

Working up an appetite for lionfish: A market-based approach to manage the invasion of *Pterois volitans* in Belize

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ABSTRACT

Located on the Caribbean coast of Central America and flanked by the second longest barrier reef in the world, Belize is a nation reliant upon marine resources. Each year, the country's predominantly small-scale fisheries generate an estimated US\$22 million in revenue – 1.8% of GDP – and employ 3000 people. However, the nation's fishing communities are facing an unprecedented challenge. Existing threats posed by declining fish stocks have been exacerbated by the introduction of the invasive alien red lionfish *Pterois volitans* in 2008. This Indo-Pacific predator has the potential to cause significant losses to the recruitment of native fish, in turn disrupting coral reef community dynamics in the Belize Barrier Reef Reserve System, a UNESCO World Heritage Site. However, targeted lionfish fishing may offer a cost effective means to control the invasion, while also creating an alternative livelihood solution and improving food security among Belize's coastal fishing communities. This study summarises the recent history of the lionfish invasion in Belize, describes the multi-sector approach being used to address the invasion, and presents preliminary research summarising the characteristics of invasive alien lionfish in Belize. Data from Belize's nascent 'lionfishery' are also presented, demonstrating that demand for lionfish is outweighing supply – largely as a result of awareness-raising initiatives – and highlighting the strong potential for replication of this approach elsewhere in the Caribbean. The study concludes by discussing the barriers and potential solutions to this market-based approach to invasive species management.

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1. Introduction

1.1. A need for fisheries diversification in Belize

In Belize, small-scale fisheries account for 95% of national fisheries landings [1]. A 2010 ban on trawling saw an end to the country's shrimp industry and the few remaining industrial tuna, billfish and sharks fisheries are typically foreign-owned, contributing less than 1% of finfish caught for the domestic market [2].

The country's commercial fisheries are dominated by Queen conch (*Strombus gigas*) and Caribbean spiny lobster (*Panulirus argus*) which together generate US\$13 million/year in revenue [3,4]. The majority of lobster and conch landings (47% and 90%, respectively) are exported, primarily to the USA, with smaller volumes (37% of lobster) being sold to the tourist market and even fewer (16% lobster, 10% conch) reaching domestic markets [2]. Both fisheries are considered to be fully- or over-exploited, with total reported landings steadily declining since the advent of

commercial fishing in the 1970s [2,4–7].

Domestic seafood demand is met by subsistence and artisanal finfish fisheries, with yellowtail snapper (*Ocyurus chrysurus*) and mutton snapper (*Lutjanus analis*) the most commonly caught species [2]. These finfish fisheries provide not only a vital source of income but important food security in a country where 43% of the population – particularly those in coastal communities – live below the poverty line [8–10]. However, like conch and lobster, finfish landings have been in decline since the 1980s [2]. For example, total landed catch for the mutton snapper fishery at the Gladden Spit spawning aggregation in southern Belize decreased from over 70 t in 1987 to less than 20 t annually since 1990 [11]. Catch per unit effort (CPUE) also decreased significantly in the early 2000s [11,12], with a 59% decline recorded from 2000 to 2002 [12]. Although fishing restrictions appear to have stabilised the CPUE at this site since 2006 [11], competition for fisheries resources elsewhere is growing. The number of fishers in northern Belize has risen sharply in recent years due to the erosion of sugarcane markets in the USA and Europe, prompting farmers to convert to the fishing industry [13].

Despite measures to protect Belize's marine resources – over 20% of the country's territorial sea is under management, constituting Belize marine protected area (MPA) system, only 2.1% is

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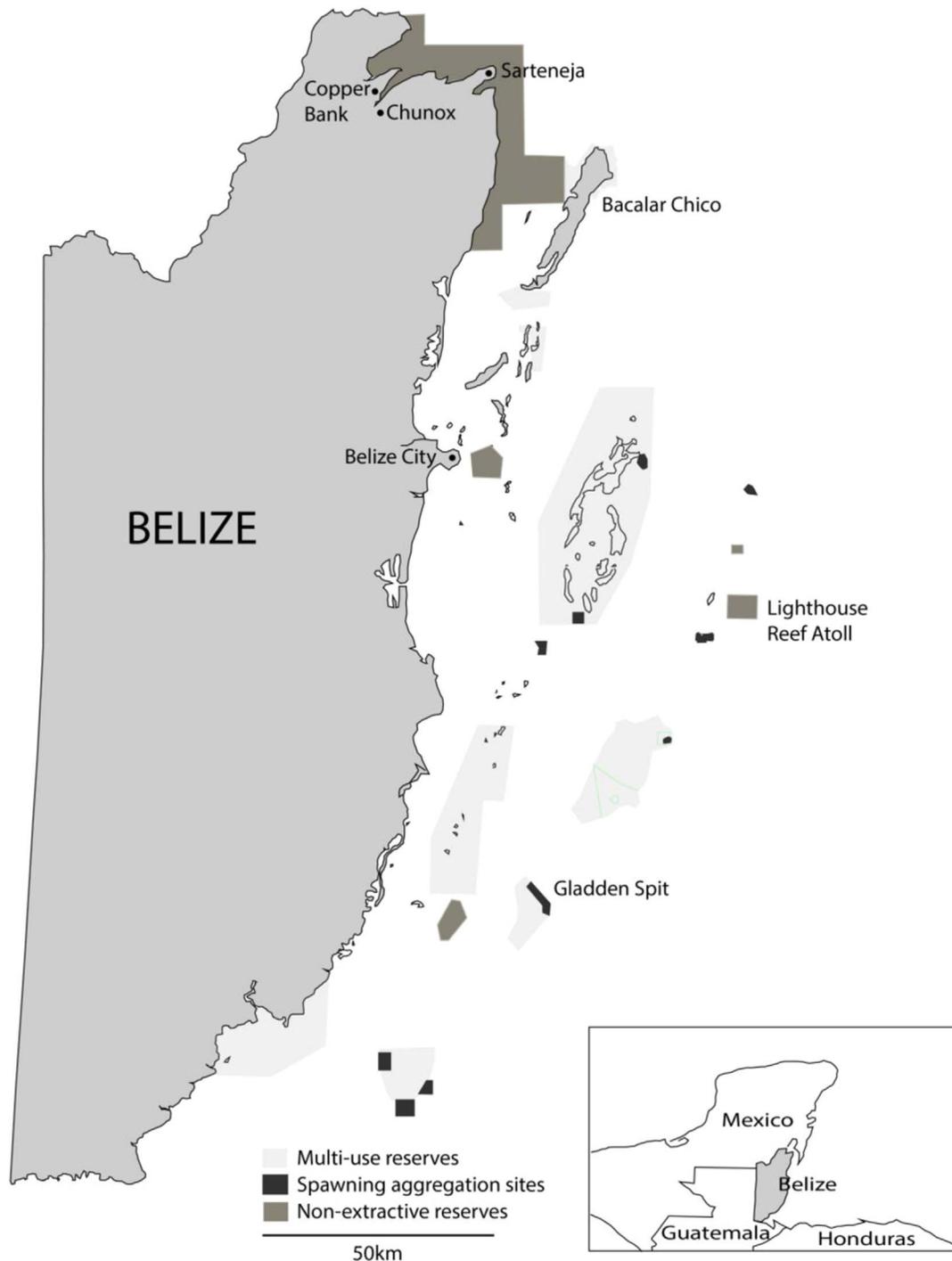


Fig. 1. Map of Belize showing the locations of the country's marine protected areas and the field sites detailed within this study.

non-extractive [14]. Although conch and lobster respond well to full protection [15,16], populations show declining trends within the majority of Belize's MPAs [17–19,20], suggesting that existing MPA management is not effective in safeguarding stocks.

Despite the declining state of fisheries, the expansion of no take zones (NTZs) to address declining stocks could have significant negative socio-economic impacts on coastal fishing communities in the short term. This is of particular concern in Sarteneja, Belize's largest fishing community, where over 80% of households are directly dependent upon fishing as their primary source of income [21]. Sartenejan fishing boats are active throughout the Belize Barrier Reef System (BRRS) [22] and are the primary users of six of

Belize's nine marine reserves, as well as Lighthouse Reef Atoll Management Unit and Corozal Bay Wildlife Sanctuary [23–26] (Fig. 1). With such a high dependency upon fishing across the BRRS, Sarteneja's fishing economy is particularly vulnerable to declining fish stocks. Livelihood diversification is therefore required to reduce the community's dependence on declining fisheries.

2. Invasive lionfish threaten coral reefs and fisheries

Across the Caribbean, the invasion of red lionfish (*Pterois*

volitans) poses a pervasive threat to marine ecosystems and coastal fishing communities. The alien invasive species, native to the tropical Indo-Pacific, was first reported in the Atlantic Ocean off South Florida in the 1980s, with release from aquaria the most likely route of its original introduction [22,27]. The species quickly established and spread and was first documented in Belize in December 2008 [28]. Recent genetic tests confirm that the introduced population's range has since expanded as far south as Brazil [29].

The high fecundity and generalist diet of lionfish has enabled the species to establish quickly in diverse habitats including coral reefs, mangroves, seagrass beds and man-made structures (e.g. oil rigs, artificial reefs, ship wrecks) from surface waters to depths of 300 m throughout the wider Caribbean region [28,30,31]. Female lionfish reach reproductive maturity in < 1 year compared to 2–4 years for comparable native species such as the mutton snapper, tiger grouper and Nassau grouper and produce between 10,000 and 40,000 eggs per spawning event [4,32]. Although lower than the per-event fecundity of ecologically similar native Caribbean mesopredators such as the Mutton snapper *Lutjanus analis* and Nassau grouper *Epinephelus striatus* – both of which produce over 300,000 eggs per annual spawning event [33] – lionfish are reproductively active throughout the year, releasing up to 2 million eggs per year when conditions are favourable [27].

Lionfish have almost three times the prey consumption rate of native counterparts such as the coney grouper (*Cephalopholis fulva*) [34] and considerably higher rates of consumption in the Caribbean than in their native range [35]. They therefore have the potential to pose a significant threat to fish recruitment and cause the competitive exclusion of other native predators [27,34,36]. In an experimental study in the Caribbean, lionfish reduced the abundance of native reef fish by up to 94% and reduced species richness by 5 species within a period of 8 weeks [34]. While another small-scale study in the Bahamas indicates that increases in the abundance of lionfish between 2004 and 2010 caused a 65% decline in the biomass of native prey species [37]. This success has been attributed to their abundant venomous spines resulting in a lack of predatory pressure [38,39].

3. Characteristics of Belizean lionfish populations

Due to their cryptic nature and crepuscular activity patterns, the density of lionfish is often underestimated by traditional underwater visual census (UVC) techniques [40]. Accurate estimates of lionfish density and biomass across multiple depths have previously been lacking in Belize. However, lionfish sighting data collected in Bacalar Chico Marine Reserve (BCMR) since 2010 indicate that the size and abundance of lionfish have increased over the past four years of monitoring.

By adapting the lionfish-focused search (LFS) method [40] to allow surveying of coral reefs from 1 to 30 m in depth, preliminary results indicate that in 2014, mean lionfish population density across BCMR had reached 27.1 ± 8.8 fish ha^{-1} (max 57.1 ± 17.4 fish ha^{-1} ; $n = 59$ transects), while in Gladden Spit and Silk Cayes Marine Reserve (GSSCMR), the mean density was 26.2 ± 157.54 fish ha^{-1} (max 550 ± 150 fish ha^{-1} ; $n = 16$ transects). These initial records suggest that in some parts of the Belize Barrier Reef Reserve System, lionfish densities are higher than those reported in their native range: 0.27–47.9 fish ha^{-1} [41,42], however they remain lower than those reported elsewhere in the Caribbean (e.g. Bahamas 101.7 ± 103.0 fish ha^{-1} [43]). The only other lionfish density surveys conducted in Belize following the LFS method reported a mean density of 11.1 ± 4.2 fish ha^{-1} in 2013 across 15 sites spanning the 250 km length of the country [44]. However lionfish were only sampled at a narrow depth range of 12–15 m, while in

this study much higher densities of lionfish were observed on transects at a depth of 18–30 m (43.39 ± 13.76 fish ha^{-1}) than on shallower reefs (at 1–5 m depth density = 5.56 ± 5.56 fish ha^{-1} ; 8–15 m depth, density = 29.63 ± 14.10 fish ha^{-1}).

By combining length estimates from lionfish-focused UVC with measurements of culled lionfish from BCMR using weighted means, it is estimated that the total body length of lionfish has increased from a mean of 23.06 ± 0.27 cm in 2011 ($n = 248$ culled fish, 675 sightings) to 26.34 ± 0.33 cm in 2014 ($n = 191$ culled fish and 775 sightings). These results are comparable with lionfish length estimates elsewhere in the Caribbean such as the Bahamas [43] and the Florida Keys [45] and larger than *Pterois* spp. elsewhere in their native range in the Philippines [46] and Kenya [43]. In 2011, the largest lionfish recorded in Belize was caught in Hol Chan Marine Reserve, with a total length of 42 cm [47]. However, this record was broken by a lionfish caught in Sapodilla Cayes Marine Reserve in 2013, weighing 1.2 kg and 44 cm in length (J. Scott-Smith, ReefCI, pers. comm.).

4. Initial management of the lionfish invasion in Belize

Given its now widespread distribution, lack of predators, and life history characteristics, population models indicate that eradicating the Caribbean lionfish population is unlikely to be possible [48]. As larval recruitment and adult survivorship are greater than natural mortality [49], Caribbean lionfish population densities are expected to grow to approximately 10 t km^{-2} in the absence of human intervention [50]. Nonetheless, modelling projections suggest that the consistent removal of at least 27% of the adult population would prevent further population growth [44], and that suppressing lionfish populations to site-specific threshold densities could lead to a 50–70% increase in native fish biomass and a cost effective management solution [51]. In order to be effective, such removal efforts must be sustained over time, as populations recover quickly when removals are reduced or stopped [50,52].

Since the first lionfish was reported in Belize in 2008, multi-sector collaborations between marine conservation organisations (e.g. Blue Ventures, ECOMAR, SEA and ReefCI), government agencies (Belize Fisheries Department) and fishing associations have been established to address lionfish population monitoring, research and management. In 2009, a formal lionfish sub-committee was formed under the National Coral Reef Monitoring Network.

Lionfish eradication efforts began in June 2009 when a US\$25 bounty was awarded for each lionfish delivered to the Belize Fisheries Department (BFD), in an immediate effort to prevent the species becoming established. However the scheme was discontinued after just three months due to overwhelming numbers of lionfish being delivered to the BFD [47]. Efforts to limit the introduction failed and by 2010 lionfish were well established on the BBRS and its associated ecosystems, including estuaries and mangroves [53]. Recognising the potential for targeted fishing, subsequent management efforts included a fisher exchange to the Bahamas, promoting a fishery for Belize; a lionfish education and consumption campaign in coastal communities throughout Belize; and monthly lionfish fishing tournaments throughout Belize [53]. In 2012 management efforts were formalised in the Belize Lionfish Management Plan [21].

5. The foundations of a market-based solution

The effective long-term control of invasive lionfish requires a unique approach: one that is financially sustainable, cost effective, socially and environmentally responsible, and that can be

implemented rapidly at a national scale.

Targeted fishing for human consumption is considered to be the most cost-effective and feasible lionfish management intervention among the seafood industry, distributors, chefs, researchers, fishers and conservationists [54,53]. As well as supporting the lionfish population suppression, the development of a profitable market for lionfish could help alleviate pressures on over-exploited native fisheries and potentially offer an accessible alternative livelihood for existing small scale fleets, as harvesting can take place at existing sites using selective hook-sticks or Caribbean slings which require minimal financial outlay. This is particularly important given the growing resource demand on fisheries by cane farming communities.

Similar fishery approaches to the lionfish invasion are being explored elsewhere in the Caribbean, including the Bahamas, Guadeloupe, St-Martin and St-Barthelemy [55], and Jamaica [56], with the available evidence indicating promising results [57].

5.1. Gauging domestic demand for lionfish

To gather data on the levels of lionfish awareness as well as attitudes towards lionfish harvesting, sales and consumption among coastal communities, tailored questions were incorporated within biannual household surveys conducted by the Sarteneja Alliance for Conservation and Development (SACD). In 2014, surveys were conducted in Belize's three major northern fishing communities (Sarteneja, Chunox and Copperbank), which together account for 24% of Belize's small scale fleet (J. Maaz, Wildlife Conservation Society, pers. comm.).

Outreach activities have taken place at a national (television, radio, newspaper) and regional scale and have also safe-handling demonstrations and taster events in all three communities, although somewhat less frequently in Copper Bank due to reduced accessibility. As no baseline data were collected prior to the start of outreach activities it was not possible to collect data on 'control' villages.

The survey results indicate that fishing communities had high levels of awareness about the lionfish invasion (Fig. 2), a promising result as fishers with higher awareness of the lionfish problem are generally more motivated to respond [58]. Moreover, the majority of those who had tried lionfish liked the taste (91% Sarteneja; 94% Chunox; 63% Copper Bank; Fig. 2), frequently likening it to the taste of grouper and hogfish, the latter of which is one of Belize's most expensive fish. Over half of respondents in Sarteneja and over 30% of respondents in Chunox and Copper Bank said that they would be willing to eat lionfish either at home or at a restaurant,

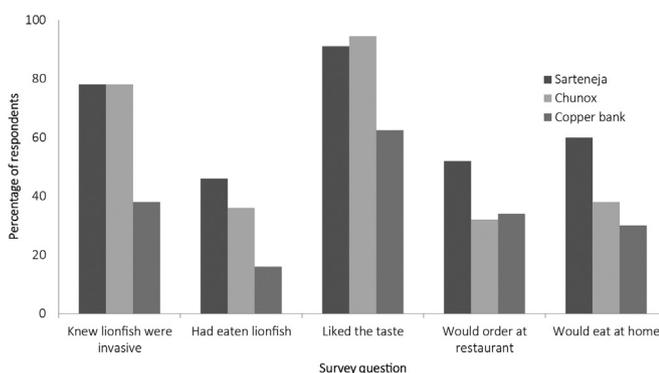


Fig. 2. Results of the 2014 SACD household survey questions about lionfish. Surveys were conducted in Belize's three major northern fishing communities: Sarteneja (n=122), Chunox (n=50) and Copper bank (n=50). The percentage of respondents who liked the taste of lionfish was calculated from the subset of respondents who had tried lionfish (n=56 Sarteneja, n=18 Chunox; n=8 Copper Bank) all other percentages were calculated across all respondents.

indicating considerable domestic demand for a lionfish market, particularly in Sarteneja (Fig. 2).

5.2. Gauging international demand for lionfish

Unmet demand for Belizean lionfish in international export markets has been estimated at 3 metric tonnes (t) per month (36 t annually), with individual US buyers requesting upwards of 0.5 t per month for export (D. Johnson, Traditional Fisheries, pers. comm.). The lionfish population density estimate for reefs within fishers' freediving depth limits (≤ 18 m) in Belize, calculated from preliminary surveys in BCMR and GSSCMR, is 35.6 ± 7.70 fish ha^{-1} ; 43% of lionfish counted during those surveys total length > 300 mm, corresponding to a 60–110 g fillet size. By conservatively halving Belize's total reef area of 58,067 ha [59] to account for reefs not accessible to fishers and those within NTZs, it is estimated that the total accessible biomass of lionfish on Belize's reefs corresponds to a fillet production of 50–101 t.

Although a thorough stock assessment for Belizean lionfish is required to fully verify the economic feasibility of this new fishery, estimates, based on currently available data, indicate that Belize has potential to meet international demand. However, the current lack of a certified central handling facility and high shipping costs currently present a bottleneck to lionfish supply. Until an export market for lionfish is guaranteed, and a reliable year-round supply of lionfish assured, the lionfishery presents a financial risk for fishers and exporters alike. Belize's 'lionfishery' thus remains a niche sector, with fishers and buyers hesitant to invest.

6. Next steps: building the lionfish market

Growing consensus across the NGO, government, research and commercial sectors supports fisheries-based extraction as the most feasible, geographically scalable and financially sustainable long term approach to lionfish control [54]. In 2010, the National Oceanographic and Atmospheric Administration (NOAA) teamed up with the Reef Environmental Education Foundation (REEF) to encourage the capture and consumption of lionfish in the Caribbean [60]. However a number of barriers to meeting the apparent demand for lionfish in Belize remain (Table 1), and the potential threats to the success of a market-based programme must be considered.

Two recent workshops have convened multi-sector actors across the wider Caribbean to shape lionfish management actions and policy with the most recent prompting the formation of a Regional Strategy for the Control of Lionfish in the Mesoamerican Reef (MAR) region [61]. The strategy identifies a number of key actions that are central to effective lionfish management. They include:

- The creation and implementation of economic instruments that incentivise the control and exploitation of lionfish.
- The need for research that informs effective lionfish management.
- The need for country-wide lionfish management plans across the MAR.
- The development of studies to ensure lionfish market development is socially responsible.

Over the past four years, a collaboration between government, NGO and fishing sector partners has developed a programme of outreach activities to deliver these actions and overcome barriers to a lionfish market in Belize (Table 1).

In order to develop commercial markets for lionfish products, this partnership has coordinated a series of safe-handling demonstrations, taster events and jewellery-making workshops in

Table 1
Key barriers to market growth and effective management of lionfish populations in Belize, and potential solutions.

Barrier	Description	Potential Solutions
Minimum size of export market discourages fishers.	<ul style="list-style-type: none"> • Lucrative US export market demand is for large fillets (≥ 85 g/30 cm body length) reducing potential export volumes and decreasing the attractiveness of the market. • Lionfish reach reproductive maturity as small as 10 cm length so targeted removal of smaller adults is essential to effective population suppression. 	<ul style="list-style-type: none"> • Foster domestic market growth through fisher-restaurant partnerships and awareness campaigns. • Identify and promote value-added lionfish product markets that utilise smaller individuals, e.g. jewellery, reconstituted fish products.
Fishers harvest lionfish opportunistically, maintaining traditional fisheries as their primary target.	<ul style="list-style-type: none"> • Fishers dissatisfied with current lionfish prices (BZ\$5–15/US \$2.5–5) per 500 g for fillets (2014), compared to BZ\$14–25 (US\$ 7–12.5) per 500 g for lobster. • Perceived risk of envenomation by lionfish spines deters new entrants to the fishery. 	<ul style="list-style-type: none"> • Develop awareness campaign to increase demand and willingness to pay for lionfish. • Orchestrate the establishment of a special fishing fleet that targets only lionfish. • Conduct lionfish outreach and safe-handling demonstrations in fishing communities countrywide.
Domestic market is seasonal, poorly coordinated and inconsistent.	<ul style="list-style-type: none"> • The majority of domestic demand is derived from tourist restaurants resulting in highly seasonal demand. • Local markets in their infancy: many fishers and restaurants have yet to establish supply relationships. 	<ul style="list-style-type: none"> • Foster fisher-restaurant partnerships. • Develop awareness campaign to increase demand and willingness to pay for lionfish.
Fishing restrictions in marine protected areas make commercial markets unavailable as a management tool.	<ul style="list-style-type: none"> • To prevent MPAs from providing a haven for lionfish, sustainable methods for managing lionfish within these areas (and in accordance with regional fisheries management initiatives) are urgently required. • SCUBA divers targeting lionfish recreationally can play an important role in controlling lionfish in no-take zones as part of lionfish competitions. 	<ul style="list-style-type: none"> • Increase the impact of national lionfish tournaments. • Develop best-practice guidelines for and promote responsible lionfish-culling tourism activities. • Orchestrate the establishment of a special fishing fleet that targets only lionfish.

Belize's northern fishing communities. The aim of these activities has been to encourage new entrants into the fishery to increase supply; to drive demand for lionfish among local and tourist populations; and to encourage the production of value-added lionfish products, offering a new income source to women in fishing communities and the use of an otherwise discarded part of the fish.

Ongoing lionfish population monitoring work will inform Belize's national plan of action by enabling threshold lionfish densities in key sites across the BBRRS to be identified and sustainable harvesting targets established. Ongoing monitoring will enable evaluation and adaptation of lionfish management efforts to assess the impacts of lionfish on wider coral reef ecosystems.

Further work will allow evaluation of the long term economic feasibility of lionfish as a primary target not only for existing fishing communities, but also for new entrants to the fishing sector. Lionfish culling tournaments have removed > 8000 lionfish from Belizean reefs since 2010 [21], demonstrating the potential for recreational fishers to supplement removal efforts by commercial fishers. Working with government to find an acceptable way to allow access to marine NTZs for lionfish-specific fishing tournaments may also help to manage lionfish populations, while preventing the overfishing of native stocks.

Not only would the development of commercial a lionfish fishery provide the government and marine management bodies with a cost-effective or even cost-neutral means of controlling the alien invasive species population, profits made through lionfish sales and the entry fees of lionfish tournaments could also be re-invested in lionfish management efforts.

6.1. Recognising the risks

Despite the clear potential, it is important to note that market-based approaches to invasive species management can have undesirable consequences, potentially leading to the further spread of the target species [21]. For example, high market demand for the target species might encourage the development of mariculture, or the intentional release of individuals into uninvaded areas for financial gain [21]. This problem has been experienced in UK lakes where recreational anglers have introduced non-native game species, posing a threat to prey populations and

native ecosystems alike [62]. However, a recreational angling initiative that aimed to reduce the abundance of predatory pike-minnow (*Ptychocheilus oregonensis*) from Columbia and Snake Rivers, USA, by paying anglers USD \$4–\$8 bounty for each individual that they captured has been highly successful, with a 40% reduction in predation on native juvenile salmonids [63,21]. Along similar lines, 'derby-style' tournaments that challenge teams of recreational divers to remove as many lionfish as they can in one day have also seen the removal of 16,000 lionfish from the Florida Keys and the Bahamas since 2009 [64]. The continued use of derbies in Belize would likely complement the lionfish fishery, particularly if they were conducted within areas where commercial fishing is prohibited.

From a socioeconomic perspective, fishers in Belize may become economically dependent on lionfish, or may discover that once the population size begins to fall, the effort required to capture lionfish, a cryptic and crepuscular species, is too high to be economically lucrative, discouraging control or local eradication efforts, prompting fishers to a return to the fishing of native species. It is therefore vital to assess the commitment and ability of local fishing communities to meet the necessary threshold level of lionfish harvesting, and to develop outreach awareness raising activities to boost fisher engagement [58] before formal long term harvesting strategies are adopted. Their future abandonment could trigger the rapid recovery of lionfish populations [21,49,52,58,65].

Finally, in some parts of the Caribbean, lionfish are reported to carry ciguatera, a form of fish poisoning that is carried by over 400 fish species [54], including commercially targeted native species such as grouper. The toxins can cause severe and acute neurologic and gastrointestinal side effects when consumed by humans [66]. Recent research in North Carolina lionfish populations indicates that the venomous toxins in lionfish tissues may prompt false positive test results for ciguatera in parts of the Caribbean, e.g. Florida where many lionfish have tested positive, but no confirmed cases of ciguatera poisoning have been reported [60]. The development of more specific ciguatera tests are therefore required and may broaden the viability of fishery-based management approaches in the Caribbean [60]. In the interim, as with all reef-associated fish in Caribbean waters, precautions should be taken [8].

7. Conclusion

To summarise, fisheries-based management may offer an effective solution to the growing lionfish problem in Belize. These preliminary findings suggest that domestic demand for lionfish is growing among both individuals and the commercial sector in Belize, and that fishers are receptive to livelihood diversification. However, further efforts are required to foster fisher-restaurant and fisher-export partnerships to drive the supply of lionfish meat and assure the longevity of the lionfish market as an alternative livelihood source for coastal communities. The expansion of outreach activities that have proved successful in Belize, elsewhere in the Caribbean as well as in coastal South America may help to drive broader adoption of a market-based approach to lionfish management as a unified response to the inevitable on-going expansion of lionfish populations.

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