a social media forum created by a community-based group was used by its participants.

The nonprofit group we studied, Reef Guardians BVI, was formed "to stem the lionfish invasion in the British Virgin Islands (BVI) before it worsens" (Reef Guardians 2014). Lionfish from the Indo-Pacific (Wilcox et al. 2017); primarily hybrids of *Pterois miles* (Bennett, 1828) and a lineage encompassing *P. lunulate* (Temminck & Schlegel, 1843) and *P. russelii* (Bennett, 1831) have spread rapidly through the Caribbean, Gulf of Mexico and northwestern Atlantic since 2000 (Schofield 2009). Invasive lionfish are efficient predators of small fish and invertebrates and so can influence the ecological composition and function of coral reefs in the Atlantic (Albins 2013; Ballew et al. 2016; Côté and Smith 2018; Green et al. 2012). Volunteers have participated in lionfish culling programs throughout its invasive range, which have been the primary method to limit their spread (Morris 2012). To a lesser extent volunteers have been involved in lionfish monitoring (Carballo-Cárdenas and Tobi 2016; Lopez-Gomez et al. 2014).

Reef Guardians BVI was led by volunteers, whereas most culling and monitoring programs were run by resource managers or scientists who recruit and train volunteer divers and snorkelers. Some culling programs were based on "derbies", which are organized competitions to remove as many lionfish as possible in a fixed time-interval (Boag 2014; Malpica-Cruz et al. 2016; Moore 2012). In other programs, including Reef Guardians, participants act independently, or in small groups, to remove lionfish on their own schedule (Andradi-Brown et al. 2017; Dahl et al. 2016; de León et al. 2013; Frazer et al. 2012; Gleason and Gullick 2014; Sandel et al. 2015).

Reef Guardians BVI was formed by local divers, primarily dive instructors working for BVI companies. The use of spear guns and hand nets is not normally allowed in BVI waters; however, these individuals were granted special permission by the BVI Ministry of Natural Resources to use those methods solely for removing lionfish. Divers and snorkelers who were not authorized to use spear guns or hand nets were encouraged to mark sites where they spotted lionfish. Markers consisted of a small weight attached to a length of flagging tape and a wine cork and were dropped on the reef next to lionfish. Use of these markers was also promoted by other lionfish culling programs, including those in the US Virgin Islands, Netherlands Antilles, and Cayman Islands (Carballo-Cárdenas and Tobi 2016; Johnson et al. 2010; Morris 2012). Individuals who placed markers in the BVI were encouraged to contact Reef Guardians, BVI Ministry of Natural Resources, or a local dive operator so that those with permits could visit the site later and attempt to find the marker and remove the lionfish (Johnson et al. 2010). Our impression was that Reef Guardians' public Facebook group rapidly became the primary means of communication among participants and, although users were encouraged to "post all [their] BVI lionfish sightings, markings and culls here", the page was an open forum and individuals were free to decide how to use the group page.

Our three objectives were to examine how social media might be used to (1) document the effectiveness of removals, (2) influence the nature of participation in group activities and (3) share attitudes about invasive species. (1) *Effectiveness of removals* – Monitoring the effect of culling programs on invasive populations is essential (Pasko and Goldberg 2014). Lionfish culling programs have typically been evaluated using SCUBA-based population counts done by scientists (e.g. Barbour et al. 2011; de León et al. 2013; Frazer et al. 2012; Sandel et al. 2015; Usseglio et al. 2017). Population trends for other harvested fishes have, however, been effectively documented by fishers themselves (e.g. Beaudreau and Levin 2014; Bender et al. 2013). We therefore tested whether reports about lionfish abundance, body sizes and behaviours matched those documented in a SCUBA-based scientific survey. (2) *Participation* – We examined possible influences on the nature of participation, focusing on the possibility that the Facebook page might be used to coordinate marking and culling activity among group members, and to motivate and encourage group members. We also investigated whether the Reef Guardians page might influence the number of volunteers choosing to participate, perhaps by increasing awareness of the group. (3) *Sharing attitudes and perceptions* – The choice to engage in culling invasive species is influenced by a complex mix of intrapersonal, interpersonal and contextual factors that have been revealed primarily by scientists using formal structured or semi-structured interviews (Niemiec et al. 2016; Sharp et al. 2011). We explored if, and how, participants chose to share attitudes about conservation and invasive species and, because the forum was public, whether there were any interactions dialogue between Reef Guardians and Facebook users not affiliated with the group.

Materials and methods

Documenting group activity on social media

The Reef Guardians public Facebook page was created in September 2011, and we transcribed the text of all 654 lionfish-related posts up to the date of our SCUBA surveys in July 2014. Profile names associated with each post, any participant names, and identities of businesses and organizations mentioned (e.g. dive operators, charter yachts) were converted to numeric identifiers and only numerical identifiers were saved in data files. In all posts that reported lionfish sightings or removals, we coded information relevant to assessing the effect of group activity on lionfish abundance, sizes and behaviour (Objective 1). In each post, we recorded the number of lionfish sighted, the number removed, and any unsuccessful removal attempts (missed or injured). Mentions of lionfish size (body length) were coded in broad size-classes (0–10, 11–20, 21–30, 31–40, > 40 cm total length) based on statements in the post or measurements from user-submitted photographs. Using names of reported locations, we estimated the latitude and longitude of each sighting or removal and recorded them on a GIS map of the area (ESRI, Arc GIS 9.2). We noted whether participants reported diving or snorkeling, and at what water depth, and noted methods used for removals.

We also performed a qualitative content and sentiment analysis of the text within the posts (Bhattacherjee 2012). The raw text was examined manually using open coding to identify concepts and link them to portions of text (coding units). Coding units were organized into themes (Ritchie et al. 2013) that were guided by our aim of understanding the role of online interactions in communicating, coordinating, motivating and organizing participant activity (Objective 2), and communicating attitudes about invasive species (Objective 3). For example, one theme addressed whether participants shared information in a way that reflected coordination of marking and culling activity (Objective 2). Posts in which participants mentioned lionfish markers or referred to a previous sighting yielded coding units that mentioned placing a marker to record the location of a lionfish (placed), using a previously placed marker to locate and remove a lionfish (successful follow-up), and finding a previously placed marker but not finding a lionfish nearby (unsuccessful follow-up). Sentiment analysis was used to code posts describing attitudes or perceptions as either positive, neutral or negative (Objectives 1, 2 and 3) (Bhattacherjee 2012). We used how often a term or coding unit was mentioned in the posts (term frequency) as a rough indicator of its importance.

SCUBA surveys of lionfish behaviour and abundance

We performed a SCUBA-based survey from July to August 2014, the results of which were compared to Reef Guardians comments about lionfish population densities, body sizes and behaviours (Objective 1). We surveyed 16 Reef Guardians sites plus 11 nearby sites with no recorded visits to serve as spatial controls. The Reef Guardians sites were classified based on how many visits with culls were reported on Facebook: few (1–5 visits, n = 8 sites) or many (6–22 visits, n = 8 sites). The 11 control sites lacked reported visits and were not established dive/snorkeling sites, but were similar to Reef Guardians' sites in depth, wave exposure, topographic relief, proximity to land and human development. This study design is based on the assumption that actual culling activity at a site is correlated with culling activity reported on Facebook and that control sites were relatively free of culling (de León et al. 2013). We suggest that this assumption was reasonable because Reef Guardians was the only group removing lionfish in the BVI. Although anecdotal information suggested some culling by authorized divers was not reported on Facebook, and there may have been some illegal culling, we consider it likely that most of this activity would occur at established dive sites (Reef Guardians sites) rather than control sites.

At each site, two divers systematically searched ≈ 0.5 hectare of reef, taking care to inspect crevices and overhangs for lionfish (Green et al. 2013). We recorded all lionfish encountered and visually estimated their body length (using the size-classes previously described for Reef Guardian reports). Because lionfish abundance can be related to reef topography (Bejarano et al. 2015; Green et al. 2013), we quantified vertical reef using the consecutive height different method (McCormick 1994). At each site, transect tapes were stretched tight across the reef surface (3–8 tapes per site, each 30-m long), and we measured the distance in cm perpendicular from the tape to the reef surface every 50 cm. Vertical relief (in cm) was calculated as the square root of the sum of the squared differences between successive height measurements (McCormick 1994).

Because lionfish may learn to avoid divers as culling progresses, we scored their level of concealment when first sighted (1 = out in the open; 2 = sheltered

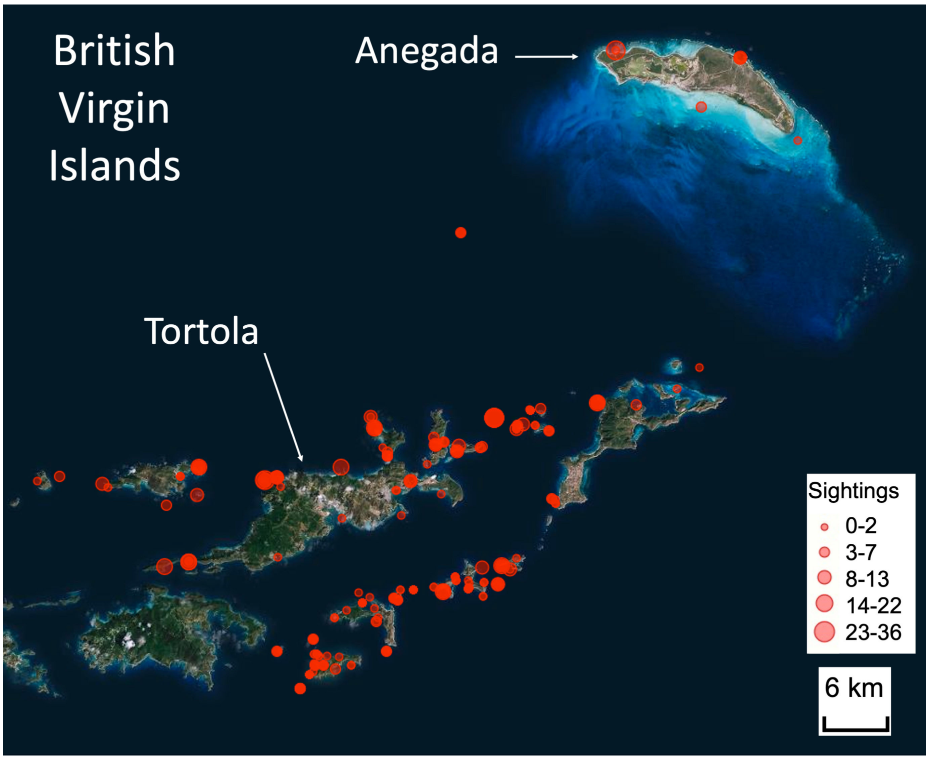

Figure 1. Locations of lionfish sightings reported on the Reef Guardians Facebook page. The size of circle indicates the number of lionfish sightings reported per site. The latitude and longitude of each sighting was estimated based on information provided in the post and mapped using GIS software (Arc GIS 9.2 by ESRI). Source of map imagery: Earthstar Geographics.

within reef but easily visible, 3 = in shelter and not easily visible) (Côté et al. 2014). If they were out in the open or visible, we also recorded their reaction as the approach continued (1 = remain in the open, 2 = retreat slowly to shelter, 3 = flee rapidly to shelter). Because sample sizes were small, we pooled sites into two categories (visited and control) for this analysis.

Results

Objective 1: Effects of culling on lionfish abundance, size-distribution and behaviour

In total, group participants reported culling 1451 lionfish and sighting an additional 629 lionfish. Most activity occurred while diving (81% of posts) at typical recreational diving depths (mean = 12 m, range = 1–42 m). Lionfish sightings were reported at 147 sites, and removals occurred at 117 of those sites (Figure 1). The 35 most frequently visited sites (6–78 reports each) were all established dive/snorkel sites with mooring buoys, which appear on maps and web pages oriented towards visitors. However, most sites were visited infrequently (2–5 reports, n = 50 sites) or just once (n = 62 sites).

Reef Guardians' perceptions about whether culling reduced lionfish abundance were mixed. Some participants perceived an impact of removals on the lionfish population (e.g. "We're not seeing a lot there anymore after a few dives with 6–7 lionfish removed. It seems to be working down there", "whenever there is a concentrated culling effort in a specific place it keeps

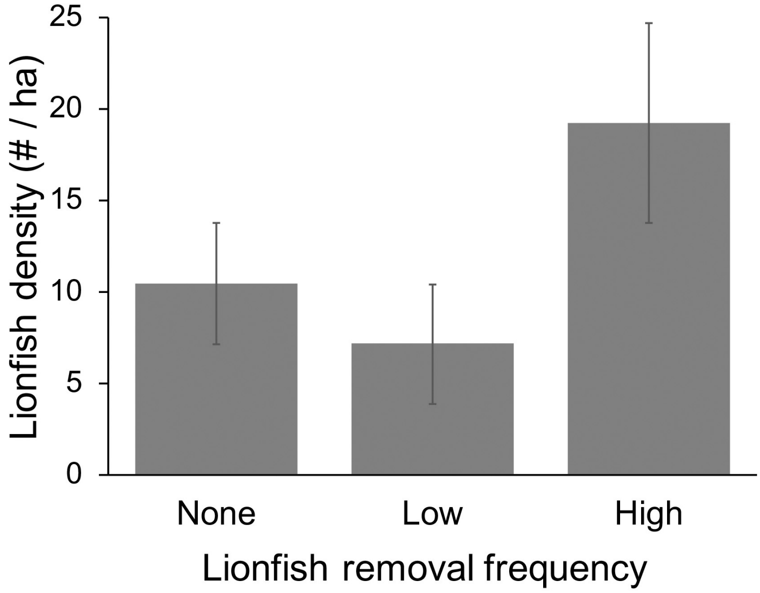

Figure 2. Mean lionfish densities (± SE) from our SCUBA survey at sites with differing numbers of reported Reef Guardian visits (none = 0, low = 1–5 visits, high = 6–22 visits). Densities were not affected by removal frequency (ANCOVA: $F_{2,21} = 7.2$, $p = 0.19$).

the number of returning Lion Fish down"). Others mentioning seeing fewer than previously (e.g. "seeing less lionfish than we have been down there", "feared it would be infested, not so") and there were 12 reports of searching for, but not finding lionfish at established dive sites. In contrast, other participants perceived culling to be ineffective (e.g. "From what I see diving and killing at the rate things are going is having about zero effect on this invasion), or noted high lionfish densities (e.g. "This area is a real hot spot", and "quite disturbing to see at least one Lionfish on top of every major coral head").

Our SCUBA survey detected no reduction in population density at culling sites relative to controls, so was qualitatively consistent with Reef Guardians' mixed perceptions. We used analysis of covariance (ANCOVA) to test for differences in lionfish density among sites varying in the frequency of Reef Guardians visits (a fixed categorical effect, levels = zero visits, few visits (1–5), and many visits (6–22)) and reef topographic complexity (a continuous covariate). Lionfish density at the 27 survey sites was not related to the frequency of Reef Guardians visits (ANCOVA: $F_{2,21} = 7.2$, $p = 0.19$; Figure 2), after accounting for a non-significant trend for lionfish density to be higher at sites with greater vertical relief (ANCOVA: $F_{1,21} = 7.2$, $p = 0.06$).

Lionfish size-distributions estimated from our SCUBA surveys (n = 86) were broadly similar to those derived from Reef Guardians' reports of lionfish culled (n = 330) and sighted (n = 33) (Figure 3). Neither dataset suggested an effect of culling on the population size-distribution. Our survey revealed no difference in lionfish sizes at Reef Guardians sites relative to control sites (Chi^2 test: Likelihood-ratio $Chi^2 = 6.5$, $df = 4$, $p = 0.16$; Figure 4).

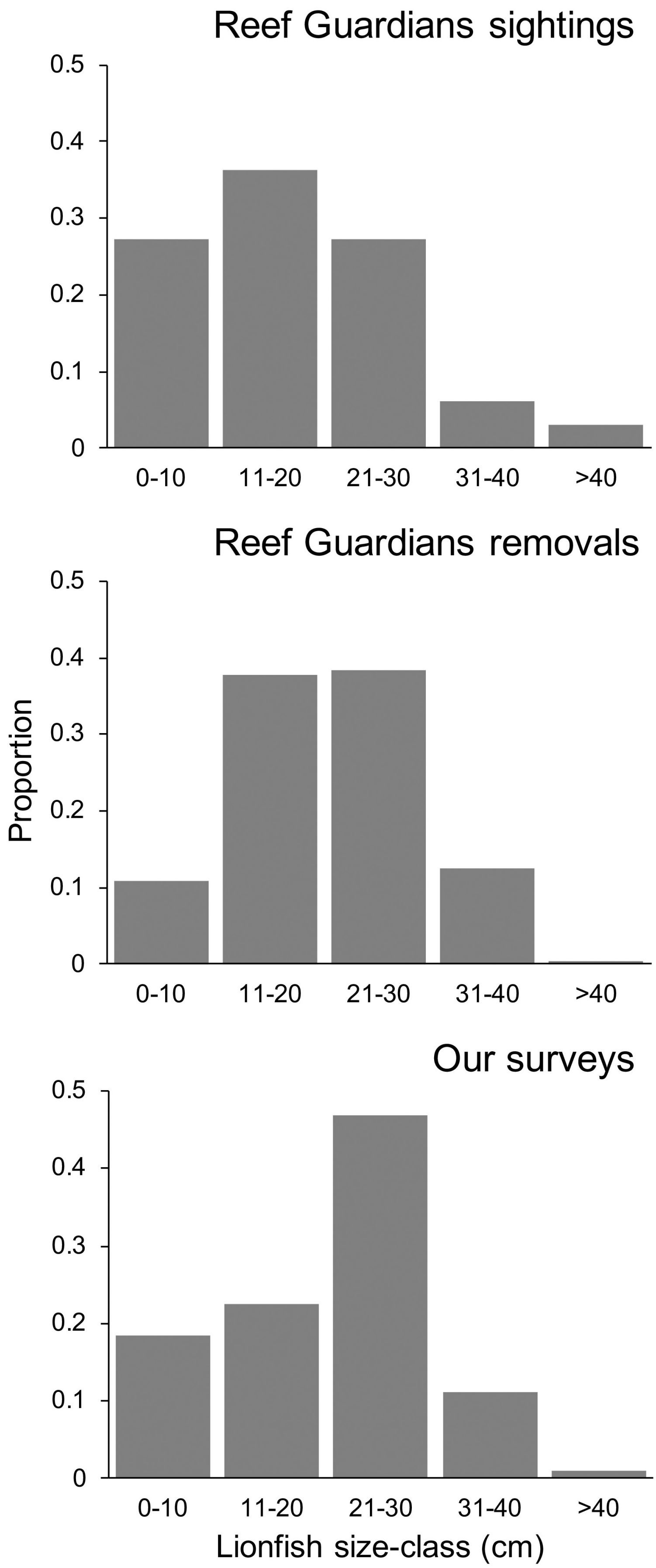

Figure 3. Overall size-distributions of lionfish sighted by Reef Guardians (top), culled by Reef Guardians (middle) and observed during our SCUBA surveys (bottom).

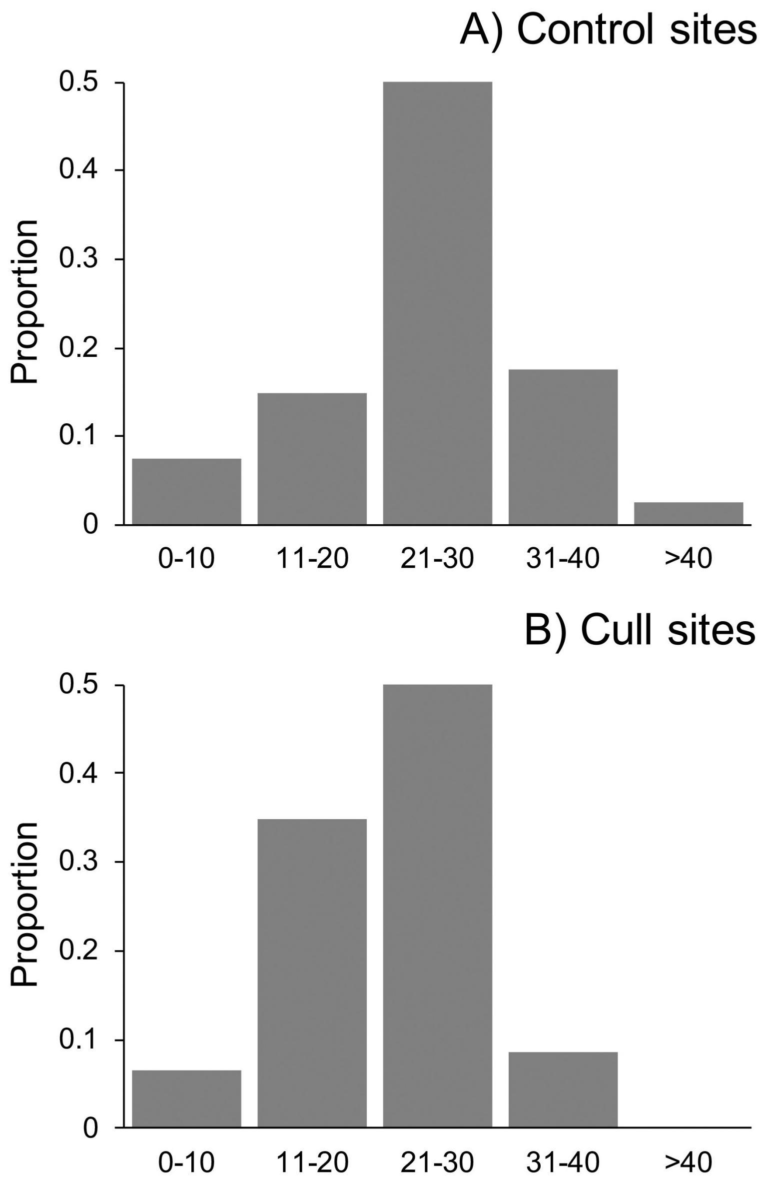

Figure 4. Lionfish size-distributions from our SCUBA survey at sites with (cull sites) and without (control sites) reported Reef Guardian visits. Size-distributions did not differ among cull and control sites ($Chi^2 = 6.5$, $df = 4$, $p = 0.16$).

Similarly, lionfish sizes reported by Reef Guardians' were unrelated to how often a site was subject to culling activity (Chi^2 test: Likelihood-ratio $Chi^2 = 8.17$, $df = 8$, $p = 0.42$; Figure 5).

Both Reef Guardian comments and our SCUBA surveys indicated that culling may have affected lionfish behaviour. Participants made 39 mentions of lionfish reacting when approached, with responses described most commonly as "skittish" (10 comments) or "hid" (8 comments), as well as "flighty", "sneaky", and "elusive". Our observations during the SCUBA survey corroborated these reports. Most lionfish we observed at control sites were sheltering but visible when first seen, whereas at Reef Guardians sites most lionfish were completely hidden in within the reef (Table 1). Lionfish we approached at Reef Guardians sites retreated slightly more frequently than those at control sites (but sample sizes were too small

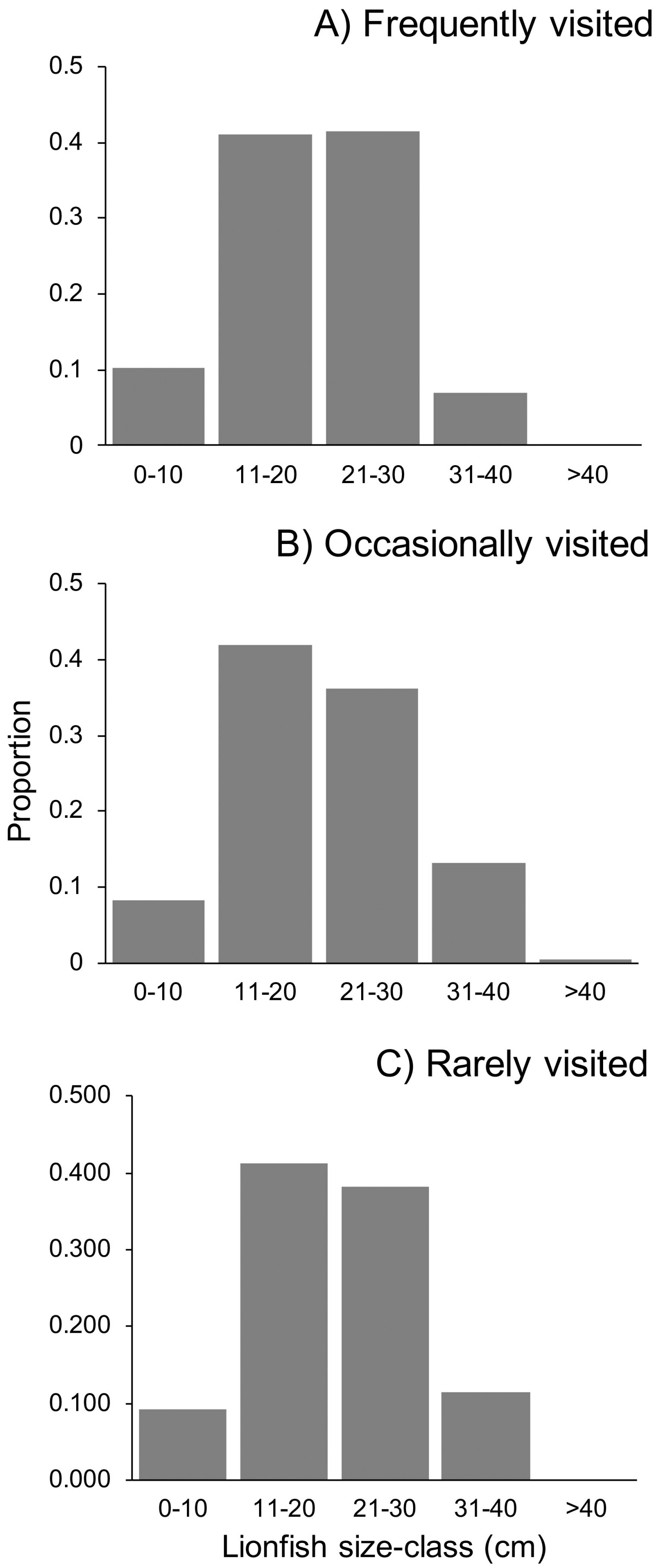

Figure 5. Lionfish size-distributions reported by Reef Guardians from sites with differing numbers of visits by participants: A) Frequent = 6–78 visits, B) Occasional = 2–5 visits and C) rare = 1 visit. Size-distributions were not affected by visitation ($Chi^2 = 8.17$, $df = 8$, $p = 0.42$).

Table 1. Culling lionfish increases their sheltering behaviour. Frequency (and %) of differing sheltering behaviours when lionfish were first observed: visible = out in the open; part-visible = sheltered within reef but easily visible, hidden = in shelter and not easily visible. Observations were made at sites visited by Reef Guardians (= cull sites) and sites with no recorded visits (= control sites), and frequencies differed among sites (Yates' $Chi^2 = 6.4$, $df = 2$, $p = 0.04$).

Behaviour	Cull sites	Control sites
Hidden	16 (53%)	10 (26%)
Part-visible	6 (20%)	20 (51%)
Visible	8 (27%)	9 (23%)

Table 2. Effect of culling on lionfish flight response. Frequency (and %) of differing responses when lionfish were approach by a diver: remain = remain in the open, retreat = retreat slowly to shelter, flee = flee rapidly to shelter. Observations were made at sites visited by Reef Guardians (= cull sites) and sites with no recorded visits (= control sites). Frequencies did not differ among sites (Yates' $Chi^2 = 0.9$, $df = 2$, $p = 0.61$) but sample sizes are too small for a reliable test.

Behaviour	Cull sites	Control sites
Flee	2 (8%)	2 (5%)
Retreat	11 (44%)	11 (30%)
Remain	12 (48%)	24 (65%)

for a statistical test; Table 2). One plausible reason for these reactions to divers was that attempted culls sometimes resulted in lionfish that "got away", were "missed" (44 posts) or "wounded" (6 posts).

Objective 2: Social media and participation in group activity

Group members differed greatly in the extent and nature of their activity, and their comments suggest that seeing the Facebook page may have encouraged some to participate. Of the 117 individuals who made Facebook posts, the ten most active accounted for 50% of all postings (11–107 posts each). These frequent participants were focused on removals (culls recorded in 78% of their posts) and accounted for 68% of all lionfish culled (981 lionfish). Thirty-five participants were moderately active (2–10 posts each) and their activity was split evenly between sightings and removals (culls mentioned in 43% of reports). The 72 remaining participants made just one report each, mostly sightings (72% of reports) and accounted for just 6% of culls (81 lionfish). Textual analysis indicated that all 10 frequent participants were employed locally in the marine tourism industry, and most moderately active participants were also BVI residents. Many infrequent participants, in contrast, appeared to be visitors and included snorkelers as well as divers (e.g. "I am a guest visiting Tortola for a snorkeling vacation"). Some infrequent participants first learned about lionfish from the group page (e.g. "was unaware of the species until saw a posting") or were encouraged to participate after seeing the page, sometimes after their visit to the BVI (e.g. "We have just returned from 10 days cruising in the BVI ", "just learned that they were an unwanted guest here in the BVIs, so we are contacting you to report our sighting"). By increasing awareness of the group, the Facebook page may thus have increased the total number of visitors who participated. These infrequent participants may not otherwise have become involved in group activity and acted primarily as spotters.

The content of posts indicated that the Facebook group was frequently used to coordinate culling activity by sharing information about the location of lionfish. Specific underwater locations of lionfish sighted were included in 49% of posts (320 posts) and in 45% of those posts (99 posts) participants mention placing markers where they had seen lionfish. Sighting locations were usually described in detail and included descriptions of above-water and under-water land marks, depth, habitat (e.g. "large coral head", "under ledge", "wall") with the implicit understanding that the information would be sufficient for other group members to find the lionfish. Most culling was apparently done with spear guns (mentioned in 40 posts) or hand nets (mentioned in 5 posts), both of which require searching underwater. Reef Guardians frequently reported (in 38 posts) searching for lionfish whose location had been previously marked (e.g. "found 2 Lionfish at your marker") or described (e.g. "got the two that were in the sand at pelican and also one by the mooring ball") or were following up on information received outside the Facebook group (e.g. "Thanks to …. for the tip"). Interactions among group members also included sharing or requesting information about removal activities (e.g. "Systematic searches are needed in this area", "My co-worker said there were more at … to go and get"). Overall, although many posts were simple reports of culls that did not mention prior sightings, it was clear that infrequent participants frequently used the Facebook page to report sightings and that Reef Guardians used those reports to gather information about where to hunt.

Although less explicitly connected to culling activity, many posts contained remarks apparently intended to motivate or encourage other participants. Most comments were non-specific (e.g. "great job", "yeah!", "lets keep up the good work", "go get em"), whereas others were implicitly or explicitly linked to reported sightings (e.g. "can't miss it", "Please kill and let me know?", "Still lots there though!", "Anyone available to remove it?").

Participants also requested and shared information about equipment, interactions with other fish while culling, consuming lionfish, and lionfish biology. Regular participants occasionally mentioned culling equipment (e.g. "My band has rotted thru on our gun, does anyone have a spare?"), but most comments about equipment were made by infrequent participants apologizing for not having markers to place at a sighting, reporting running out of markers, or asking where to get them (e.g. "I dont have those markers, any place I can pick up some?"). Several comments described consuming culled lionfish, sometimes sharing suggestions for handling and preparation (e.g. "were eaten for Supper filleted and wrapped in bacon"). Participants also shared information about lionfish ecology (e.g. "stomach empty", "regurgitated 4 small fish after we nailed him", "out in groups or mating pairs of 2"). The group thus provided a forum for sharing a variety of information, some of which was plausibly related to increased efficiency of locating and removing lionfish by participants.

Objective 3: Sharing attitudes and perceptions of participants about lionfish removal

The content of posts suggested participants were motivated by concern for the environment and viewed lionfish as a problem. Group activities were described as "protecting" or "saving" BVI reefs from the "invasive lionfish problem", and successful removals were described as "defeats" for lionfish. Lionfish themselves were always portrayed in negative terms (e.g. "mongrels", "beastly", "bugger"), and sites with high numbers were described in terms usually reserved for diseases ("infected", "infested", "plagued") or as "sad". Aspects of culling activity that could plausibly have been described in negative or discouraging terms were instead always described in neutral or positive language. Lionfish have venomous spines (Morris et al. 2009), and three reports of being stung by lionfish during attempted culls were reported in neutral terms accompanied by comments about first aid. Similarly, 17 posts mentioned feeding speared lionfish to predatory fish underwater (eels or sharks) and, although several mentioned "close passes" or "attention" from sharks, they did so in neutral language. Ciguatera poisoning, a potential health risk from consuming lionfish (Cearnal 2012), was mentioned just twice, and only in the context of submitting culled lionfish for testing.

Discussion

Objective 1: Effectiveness of removals

The Reef Guardians group was not run by professional scientists or resource managers, nor was its primary purpose to collect data for scientists. Information posted on the Facebook page was however amenable to scientific analysis, and the findings complemented and expanded upon our scientific assessment of the effect of culling on lionfish populations. Body-size data from Facebook and our scientific survey led to the same qualitative conclusion – no obvious impact of culling. Reef Guardians' perceptions about lionfish behaviour and abundance were also consistent with our survey data in suggesting that culling had made lionfish wary but did not appreciably reduce their population density.

Other efforts to assess lionfish culling programs consistently found that lionfish became wary of divers at culling sites (Andradi-Brown et al. 2017; Côté et al. 2014), but reported varying impacts on lionfish populations. Similar to our survey results, lionfish densities and body sizes were unaffected by culling inside a Costa-Rican marine park although culling also occurred at one or more of the outside sites used as a control (Sandel et al. 2015). In contrast, studies of volunteer culling programs in Bonaire and Little Cayman reported fewer and smaller lionfish at sites with higher levels of culling activity (de León et al. 2013; Frazer et al. 2012). One possible contributor to these differential impacts of culling is the relative rarity of lionfish in the BVI (Green and Cote 2009; Whitfield et al. 2007). Compared to BVI sites with no reported culling activity, lionfish were ≈ 3 times as dense at control sites in Bonaire, ≈ 6 times as dense in Costa Rica, and ≈ 10–40 times as dense in Little Cayman. Culling impacts are less likely when fish are sparse because, in spear-fisheries, catch-per-unit-effort and depletion rates decline when populations are small (Frazer et al. 2012; Godoy et al. 2010, 2016). Another contributing factor may be higher culling activity in Bonaire and Little Cayman. Culling in Little Cayman was organized for the study and may have concentrated effort at the 3 culling sites studied (Frazer et al. 2012), whereas high culling effort is expected in Bonaire simply because it reportedly has the most diving activity in the region (Tourism Corporation of Bonaire 2011). Systematic mining of fishers' knowledge and perceptions is increasingly being used by fisheries scientists to detect trends in the abundance of harvested fishes (e.g. Ainsworth 2011; Beaudreau and Levin 2014; Bender et al. 2013) and their response to harvesting (Hind 2015). Our findings suggest that this approach could also fruitfully be applied to self-reported information from social media networks (Ghermandi and Sinclair 2019). Such analysis may help explain differences in the reported effects of lionfish culling across their invasive range and assess the impact of culling programs generally (Shackleton et al. 2019).

Objective 2: participation

Advocating the use of lionfish markers was based on the assumption that it would "minimize search time during subsequent removal efforts" and "requires planned follow-up actions" (Carballo-Cárdenas and Tobi 2016; Morris 2012). A regionwide lionfish control and management guide noted that "Some divers in areas using markers have complained of the lack of response to marked fish and the negative aesthetics associated with seeing a dozen lionfish markers on a single dive site" (Morris 2012). Comments about markers on the Reef Guardians Facebook page were, in contrast, always positive or neutral in tone, suggesting ongoing support for their use. The Facebook page was also an effective mechanism for sharing information between the many casual participants who primarily reported sightings and facilitated follow-up by those actively culling lionfish. When fish are rare, and when repeated culling makes them go into hiding, spear fishers can spend much longer searching for targets and their catch-per-unit effort diminishes sharply (Coll et al. 2004; Godoy et al. 2016). We hypothesize that social networking may have decreased search times for those removing lionfish in the BVI because checking the Facebook group page before diving allowed them to identify sites where lionfish had already been located. Testing this hypothesis would, however, require comparative data from programs without "spotters".

How to effectively engage volunteers in environmental projects, including invasive species removals, has been studied extensively (Pages et al. 2019; Reed et al. 2018; Shackleton et al. 2019), but the use of social media groups has been largely ignored in these analyses (Triezenberg et al. 2012). Our intent was not to evaluate Reef Guardians' strategy for engagement, but we found it noteworthy that the Facebook page may have increased awareness of culling activity in the BVI and attracted casual participants who acted as "spotters". Perhaps more importantly, the group was used as a forum by core members to share information about lionfish and was frequently used to motivate and encourage one another. The forum allowed for a bidirectional flow of information between multiple participants and open conversational exchanges, both of which have been advocated as design features for successful engagement plans (Pages et al. 2019; Reed et al. 2018; Shackleton et al. 2019). For groups like Reef Guardians, whose members are dispersed and primarily act independently, dialogue over social media may thus help create a community of practice (Liberatore et al. 2018) and facilitate collective action (Lubeck et al. 2019; Marshall et al. 2016).

Objective 3: sharing attitudes and perceptions

Based on their Facebook comments, many Reef Guardians were motivated by concern for the environment, and connected eradicating lionfish to environmental stewardship. Helping the environment motivates volunteers to participate in many conservation activities (e.g. Bramston et al. 2011; Ryan et al. 2001; Schuett et al. 2014), and linking this perspective with hostility towards invasive species is characteristic of small volunteer groups committed to their eradication (e.g. Atchison et al. 2017; Shine and Doody 2011; Stromberg et al. 2009). Most core members of Reef Guardians were employed in the marine tourism industry, so they may also consider lionfish a threat to their livelihoods because coral reefs are one of the main attractions for BVI tourists (Hime 2008). Lionfish impacts on BVI reef ecosystems could thus reduce its attractiveness as a travel destination (Ballew et al. 2016; Green et al. 2012; Malpica-Cruz et al. 2017).

Scientists debate whether invasive species are "good" or "bad" (e.g. Brown and Sax 2004; Cassey et al. 2005; Colautti and MacIsaac 2004; Davis et al. 2011; Larson 2007) and public perceptions of invasive species are also complex and varied (Bremner and Park 2007; Schuttler et al. 2011). The dominant discourse among scientists and resource managers during the study period portrayed lionfish as a menace that placed entire reef ecosystems in jeopardy, and promoted lionfish culling as a way to fight this "enemy" (Carballo-Cárdenas 2015; Moore 2012). Although Reef Guardians and many other stakeholders in the region invaded by lionfish adopted this perspective, others raised a variety of ethical, economic and safety concerns and some did not support culling (Carballo-Cárdenas 2015; Carballo-Cárdenas and Tobi 2016; Jimenez et al. 2017; Malpica-Cruz et al. 2017; Scyphers et al. 2015). We cannot be certain why none of these alternate viewpoints were expressed on the Reef Guardians' Facebook page. One possible explanation is the tendency for social networks to aggregate individuals with similar values and attitudes. This phenomenon, observed primarily in social networks developed through interpersonal interaction, may also occur in social-media networks (Triezenberg et al. 2012).

Conclusions

The use of social media to recruit participants, collect scientific data and disseminate information has been well-studied (Bonney et al. 2014; Stafford et al. 2010). We found that networking via social media also provided Reef Guardians an effective means to facilitate communication amongst members, which helped coordinate and organize the groups' activity and motivated participants. Managing and directing volunteer interest is viewed as expensive, time-consuming and dependent on trained personnel (Morris 2012), giving an advantage to government agencies and large NGOs with greater resources (Bryce et al. 2011). Because community-based groups, like Reef Guardians, emphasize a "culture of action", they are informal and person-driven, with limited formal internal management (Lewis 2003). Similar groups include those focused on river restoration (Freeman and Ray 2001), sustainable forestry (Bradshaw 2003), cleaning up marine debris (Martin 2013), and culling other invasive species (Chao and Lin 2017; Pages et al. 2019; Shine and Doody 2011; Stromberg et al. 2009). For such groups, we hypothesize that social networking platforms provide a low-cost tool for group organization that will become increasingly important (Triezenberg et al. 2012). A comparative analysis of terrestrial control programs in Australia suggested that agency-initiated programs resulted in greater invasive species reductions than community-initiated actions, putatively because they were better funded and had more resources (Ford-Thompson et al. 2012). We hypothesize that expanded use of social-media networking may contribute to increasing the effectiveness of small volunteer groups. Lionfish management programs in other areas (e.g. Aruba, Bonaire, Curacao, Florida) have also created Facebook groups, which suggests the possibility of testing this hypothesis by examining how the use of social-media in volunteer-led lionfish removals compares to that in agency-led programs and derbies (Malpica-Cruz et al. 2016).

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Ethics and Permits

Research was performed under a marine scientific research permit issued by the Department of Conservation and Fisheries, Govt. of British Virgin Islands, and complied with institutional policies governing the humane and ethical treatment of the experimental subjects (URI IRB HU1112-140 and IACUC AN13-04-016).

References

Ainsworth CH (2011) Quantifying Species Abundance Trends in the Northern Gulf of California Using Local Ecological Knowledge. *Marine and Coastal Fisheries* 3: 190–218, https://doi.org/10.1080/19425120.2010.549047

Albins MA (2013) Effects of invasive Pacific red lionfish *Pterois volitans* versus a native predator on Bahamian coral-reef fish communities. *Biological Invasions* 15: 29–43, https://doi.org/10.1007/s10530-012-0266-1

Andradi-Brown DA, Grey R, Hendrix A, Hitchner D, Hunt CL, Gress E, Madej K, Parry RL, Regnier-McKellar C, Jones OP, Arteaga M, Izaguirre AP, Rogers AD, Exton DA (2017) Depth-dependent effects of culling-do mesophotic lionfish populations undermine current management? *Royal Society Open Science* 4: 170027, https://doi.org/10.1098/rsos.170027

Arnstein SR (1969) A ladder of citizen participation. *Journal of the American Institute of Planners* 35: 216–224, https://doi.org/10.1080/01944366908977225

Atchison J, Gibbs L, Taylor E (2017) Killing Carp (*Cyprinus carpio*) as a Volunteer Practice: implications for community involvement in invasive species management and policy. *Australian Geographer* 48: 333–348, https://doi.org/10.1080/00049182.2016.1265229

Ballew NG, Bacheler NM, Kellison GT, Schueller AM (2016) Invasive lionfish reduce native fish abundance on a regional scale. *Scientific Reports* 6: 32169, https://doi.org/10.1038/srep32169

Barbour AB, Allen MS, Frazer TK, Sherman KD (2011) Evaluating the Potential Efficacy of Invasive Lionfish (*Pterois volitans*) Removals. *PLoS ONE* 6: e19666, https://doi.org/10.1371/journal.pone.0019666

Beaudreau AH, Levin PS (2014) Advancing the use of local ecological knowledge for assessing data-poor species in coastal ecosystems. *Ecological Applications* 24: 244–256, https://doi.org/10.1890/13-0817.1

Bejarano S, Lohr K, Hamilton S, Manfrino C (2015) Relationships of invasive lionfish with topographic complexity, groupers, and native prey fishes in Little Cayman. *Marine Biology* 162: 253–266, https://doi.org/10.1007/s00227-014-2595-3

Bender MG, Floeter SR, Hanazaki N (2013) Do traditional fishers recognise reef fish species declines? Shifting environmental baselines in Eastern Brazil. *Fisheries Management and Ecology* 20: 58–67, https://doi.org/10.1111/fme.12006

Bhattacherjee A (2012) Social science research: Principles, methods, and practices. University of South Florida, Tampa, Florida, USA, 159 pp

Boag H (2014) Invasive-species control: Bounty hunters. *Nature* 513: 294–295, https://doi.org/10.1038/513294a

Bonney R, Shirk JL, Phillips TB, Wiggins A, Ballard HL, Miller-Rushing AJ, Parrish JK (2014) Next Steps for Citizen Science. *Science* 343: 1436–1437, https://doi.org/10.1126/science.1251554

Bradshaw B (2003) Questioning the credibility and capacity of community-based resource management. *Canadian Geographer* 47: 137–150, https://doi.org/10.1111/1541-0064.t01-1-00001

Bramston P, Pretty G, Zammit C (2011) Assessing Environmental Stewardship Motivation. *Environment and Behavior* 43: 776–788, https://doi.org/10.1177/0013916510382875

Bremner A, Park K (2007) Public attitudes to the management of invasive non-native species in Scotland. *Biological Conservation* 139: 306–314, https://doi.org/10.1016/j.biocon.2007.07.005

Brown JH, Sax DF (2004) An essay on some topics concerning invasive species. *Austral Ecology* 29: 530–536, https://doi.org/10.1111/j.1442-9993.2004.01340.x

Bryce R, Oliver MK, Davies L, Gray H, Urquhart J, Lambin X (2011) Turning back the tide of American mink invasion at an unprecedented scale through community participation and adaptive management. *Biological Conservation* 144: 575–583, https://doi.org/10.1016/j.biocon.2010.10.013
Butcher J (2007) Ecotourism, NGOs and Development: A Critical Analysis. Routledge, New York, New York USA, 222 pp, https://doi.org/10.4324/9780203962077
Carballo-Cárdenas EC (2015) Controversies and consensus on the lionfish invasion in the Western Atlantic Ocean. *Ecology and Society* 20: 24, https://doi.org/10.5751/ES-07726-200324
Carballo-Cárdenas EC, Tobi H (2016) Citizen science regarding invasive lionfish in Dutch Caribbean MPAs: Drivers and barriers to participation. *Ocean & Coastal Management* 133: 114–127, https://doi.org/10.1016/j.ocecoaman.2016.09.014
Carroll TF (1992) Intermediary NGOs: the supporting link in grassroots development. Kumarian Press, West Hartford, 288 pp
Cassey P, Blackburn TM, Duncan RP, Chown SL (2005) Concerning invasive species: Reply to Brown and Sax. *Austral Ecology* 30: 475–480, https://doi.org/10.1111/j.1442-9993.2005.01505.x
Cearnal L (2012) Red Lionfish and Ciguatoxin Menace Spreading Through Western Hemisphere. *Annals of Emergency Medicine* 60: 21A–22A, https://doi.org/10.1016/j.annemergmed.2012.05.022
Chao RF, Lin TE (2017) Effect of citizen action on suppression of invasive alien lizard population: A case of the removal of Eutropis multifasciata on Green Island, Taiwan. *Applied Ecology and Environmental Research* 15: 1–13, https://doi.org/10.15666/aeer/1502_001013
Checkoway B (1995) Six strategies of social change. *Community Development Journal* 30: 115–133, https://doi.org/10.1093/cdj/30.1.2
Colautti RI, MacIsaac HJ (2004) A neutral terminology to define 'invasive' species. *Diversity and Distributions* 10: 135–141, https://doi.org/10.1111/j.1366-9516.2004.00061.x
Coll J, Linde M, García-Rubies A, Riera F, Grau AM (2004) Spear fishing in the Balearic Islands (west central Mediterranean): species affected and catch evolution during the period 1975-2001. *Fisheries Research* 70: 97–111, https://doi.org/10.1016/j.fishres.2004.05.004
Côté I, Smith N (2018) The lionfish *Pterois* sp. invasion: Has the worst-case scenario come to pass? *Journal of Fish Biology* 92: 660–689, https://doi.org/10.1111/jfb.13544
Côté IM, Darling ES, Malpica-Cruz L, Smith NS, Green SJ, Curtis-Quick J, Layman C (2014) What Doesn't Kill You Makes You Wary? Effect of Repeated Culling on the Behaviour of an Invasive Predator. *PLoS ONE* 9: e94248, https://doi.org/10.1371/journal.pone.0094248
Dahl KA, Patterson WF, Snyder RA (2016) Experimental assessment of lionfish removals to mitigate reef fish community shifts on northern Gulf of Mexico artificial reefs. *Marine Ecology Progress Series* 558: 207–221, https://doi.org/10.3354/meps11898
Daume S, Galaz V (2016) "Anyone Know What Species This Is?" - Twitter Conversations as Embryonic Citizen Science Communities. *PLoS ONE* 11: e0151387, https://doi.org/10.1371/journal.pone.0151387
Davis M, Chew MK, Hobbs RJ, Lugo AE, Ewel JJ, Vermeij GJ, Brown JH, Rosenzweig ML, Gardener MR, Carroll SP, Thompson K, Pickett STA, Stromberg JC, Del Tredici P, Suding KN, Ehrenfeld JG, Grime JP, Mascaro J, Briggs JC (2011) Don't judge species on their origins. *Nature* 474: 153–154, https://doi.org/10.1038/474153a
de León R, Vane K, Bertuol P, Chamberland VC, Simal F, Imms E, Vermeij MJA (2013) Effectiveness of lionfish removal efforts in the southern Caribbean. *Endangered Species Research* 22: 175–182, https://doi.org/10.3354/esr00542
Donlan CJ, Tershy BR, Campbell K, Cruz F (2003) Research for Requiems: the Need for More Collaborative Action in Eradication of Invasive Species. *Conservation Biology* 17: 1850–1851, https://doi.org/10.1111/j.1523-1739.2003.00012.x
Ford-Thompson AES, Snell C, Saunders G, White PCL (2012) Stakeholder Participation in Management of Invasive Vertebrates. *Conservation Biology* 26: 345–356, https://doi.org/10.1111/j.1523-1739.2011.01819.x
Frazer TK, Jacoby CA, Edwards MA, Barry SC, Manfrino CM (2012) Coping with the Lionfish Invasion: Can Targeted Removals Yield Beneficial Effects? *Reviews in Fisheries Science* 20: 185–191, https://doi.org/10.1080/10641262.2012.700655
Freeman RE, Ray RO (2001) Landscape ecology practice by small scale river conservation groups. *Landscape and Urban Planning* 56: 171–184, https://doi.org/10.1016/S0169-2046(01)00181-5
Ghermandi A, Sinclair M (2019) Passive crowdsourcing of social media in environmental research: A systematic map. *Global Environmental Change* 55: 36–47, https://doi.org/10.1016/j.gloenvcha.2019.02.003
Gleason J, Gullick H (2014) Bermuda Lionfish Control Plan. Bermuda Lionfish Task Force, Bermuda, 60 pp
Godoy N, Gelcich S, Vásquez JA, Castilla JC (2010) Spearfishing to depletion: evidence from temperate reef fishes in Chile. *Ecological Applications* 20: 1504–1511, https://doi.org/10.1890/09-1806.1
Godoy N, Gelcich S, Castilla JC, Lima M, Smith A (2016) Artisanal Spearfishery in Temperate Nearshore Ecosystems of Chile: Exploring the Catch Composition, Revenue, and

Management Needs. *Marine and Coastal Fisheries* 8: 436–447, https://doi.org/10.1080/19425120.2016.1185062
Green SJ, Cote IM (2009) Record densities of Indo-Pacific lionfish on Bahamian coral reefs. *Coral Reefs* 28: 107–107, https://doi.org/10.1007/s00338-008-0446-8
Green SJ, Akins JL, Maljkovic A, Cote IM (2012) Invasive Lionfish Drive Atlantic Coral Reef Fish Declines. *PLoS ONE* 7: e32596, https://doi.org/10.1371/journal.pone.0032596
Green SJ, Tamburello N, Miller SE, Akins JL, Côté IM (2013) Habitat complexity and fish size affect the detection of Indo-Pacific lionfish on invaded coral reefs. *Coral Reefs* 32: 413–421, https://doi.org/10.1007/s00338-012-0987-8
Hime SP (2008) The Effect of Marine Based Tourism on the Coral Reefs of the British Virgin Islands. PhD thesis, University of East Anglia, Norwich, United Kingdom, 218 pp
Hind EJ (2015) A review of the past, the present, and the future of fishers' knowledge research: a challenge to established fisheries science. *ICES Journal of Marine Science* 72: 341–358, https://doi.org/10.1093/icesjms/fsu169
Jimenez C, Andreou V, Hadjioannou L, Petrou A, Alhaija RA, Patsalou P (2017) Not everyone's cup of tea: Public perception of culling invasive lionfish in Cyprus. *Journal of the Black Sea/Mediterranean Environment* 23: 38–47
Johnson B, Gore S, Lockhart K (2010) Red Lionfish (*Pterois volitans*) Control Strategies in the Caribbean UK Overseas Territories (Cayman Islands, Virgin Islands, and Turks and Caicos). *Proceedings of the Sixty Third Annual Gulf and Caribbean Fisheries Institute* 63: 331–333
Larson BMH (2007) An alien approach to invasive species: objectivity and society in invasion biology. *Biological Invasions* 9: 947–956, https://doi.org/10.1007/s10530-007-9095-z
Lewis D (2003) Theorizing the organization and management of non-governmental development organizations. *Public Management Review* 5: 325–344, https://doi.org/10.1080/1471903032000146937
Liberatore A, Bowkett E, MacLeod CJ, Spurr E, Longnecker N (2018) Social Media as a Platform for a Citizen Science Community of Practice. *Citizen Science: Theory and Practice* 3: 3, https://doi.org/10.5334/cstp.108
Lopez-Gomez MJ, Aguilar-Perera A, Perera-Chan L (2014) Mayan diver-fishers as citizen scientists: detection and monitoring of the invasive red lionfish in the Parque Nacional Arrecife Alacranes, southern Gulf of Mexico. *Biological Invasions* 16: 1351–1357, https://doi.org/10.1007/s10530-013-0582-0
Lubeck A, Metcalf A, Beckman C, Yung L, Angle J (2019) Collective factors drive individual invasive species control behaviors: evidence from private lands in Montana, USA. *Ecology and Society* 24: 32, https://doi.org/10.5751/ES-10897-240232
Malpica-Cruz L, Chaves LCT, Côté IM (2016) Managing marine invasive species through public participation: Lionfish derbies as a case study. *Marine Policy* 74: 158–164, https://doi.org/10.1016/j.marpol.2016.09.027
Malpica-Cruz L, Haider W, Smith NS, Fernández-Lozada S, Côté IM (2017) Heterogeneous Attitudes of Tourists toward Lionfish in the Mexican Caribbean: Implications for Invasive Species Management. *Frontiers in Marine Science* 4: 138, https://doi.org/10.3389/fmars.2017.00138
Margerum RD (2008) A typology of collaboration efforts in environmental management. *Environmental Management* 41: 487–500, https://doi.org/10.1007/s00267-008-9067-9
Marshall GR, Coleman MJ, Sindel BM, Reeve IJ, Berney PJ (2016) Collective action in invasive species control, and prospects for community-based governance: The case of serrated tussock (*Nassella trichotoma*) in New South Wales, Australia. *Land Use Policy* 56: 100–111, https://doi.org/10.1016/j.landusepol.2016.04.028
Martin JM (2013) Marine debris removal: One year of effort by the Georgia Sea Turtle-Center-Marine Debris Initiative. *Marine Pollution Bulletin* 74: 165–169, https://doi.org/10.1016/j.marpolbul.2013.07.009
McCormick MI (1994) Comparison of field methods for measuring surface topography and their associations with a tropical reef fish assemblage. *Marine Ecology-Progress Series* 112: 87–96, https://doi.org/10.3354/meps112087
McCurley S, Lynch R (2011) Volunteer management : mobilizing all the resources of the community. Interpub Group Corporation, Plattsburgh, NY, 418 pp
Moore A (2012) The aquatic invaders: Marine Management Figuring Fishermen, Fisheries, and Lionfish in The Bahamas. *Cultural Anthropology* 27: 667–688, https://doi.org/10.1111/j.1548-1360.2012.01166.x
Morris JA (2012) Invasive Lionfish: A Guide to Control and Management. Gulf and Caribbean Fisheries Institute Special Publication Series Number 1, Marathon, Florida, USA, 113 pp
Morris JA, Akins JL, Barse A, Cerino D, Freshwater DW, Green SJ, Muñoz RC, Paris C, Whitfield PE (2009) Biology and ecology of the invasive lionfishes, *Pterois miles* and *Pterois volitans*. *Proceeding of the 61st Gulf and Caribbean Fisheries Institute* 29: 409–414
Newman G, Wiggins A, Crall A, Graham E, Newman S, Crowston K (2012) The future of citizen science: emerging technologies and shifting paradigms. *Frontiers in Ecology and the Environment* 10: 298–304, https://doi.org/10.1890/110294

Niemiec RM, Ardoin NM, Wharton CB, Asner GP (2016) Motivating residents to combat invasive species on private lands: social norms and community reciprocity. *Ecology and Society* 21: 30, https://doi.org/10.5751/ES-08362-210230
Pages M, Fischer A, van der Wal R, Lambin X (2019) Empowered communities or "cheap labour"? Engaging volunteers in the rationalised management of invasive alien species in Great Britain. *Journal of Environmental Management* 229: 102–111, https://doi.org/10.1016/j.jenvman.2018.06.053
Pasko S, Goldberg J (2014) Review of harvest incentives to control invasive species. *Management of Biological Invasions* 5: 263, https://doi.org/10.3391/mbi.2014.5.3.10
Pyšek P, Richardson DM (2010) Invasive species, environmental change and management, and health. *Annual Review of Environment and Resources* 35: 25–55, https://doi.org/10.1146/annurev-environ-033009-095548
Rabb GB, Sullivan TA (1995) Coordinating conservation: global networking for species survival. *Biodiversity and Conservation* 4: 536–543, https://doi.org/10.1007/BF00222512
Reed MS (2008) Stakeholder participation for environmental management: A literature review. *Biological Conservation* 141: 2417–2431, https://doi.org/10.1016/j.biocon.2008.07.014
Reed MS, Vella S, Challies E, Vente Jd, Frewer L, Hohenwallner-Ries D, Huber T, Neumann RK, Oughton EA, Ceno JSd, Delden Hv (2018) A theory of participation: what makes stakeholder and public engagement in environmental management work? *Restoration Ecology* 26: S7–S17, https://doi.org/10.1111/rec.12541
Reef Guardians (2014) https://www.reefguardians.org/ (accessed 12 April 2014)
Ritchie J, Lewis J, Nicholls CM, Ormston R (2013) Qualitative research practice: A guide for social science students and researchers. SAGE Publications, London, UK, 336 pp
Ryan RL, Kaplan R, Grese RE (2001) Predicting Volunteer Commitment in Environmental Stewardship Programmes. *Journal of Environmental Planning and Management* 44: 629–648, https://doi.org/10.1080/09640560120079948
Sandel V, Martinez-Fernandez D, Wangpraseurt D, Sierra L (2015) Ecology and management of the invasive lionfish *Pterois volitans/miles* complex (Perciformes: Scorpaenidae) in Southern Costa Rica. *Revista De Biologia Tropical* 63: 213–221, https://doi.org/10.15517/rbt.v63i1.14749
Schofield P (2009) Geographic extent and chronology of the invasion of non-native lionfish (*Pterois volitans* [Linnaeus 1758] and *P. miles* [Bennett 1828]) in the Western North Atlantic and Caribbean Sea. *Aquatic Invasions* 4: 473–479, https://doi.org/10.3391/ai.2009.4.3.5
Schuett MA, Kyle GT, Leitz J, Kurzawski K, Lee K (2014) Anglers' Motivations for Volunteering with Fishing or Conservation Organizations. *Fisheries* 39: 305–311, https://doi.org/10.1080/03632415.2014.924407
Schuttler E, Rozzi R, Jax K (2011) Towards a societal discourse on invasive species management: A case study of public perceptions of mink and beavers in Cape Horn. *Journal for Nature Conservation* 19: 175–184, https://doi.org/10.1016/j.jnc.2010.12.001
Scyphers SB, Powers SP, Akins JL, Drymon JM, Martin CW, Schobernd ZH, Schofield PJ, Shipp RL, Switzer TS (2015) The Role of Citizens in Detecting and Responding to a Rapid Marine Invasion. *Conservation Letters* 8: 242–250, https://doi.org/10.1111/conl.12127
Shackleton RT, Adriaens T, Brundu G, Dehnen-Schmutz K, Estévez RA, Fried J, Larson BM, Liu S, Marchante E, Marchante H (2019) Stakeholder engagement in the study and management of invasive alien species. *Journal of Environmental Management* 229: 88–101, https://doi.org/10.1016/j.jenvman.2018.04.044
Sharp RL, Larson LR, Green GT (2011) Factors influencing public preferences for invasive alien species management. *Biological Conservation* 144: 2097–2104, https://doi.org/10.1016/j.biocon.2011.04.032
Shine R, Doody JS (2011) Invasive species control: understanding conflicts between researchers and the general community. *Frontiers in Ecology and the Environment* 9: 400–406, https://doi.org/10.1890/100090
Silvertown J (2009) A new dawn for citizen science. *Trends In Ecology & Evolution* 24: 467–471, https://doi.org/10.1016/j.tree.2009.03.017
Simberloff D (2009) We can eliminate invasions or live with them. Successful management projects. Biological Invasions 11: 149-157, https://doi.org/10.1007/s10530-008-9317-z
Simberloff D, Martin J-L, Genovesi P, Maris V, Wardle DA, Aronson J, Courchamp F, Galil B, García-Berthou E, Pascal M (2013) Impacts of biological invasions: what's what and the way forward. *Trends In Ecology & Evolution* 28: 58–66, https://doi.org/10.1016/j.tree.2012.07.013
Stafford R, Hart AG, Collins L, Kirkhope CL, Williams RL, Rees SG, Lloyd JR, Goodenough AE (2010) Eu-Social Science: The Role of Internet Social Networks in the Collection of Bee Biodiversity Data. *PLoS ONE* 5: e14381, https://doi.org/10.1371/journal.pone.0014381
Staples L (2012) Community Organizing for Social Justice: Grassroots Groups for Power. *Social Work with Groups* 35: 287–296, https://doi.org/10.1080/01609513.2012.656233
Stromberg JC, Chew MK, Nagler PL, Glenn EP (2009) Changing Perceptions of Change: The Role of Scientists in Tamarix and River Management. *Restoration Ecology* 17: 177–186, https://doi.org/10.1111/j.1526-100X.2008.00514.x

Tourism Corporation of Bonaire (2011) Bonaire Tourism: Annual Statistics Report 2011. Kralendijk, Bonaire, 36 pp

Triezenberg H, Knuth B, Yuan YC, Dickinson J (2012) Internet-Based Social Networking and Collective Action Models of Citizen Science: Theory Meets Possibility: Public Participation in Environmental Research. In: Dickinson JL, Bonney R (eds), Citizen science: Public participation in environmental research. Cornell University Press, Ithaca, New York USA, pp 214–225, https://doi.org/10.7591/cornell/9780801449116.003.0016

Usseglio P, Selwyn JD, Downey-Wall AM, Hogan JD (2017) Effectiveness of removals of the invasive lionfish: how many dives are needed to deplete a reef? *PeerJ* 5: e3043, https://doi.org/10.7717/peerj.3043

Whitfield PE, Hare JA, David AW, Harter SL, Munoz RC, Addison CM (2007) Abundance estimates of the Indo-Pacific lionfish *Pterois volitans*/*miles* complex in the Western North Atlantic. *Biological Invasions* 9: 53–64, https://doi.org/10.1007/s10530-006-9005-9

Wilcox CL, Motomura H, Matsunuma M, Bowen BW (2017) Phylogeography of lionfishes (*Pterois*) indicate taxonomic over splitting and hybrid origin of the invasive *Pterois volitans*. *Journal of Heredity* 109: 162–175, https://doi.org/10.1093/jhered/esx056