



**BELIZE NATIONAL LIONFISH  
MANAGEMENT STRATEGY,  
2019-2023**

**blue ventures**  
beyond conservation



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# Foreword

As 2018 concludes, we find ourselves in a strong position, equipped with knowledge to enable informed decision-making with regards to lionfish management. Over the course of the last decade, considerable efforts have been made to address the threats of the lionfish invasion in our waters. However, given their unique and highly effective predation strategy, the establishment of lionfish in national waters continues to pose concern. There is urgency to understand how their presence will impact the health of our reefs and fisheries and their subsequent impact to the livelihoods of fishers, and the wellbeing of coastal communities.

The lionfish removal efforts are frequent and involve multiple stakeholders, and which appear to be paying off. Whilst maintaining the momentum of existing efforts, over the course of the next five years, we must continue to collaborate across sectors in order to realise effective lionfish control. We must be proactive in seeking innovative mechanisms to control the numbers of lionfish in our waters with special consideration to opportunities that could also bring additional benefits to coastal stakeholders.

The launch of this strategy marks almost exactly 10 years since the invasive red lionfish, *Pterois volitans*, were officially recorded in Belize. By 2010, this highly reproductive fish had successfully established itself throughout Belize's marine environment – from remote coral reef atolls to nearshore mangroves. It is with this in mind that we urge all interested in lionfish control to feed their efforts into the national strategy – and of course, as always, keep ordering lionfish at your favourite restaurants!

Sincerely,



Beverly Wade (Ms)

Fisheries Administrator  
Belize Fisheries Department

# Executive Summary

Across the Caribbean, the invasion of red lionfish (*Pterois volitans*) poses a pervasive threat to marine ecosystems and coastal fishing communities. First recorded in Belize in 2008, lionfish have become well established across the country's entire marine environment. Uncontrolled, invasive lionfish populations disrupt marine food webs, negatively impacting coral reef health and fisheries productivity, thereby undermining the resilience of coral reefs and reef-associated systems to global change.

This document describes how to design and implement an integrated approach to lionfish management – incorporating environmental, social and economic wellbeing goals – and provides specific recommendations for the adaptive management of lionfish in Belize.

## Chapter Outline

Belize's first Lionfish Management Plan provided critical information about lionfish biology, invasion ecology, and the current status in 2009. In this report, *Chapter 1: The Lionfish Invasion in Belize, 2008-2014*, summarises current knowledge about the lionfish invasion, including the spread of the invasion across the Caribbean as well as a summary of results of lionfish surveys that had taken place in Belize by 2015.

Covering a five year period (2009-2013), Belize's first Lionfish Management Plan also presented eight management recommendations. *Chapter 2: Strategic Planning* evaluates progress towards achieving these recommendations and summarises broader recommendations made in regional lionfish management strategies. Although lionfish are found in a wide range of marine ecosystems and to depths of at least 300 m, we have taken a pragmatic approach with this strategy, and therefore it focuses on lionfish management in shallow coral reefs (to 18 m deep). After presenting this strategy's vision and associated goals, this chapter presents an overview of the current context of human and natural systems associated with lionfish management – and how they interact – in a **socioecological framework**.

Further research on lionfish, including ecological and social surveys relevant to lionfish management, were carried out in 2015-16 to develop this strategy. Results of these surveys are presented in *Chapter 3: Adopting a Coupled Human and Natural Systems Approach*. This chapter concludes with a description of the predicted lionfish population status over ten years, projected using a Belize-specific **lionfish population dynamics model**, assuming that the status of each of these indicators remain the same – i.e. "business as usual". The coding for this model, provided as an *appendix*, is open access and includes instructions for its modification to changing conditions or different country contexts.

With high fecundity, a lack of predators and a generalist diet, lionfish have spread so rapidly and widely across the region that eradication is unlikely to be possible. The first challenge to achieving effective lionfish management is understanding what effective control looks like. In 2014, an important ecological model was published which provided evidence for optimism: lionfish population suppression below **site-specific management targets** allows native fish populations to recover. *Chapter 4: Conservation Management* describes how we calculated these targets for five protected areas in Belize, and presents a broad overview of control actions and approaches that have been taken across the wider Caribbean region.

To form recommendations for lionfish management for Belize, the impacts of different management interventions on human and natural systems were explored using a combination of the lionfish population dynamics model and the socioecological framework. The results were visualised using artistic representations of each **scenario**, and subsequently reviewed with communities during **participatory consultations**. To conclude Chapter 4, we describe how scenarios were developed, the process adopted for consultations, as well as the **strengths, weaknesses, opportunities and threats** for each scenario identified by consultation participants.

*Chapter 5: Recommendations for the Next Five Years* concludes this document, providing an overview of key data gaps, outstanding priorities from regional strategies, recommended actions identified during participatory community consultations, as well as actions required for effective monitoring, evaluation and adaptive management.

## Achieving effective lionfish management in Belize

To date, across the Caribbean, lionfish control activities have been typically haphazard and have not always focused on prioritised conservation areas. As a result, control activities may make inefficient use of limited resources, be ineffective in achieving population control, or cause unintended or undesired outcomes. To produce sound recommendations for this strategy, an interdisciplinary team consulted with a wide range of coastal stakeholders, and used the results of in-depth social and ecological research, to examine challenges and identify opportunities around lionfish management (Table 1).

Belize has already made great progress towards achieving effective lionfish control, having adopted a multi-pronged approach involving restaurants, fishers, and SCUBA divers, to control this invasive species. It is estimated that almost 90,000 lionfish were removed from Belize’s coral reefs in 2015, and dedicated lionfish surveys on coral reefs that year found that lionfish abundance was generally low. Nevertheless, ecological modelling shows that significant declines in native fish populations could be expected at almost a quarter of surveyed sites as a direct result of invasive lionfish.

Addressing this need for increased lionfish control requires careful planning: the use of market-based incentives makes it possible to achieve frequent and large volume removal of lionfish from coral reefs, however invasive species management is a field wrought with unintended outcomes. The vision of this strategy highlights that lionfish management should “protect and improve livelihoods of all Belizeans” in addition to the environmental goal of lionfish population suppression. Social research conducted in 2015 and 2016 demonstrates that markets for invasive lionfish meat and fins have the potential to deliver socioeconomic benefits to coastal communities.

For management to be effective, regular evaluation of key indicators is necessary. A total of 97 indicators were identified through the production of a *Socioecological framework*, and a subset of 20 indicators have been identified as priority, based on feasibility and relevance.

**Table 1: Summary of challenges and opportunities associated with effective lionfish management**

CHALLENGE	OPPORTUNITY
Ecological characteristics of lionfish make the possibility of eradication extremely unlikely and unrealistic.	Lionfish population suppression confers similar ecological outcomes to extirpation.
A large proportion of the lionfish population needs to be removed at regular intervals to counter fast reproductive and growth rates.	Anchoring lionfish control in small-scale fisheries-based extraction provides a geographically scalable and financially sustainable solution in areas accessible to fishers.
Unknown long-term impacts associated with the creation of commercial market for lionfish meat, and other products.	Adopting a Coupled Human and Natural Systems approach provides the best opportunity for sound decision-making surrounding lionfish management planning, addressing risks proactively. See: <a href="#">What are Coupled Human and Natural Systems</a> .
Lionfish extraction by fishers can only occur in areas physically or legally accessible to fishers – i.e. relatively shallow water environments outside of no take zones (NTZ).	The involvement of other actors in lionfish control activities in areas inaccessible to fishers can deliver different benefits to other coastal stakeholders.
Lionfish threaten the integrity of marine protected areas (MPAs), which can have the same positive effect on lionfish as native species.	The knowledge and interest exists to form a multi-stakeholder Lionfish Working Group that coordinates science-led lionfish control in MPAs.
No mechanism exists for lionfish control in deep water environments.	Traps being developed in other countries present possible solutions and interest exists to trial these in Belize.

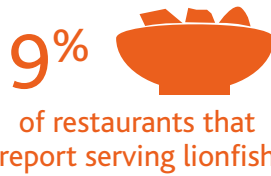
Status of the 10 key indicators in 2015



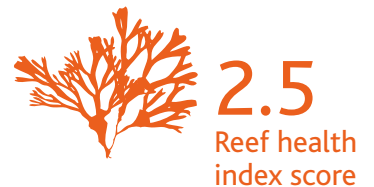
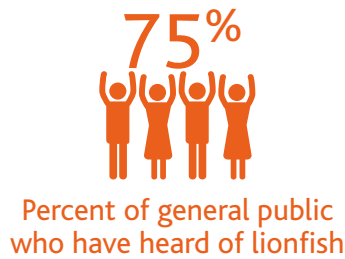
The average lionfish size **21** cm



Annual lionfish fishing  
mortality (F) = 0.1 (equiv. of  
90,000 lionfish per year)



The median stated willingness  
to pay for lionfish by restaurants  
(BZD/lb of fillet)





## Going forwards

Objectives and associated recommended actions (see *Chapter 5: Recommendations for the Next Five Years* for a complete list) have been established based on a compilation of all views and data gathered throughout the production of this strategy, as well as through reference to previous plans.

### Objectives (2019-2023)

1. A multi-stakeholder Lionfish Working Group (LWG) has been established in 2019 and coordinates lionfish management, monitoring and evaluation.
2. At least one seafood processing facility purchases lionfish from fishers by 2020.
3. A lionfish tourism certification scheme that adequately addresses associated risks, supports the needs of marine tour operators, and supports lionfish management priorities, has been established by 2020.
4. By 2021, all lionfish tournaments are registered with the LWG, raise awareness about the lionfish invasion, provide economic benefits to host communities, and record data to national database.
5. Lionfish control in Belize's no take zones (NTZ) has been implemented by 2021.
6. Conduct consistent education and outreach programmes about lionfish with a wide range of stakeholders.
7. Increase the value of lionfish catch through diversified product markets.
8. Conduct research and monitoring to fill identified knowledge gaps about lionfish ecology, management and markets, and evaluate lionfish control actions.
  - ✦ Finalise and implement a National Lionfish Monitoring Plan, which uses the Lionfish Focused Search method.
  - ✦ Prioritise lionfish population assessment at one of Belize's atolls.
  - ✦ Establish a method and database to enable the systematic monitoring of lionfish landings through fishery and tourism industries, as well as lionfish tournaments.
  - ✦ Conduct social research every three years, to adapt approach to awareness-raising and social marketing as appropriate.
9. Ensure adequate funding is available for consistent implementation of lionfish control activities, as well as monitoring and evaluation.

# The lionfish invasion in Belize, 2008-2014

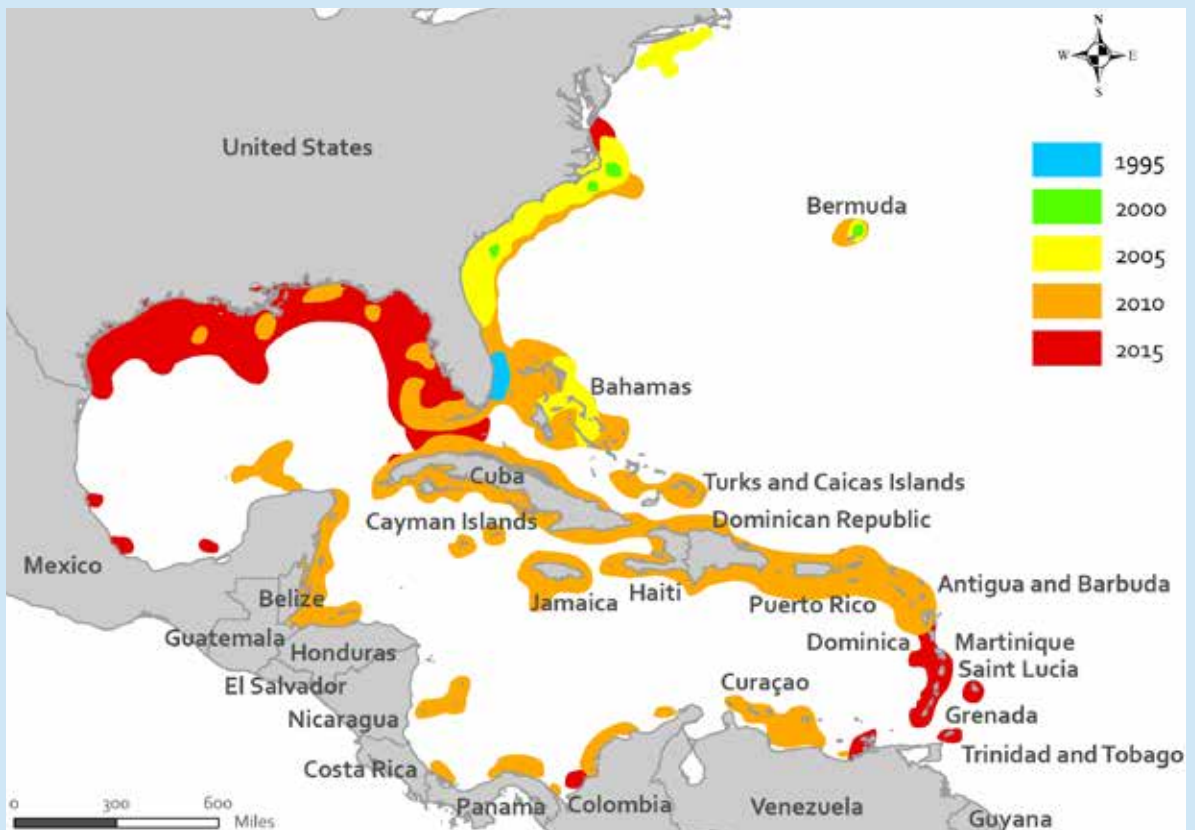
In this chapter, we provide an overview of the lionfish invasion, including:

- The history of the lionfish invasion across the Caribbean
- Impacts of the lionfish invasion on coral reefs
- A summary of results of lionfish research in Belize (to 2015)

## 1.1 A background to alien invasive lionfish

The invasion of alien lionfish (*Pterois spp.*) throughout the Western Atlantic, Gulf of Mexico, and Caribbean over the past decade is one of the top threats to biodiversity and marine-based livelihoods in the region [1].

Native to the Indo-Pacific and Red Sea, the distinct appearance of lionfish sees them prized by aquarist around the world. In fact, red lionfish (*Pterois volitans*) was among the most commonly imported live marine tropical fish to the USA in 2005 [2]. This international trade, and the subsequent release of imported individuals, is considered the most likely route by which red lionfish<sup>1</sup> became established in the Tropical Western Atlantic [3], [4].



**Figure 1:** Map of the Caribbean showing the advancement of lionfish in five year intervals, from 1995, when lionfish had only been observed in Florida, to 2015, by which time they had become widespread. Map credit: Fanny Tricone.

<sup>1</sup> Although it was originally thought that two species of lionfish invaded the Western Atlantic (*Pterois miles* and *P. volitans*), recent research indicates that *P. volitans* is not a distinct species, but a hybrid of an Indian Ocean lionfish species (*P. miles*) and a Pacific Ocean lionfish species (*P. russelii*) [96].





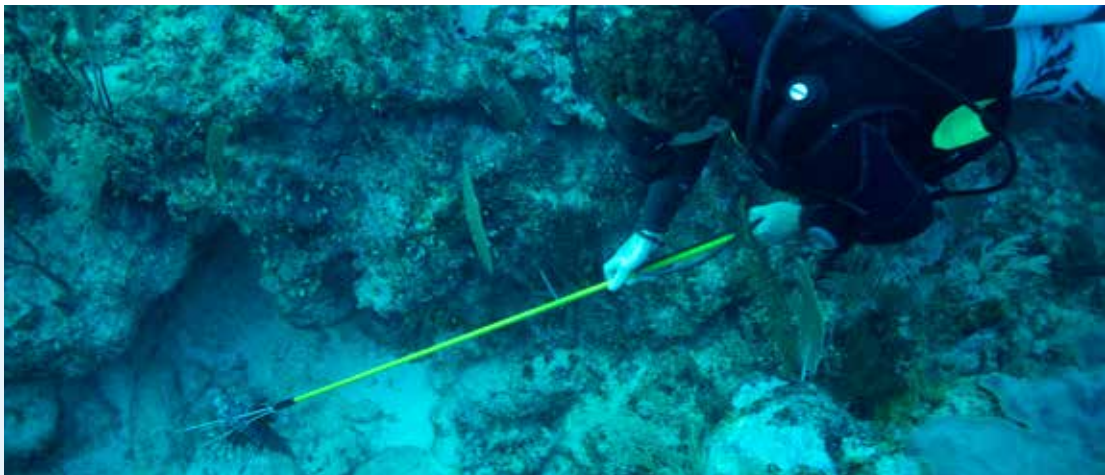
Figure 2: The red lionfish (*P. volitans*) photographed in Turneffe Atoll, Belize in 2014. Photo credit: Gordon Kirkwood.

### 1.1.1 Ecological effects of the invasion

Predation by lionfish has been associated with rapid depletions of native reef fishes, resulting in extirpation of species in some instances [6]–[7]. Native prey consumed by lionfish include small-bodied fish and invertebrates, as well as the juveniles of commercially important grouper and snapper, and ecologically important herbivores such as parrotfish and surgeonfish [9]–[13]. The list of native species consumed by lionfish will undoubtedly continue to grow with additional diet studies from across the invaded region. However, studies of lionfish prey selection suggest that solitary, narrow-bodied fish that reside near the seafloor are most vulnerable [14].

Lionfish have almost three times the prey consumption rate of native counterparts such as the coney grouper (*Cephalopholis fulva*) [8] and considerably higher rates of consumption in the Caribbean than in their native range [15]. They therefore have the potential to not only pose a significant threat to fish population recruitment, but also competitively exclude other native predators.

There is also evidence that the presence of lionfish on coral reefs may inhibit grazing activity by herbivorous fishes [16] – important for maintaining a healthy coral reef ecosystems – although the consequences for coral-macroalgal dynamics are uncertain.



### 1.1.2 Lionfish features that have led to their success

Lionfish are ecological generalists: their ability to thrive in diverse habitats including coral reefs, mangroves, seagrass beds, and man-made structures (e.g. oil rigs and ship wrecks), and from surface waters to depths of at least 300 m, has allowed them to quickly establish and spread across the wider Caribbean region [4], [17].

Compared to similar native mesopredators<sup>2</sup>, lionfish also have high fecundity: female lionfish reach reproductive maturity in less than one year and produce between 10,000 and 40,000 eggs per spawning event, which occur regularly throughout the year [18]. Annual fecundity of lionfish can exceed two million eggs when conditions are favourable, whereas native mesopredators only reach reproductive maturity in two to four years, and release approximately 300,000 eggs per annual spawning event [12].

The success of lionfish in the Caribbean is further reinforced by their lack of predators, largely due to the 18 venomous spines on their dorsal, ventral, and anal fins. Whilst lionfish envenomation typically only causes a short-lived local reaction in humans [19], it has been demonstrated to be fatal to some fish and is considered to be a significant deterrent against predation [20].

<sup>2</sup>A mesopredator is a middle-level predator, that is both predator and prey within the food web being studied.



## 1.2 The lionfish invasion in Belize

Lionfish were first reported by a recreational diver in the Sapodilla Cayes, southern Belize, in 2001, though the report was unconfirmed and does not corroborate with the expansion of the invasion across the wider Caribbean region. The first confirmed lionfish sighting was in Turneffe Atoll, central Belize, in December 2008, and this sighting was closely followed by more reports from Glover’s Reef Atoll, Lighthouse Reef Atoll and Ambergris Caye. The invasion of northern Belize was followed by the invasion of southern Belize was one of the last areas to become invaded with lionfish. By August 2009 lionfish could be found throughout most of the coastal zone of Belize. Lionfish are now present throughout the Belize Barrier Reef Reserve System UNESCO World Heritage Site [21].

### 1.2.1 Lionfish density, 2008-2014

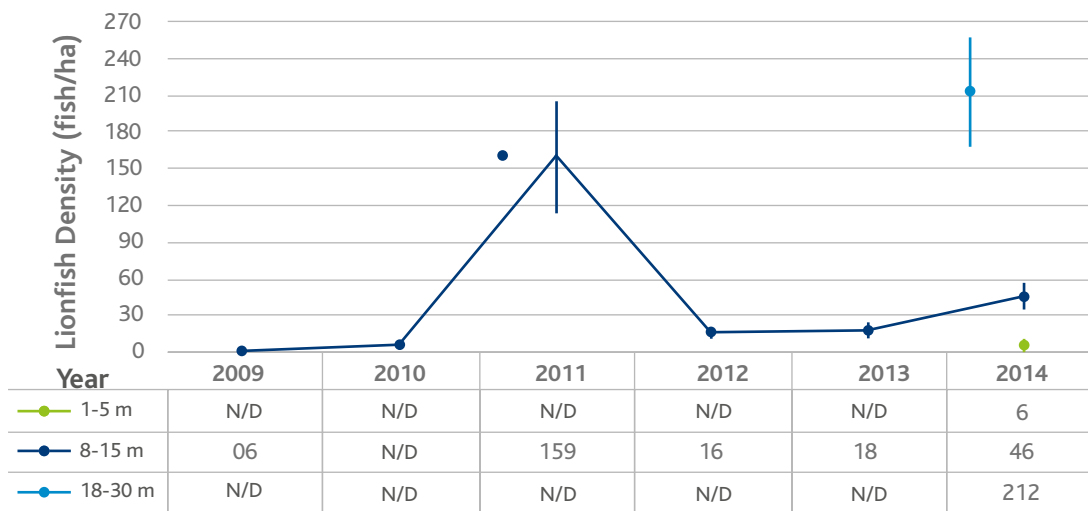
Due to their cryptic nature and crepuscular activity patterns, lionfish density is underestimated by traditional underwater visual census techniques [22]. The Lionfish Focused Search (LFS) method (see *Chapter 3, N1. Lionfish Population*) was developed to provide more accurate lionfish densities estimates [23]. Surveys using this method in varied reef types and depths have provided accurate estimates for Belize (*Table 2*).

**Table 2: Lionfish focused search surveys carried out in Belize between 2009 and 2014.**

PRINCIPAL INVESTIGATOR (YEAR)	SURVEY DETAILS	KEY RESULTS
Courtney Cox, University of North Carolina at Chapel Hill (2009-13)	<ul style="list-style-type: none"> <li>• National-level surveys</li> <li>• 12-15m: spur-and-groove</li> <li>• 14-19 sites annually</li> </ul>	<ul style="list-style-type: none"> <li>• Greatest densities observed in 2011, when mean density was 159±46 fish.ha-1</li> <li>• Sites with greatest densities were in Turneffe Atoll and South Water Caye Marine Reserves</li> </ul>
Blue Ventures (2014)	<ul style="list-style-type: none"> <li>• Bacalar Chico Marine Reserve</li> <li>• 1-5m: patch reef (2 sites)</li> <li>• 8-15m: spur-and-groove (3 sites), fringing (1 site)</li> <li>• 18-30 m: spur-and-groove, fringing (1 site each)</li> </ul>	<ul style="list-style-type: none"> <li>• Mean density was 27±9 fish.ha-1</li> <li>• Greatest density (57±18 fish.ha-1) at the deep fringing reef site</li> </ul>
Southern Environmental Association / Blue Ventures (2014)	<ul style="list-style-type: none"> <li>• Gladden Spit and Silk Cayes Marine Reserve</li> <li>• 8-15m: spur-and-groove, wall (1 site each)</li> <li>• 18-30 m: spur-and-groove (1 site)</li> </ul>	<ul style="list-style-type: none"> <li>• Mean density was 235±68 fish.ha-1</li> <li>• Greatest density (550±150 fish.ha-1) at the deep site.</li> </ul>

These records suggest that in some parts of the Belize Barrier Reef, lionfish densities are higher than those reported in their native range (0.3–48 fish.ha-1) [24], [25], but are generally lower than elsewhere in the Caribbean (e.g. Bahamas 102 ± 103 fish.ha-1) [26].

Pooling results from one depth band (8-15 m) shows that lionfish density peaked in 2011 and has since remained low (*Figure 3*).

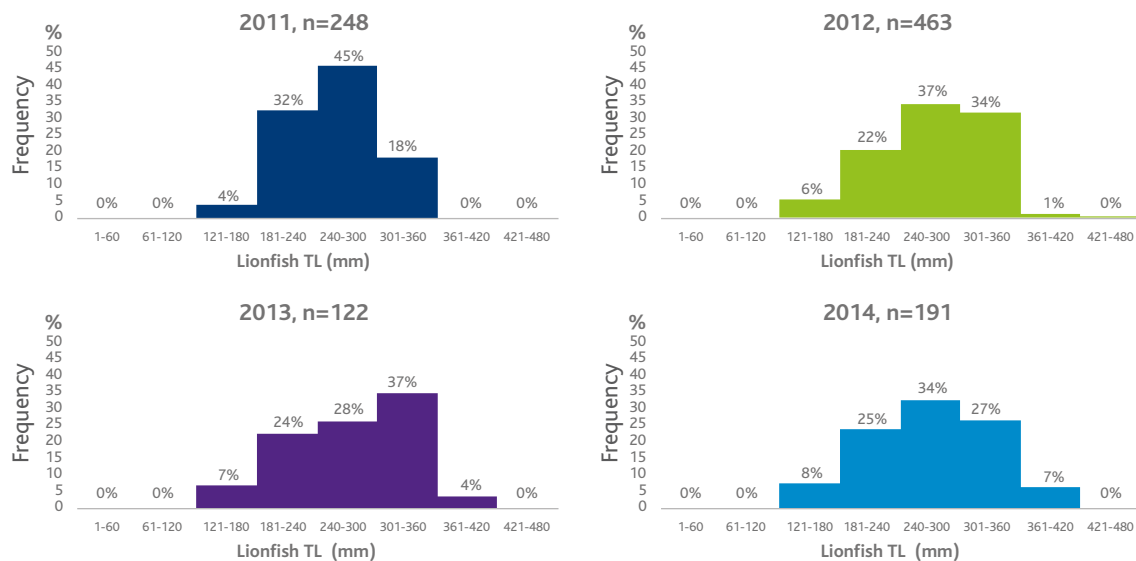


**Figure 3: Average lionfish density across Belize, results from three surveys pooled by depth. Error denotes standard error of the mean, N/D denotes no data. Figure prepared with permission using raw data provided by principal investigators (Table 2).**

### 1.2.2 Lionfish size and sighting frequency

Since 2011, as a simple but consistent means of monitoring changes in the relative abundance and sizes of lionfish across a range of depths in BCMR, Blue Ventures carried out regular lionfish dissections ([Appendix 3](#)) and kept a dedicated record of all lionfish sightings on dives.

Between 2011 and 2014, the proportion of lionfish over 36 cm total length increased from 0% to 7% [13] ([Figure 4](#)), and average size of lionfish increased annually to a maximum of 26 cm in 2014 [27]. Despite this increase in size, lionfish sighting frequency decreased significantly ( $p < 0.05$ ) from 1.2 lionfish sighted per diver hour in 2011 and 2012, to 0.9 lionfish sighted per diver hour in 2013 [27], attributed to intensive culling in 2012.



**Figure 4: Size class frequency by year of lionfish culled in Bacalar Chico Marine Reserve between 2011 and 2014, adapted from [38] with permission. TL = Total length.**

# Strategic Planning

In this chapter, we describe the context and direction for lionfish management in Belize, including:


- Summary and evaluation of earlier lionfish management plans in Belize and the region
- The vision, mission and goals for this strategy
- An introduction to socioecological systems and associated indicators
- Challenges associated with lionfish management

## 2.1 Evaluation: Belize lionfish management plan, 2008-2013

Belize's first lionfish management plan [21] presented eight management recommendations. Main achievements since the publication of this plan have been related to the development of a domestic lionfish fishery, lionfish artisan markets, and awareness-raising about lionfish amongst the general public. Belize has also participated in regional workshops for lionfish management and remained an active player in knowledge sharing opportunities with regional partners.

**Table 2: Summary of progress towards achieving recommendations in Belize's previous lionfish management plan, to 2015.**

RECOMMENDATION	PROGRESS
1. Review fisheries regulations and amend legislation to encourage lionfish removal.	Not achieved.
2. Develop a commercial market for lionfish meat to provide an incentive for fishers to remove lionfish.	Informal domestic market for lionfish exists (See <a href="#">Chapter 3, H4. Lionfish Markets</a> ).
3. Increase lionfish removal from the Belize Barrier Reef Reserve System World Heritage Site (BBRRSWHS).	Achieved through a combination of lionfish culling tourism and competitions, lionfish removals by fishers for commercial and subsistence use, and lionfish culling by fishers to support control (See <a href="#">Chapter 3, H5. Total Lionfish Catch</a> ).
4. Increase awareness that lionfish need to be managed in order to protect Belize's natural heritage.	Awareness raising activities carried out across the country, leading to a high level of knowledge about lionfish (See <a href="#">Chapter 3, H4. Lionfish Markets</a> ).
5. Establish training programs that target fishers, marine guides, marine protected area staff, artisans and visitors, for continuity of lionfish management.	Lionfish safe-handling workshops carried out with fishers, primarily in northern fishing communities. Lionfish jewellery markets established from 2013 (See <a href="#">Chapter 3, H4. Lionfish Markets</a> ).
6. Conduct in-depth scientific studies to better understand impacts to the BBRRSWHS and associated ecosystems.	Some studies carried out, providing insight into changes in lionfish population status in certain reef sites (See <a href="#">Chapter 1: The Lionfish Invasion in Belize, 2008-2014</a> ). Non-reef environments (e.g. mangroves) in Belize unassessed, and no accurate national estimates for lionfish population status or impacts to the BBRRSWHS available prior to 2015. See <a href="#">Chapter 3, N1. Lionfish Population</a> for an updated assessment.
7. Liaise with partners in the Wider Caribbean to ensure long-term management efforts.	Belize has participated in the development of two regional lionfish management strategies and has remained an active player in lionfish management, demonstrated by the broad involvement of various partners in the development of this strategy.
8. Raise funds for lionfish management through sale of lionfish-themed items (such as a lionfish cook book or lionfish t-shirts).	Not achieved.



## 2.2 Relevant regional lionfish strategies

**The Regional Strategy for the Control of Invasive Lionfish in the Wider Caribbean (2013)** [32] places a heavy emphasis on the need for governments to evaluate policy and legislation preventing effective lionfish control, as well as the development of localised control strategies and the promotion of lionfish consumption as a control strategy. The Belize Fisheries Department and the Caribbean Regional Fisheries Mechanism (CRFM) Secretariat represented Belize for the production of this strategy.

**The Regional Strategy for the Control of Invasive Lionfish in the Mesoamerican Reef (2014)** [33] highlights the need to ensure that markets that support invasive lionfish control also address social needs, and encourages adaptation within government agencies to address social, economic and environmental impacts of the invasion. This strategy also calls for the assimilation of existing information on lionfish, including estimation of lionfish fishery landings, and cites a need for further research of related socioeconomic factors. Further, it promotes the use of standardised survey methods to identify priority areas for control, as well as the development of methods for control within no take zones (NTZs). The Belize Fisheries Department, Protected Areas Conservation Trust, Coastal Zone Management Authority and Institute, Toledo Institute for Development and Environment and Blue Ventures represented Belize for the production of this strategy.

## 2.3 Current context

### 2.3.1 Environmental status of the Belize Barrier Reef

The Belize Barrier Reef (BBR) is the second longest reef in the world, and forms part of the larger Mesoamerican Reef (MAR), a system shared by Mexico, Belize, Guatemala and Honduras. In 1996, a network of seven of Belize's marine protected areas was declared the Belize Barrier Reef Reserve System (BBRRS) UNESCO World Heritage Site due to its high level of biological diversity, ecological processes, and natural beauty.

Despite conservation efforts, the overall health of the BBR was evaluated as 'poor' in 2015 [28], evidenced by declining hard coral cover, increasing macro algal cover and declining water quality [29]. Climate induced impacts including bleaching and hurricanes have further contributed to the poor status of the reef [30], and anthropogenic pressures such as coastal habitat loss through unregulated development, water pollution from sewage outflows and agricultural runoff, and unsustainable fishing, have further degraded the reef's structure, biodiversity and productivity [29].

The declining health of the BBRRS led to its inclusion on the List of World Heritage Sites in Danger in 2008 [31].

### 2.3.2 Belize's artisanal fisheries

Approximately 2,590 people actively work as fishers in Belize (pers. comm., Belize Fisheries Department, 2016), with the total direct revenue of the fishing industry in 2011 estimated to be USD 22 million [34] – 1.8% of national Gross Domestic Product [35].

Artisanal fisheries – dominated by Queen conch (*Lobatus gigas*) and Caribbean spiny lobster (*Panulirus argus*) – account for 95% of national fisheries landings [36] and generate over USD 13 million/year in revenue [34], [37]. Artisanal finfish fisheries provide not only a vital source of income but also important food security [38], taking into account that 41% of the population lives below the poverty line [39].

Belize's fisheries are under increasing pressure, partly due to erosion of sugarcane markets in the USA and Europe, prompting farmers to convert to the fishing industry [40]. Improved fisheries management [41] as well as alternative incomes and fisheries diversification [42] are recognised needs.

### 2.3.3 Governance of Belize's marine protected area network

Belize's MPA network covers approximately one million acres (22% of Belize's territorial sea) and encompasses 14 distinct areas: nine Marine Reserves, two Natural Monuments, two Wildlife Sanctuaries, and one National Park (*Figure 5*). These are managed by the Government (Fisheries or Forest Department) and some have co-management agreements with non-governmental organisations (*Appendix 1*).


Overall, only 3% of Belize's territorial sea is within fully protected zones within the MPA network [45]. Each Marine Reserve has clearly defined zones allowing for extractive (e.g. fishing) and non-extractive (e.g. tourism) uses, whereas commercial fishing is prohibited within National Parks, Natural Monuments and Wildlife Sanctuaries. An exception is made in Corozal Bay Wildlife Sanctuary to enable continued access by traditional artisanal fishers.

### 2.3.4 Managed access and rights-based fishing

In June 2016, Belize formally adopted the Managed Access program, representing a move from open-access to rights-based fishing. The entire country's territorial waters has been divided into nine Fishing Areas (*Figure 6*). All fishing licenses are now tied to a maximum of two areas (with optional access to Area 9 for deep sea fishing), based upon traditional-user rights.

Fishers must keep detailed catch logbooks and submit catch data per trip per vessel to the Fisheries Department, directly or through co-managers.



A man in a black wetsuit with 'ONYX' written on it is holding a large, spiny lionfish on a metal rod. The scene is set against a bright sunset or sunrise sky, with the fish's spines and fins glowing in the light. The man is looking towards the camera with a slight smile.

## 2.4 Belize lionfish management strategy, 2019-2023

In late 2015 and early 2016, social and ecological studies were carried out to inform the development of an updated lionfish management strategy for Belize. The results of these surveys were reviewed in June 2016 by a small group of stakeholders<sup>3</sup> involved in lionfish management, who described the scope, vision, mission and goals for lionfish management in Belize, and elaborated a socioecological framework (see *Socioecological Framework*, this chapter) to guide strategic planning and evaluation.

### Scope

Given current technological barriers to controlling lionfish beyond safe diving limits, this strategy focuses on lionfish control in shallow reefs (to 18m), both inside and outside of NTZs. However, general recommendations are also made for control in deep, non-reef environments.

### Vision

Adaptively managing lionfish in a participatory manner, to protect and improve livelihoods<sup>4</sup> of all Belizeans and the health of Belize's marine environment.

### Mission

To inform inclusive decision-making for invasive lionfish management in Belize, using an adaptive management approach that considers current conditions and future social, economic and ecological outcomes.

### Goals

1. Management is participatory and adaptive.
2. Lionfish populations are maintained below levels that affect native species.
3. Recommended actions for lionfish management consider direct and indirect outcomes to maximise socioeconomic benefits.

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<sup>3</sup>Meeting attended by representatives of Blue Ventures, the Belize Fisheries Department, Sarteneja Fishermen Association, the Belize Federation of Fishers and international academic experts (see Contributors). This was the first time that social scientists, ecological scientists, fishers, government and conservation practitioners were in the same room working on an interdisciplinary model for lionfish management and control.

<sup>4</sup>A livelihood comprises the capabilities, assets and activities required for a means of living, including food and income. [95]

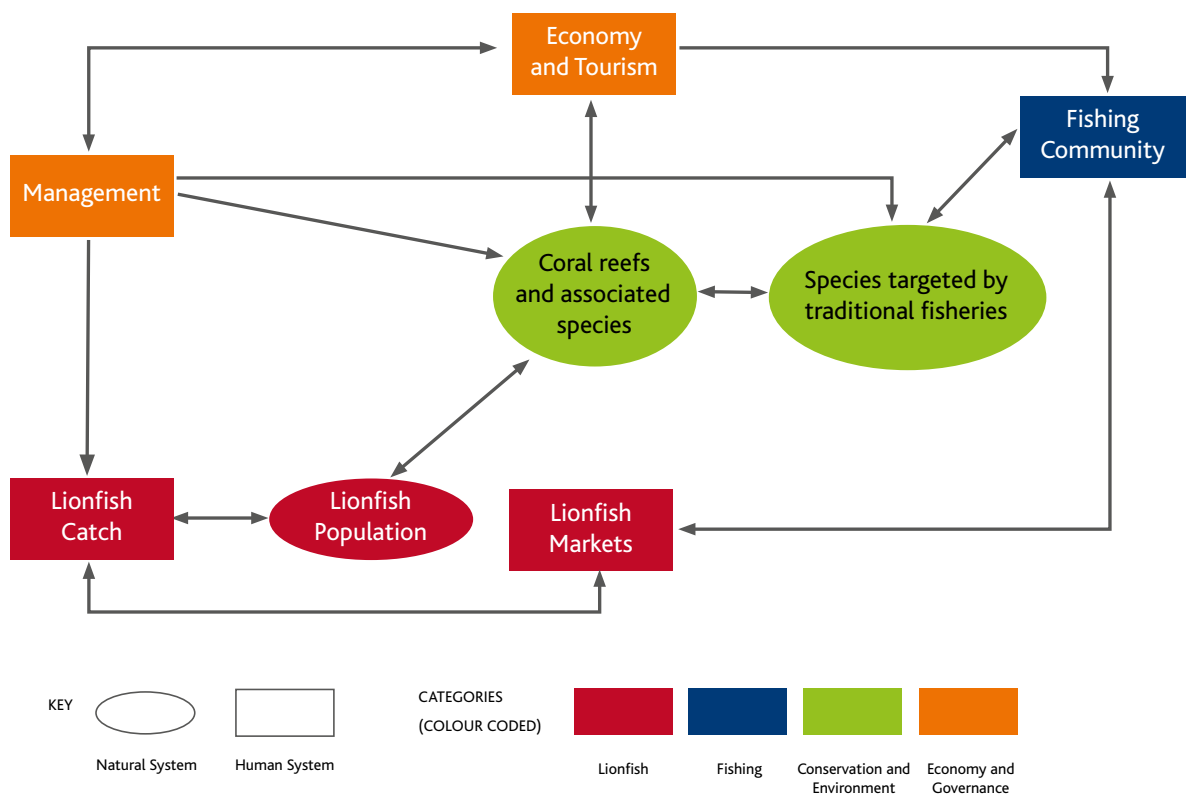
## 2.5 Introducing the Socioecological Framework (SEF)

### 2.5.1 Socioecological framework

The interactions between human and natural systems are complex, and characterised by reciprocal feedback loops that can interact across local and global scales [46], [47]. A socioecological framework (SEF) maps out the connectivity of these systems, helping conservation managers to understand the factors that influence the system(s) they seek to protect, as well as providing an opportunity to predict direct and indirect effects of management actions. SEFs can also reveal knowledge gaps, highlighting future focal areas for research.

The detailed SEF contains 97 *nodes* (representing unique indicators) that are grouped into 16 sub-systems, known as *clusters* and four categories (*Appendix 2*). Indicators associated with each *node* can be monitored for evaluation and adaptive management. Interactions between nodes occur within and between clusters and are directional: a solid line indicates a positive relationship (as A increases or decreases, so does B), and a dotted line indicates a negative relationship (as A increases, B decreases – or vice versa). This level of detail allows for accurate interpretation of management actions.

A simplified version summarises key concepts (*Figure 7*).



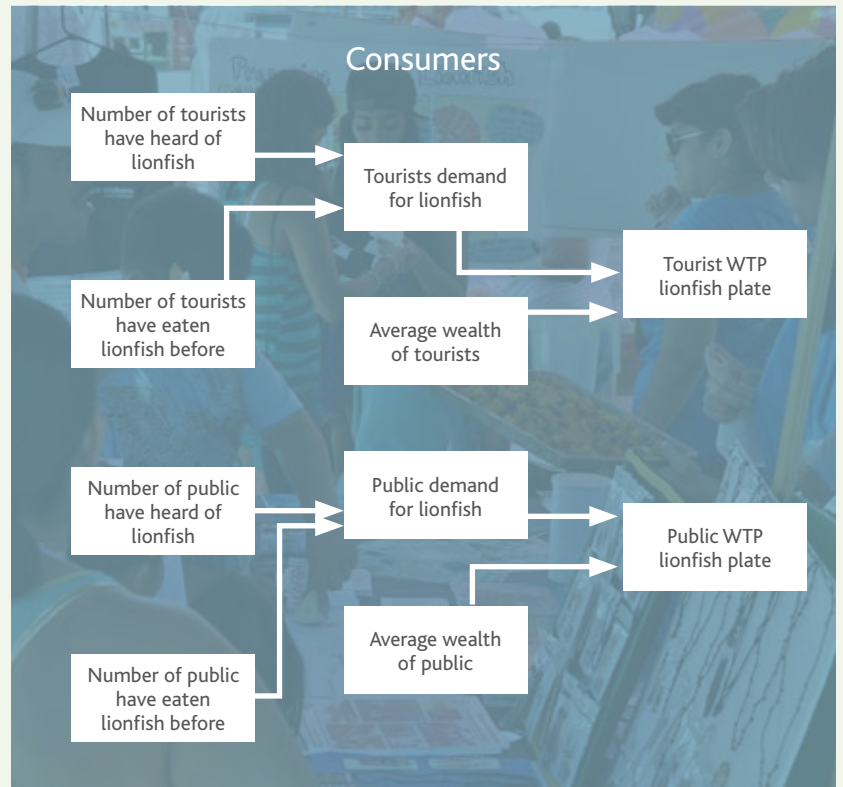
**Figure 7: Simplified socioecological framework of interactions between human and natural systems associated with lionfish management.**

See *Chapter 3 (How Do We Understand Each System?)* and *Chapter 4 (Scenario Planning)* for more details on the application of the SEF for lionfish management planning and evaluation.

## 2.5.2 How to read the SEF: examples of clusters with positive and negative interactions

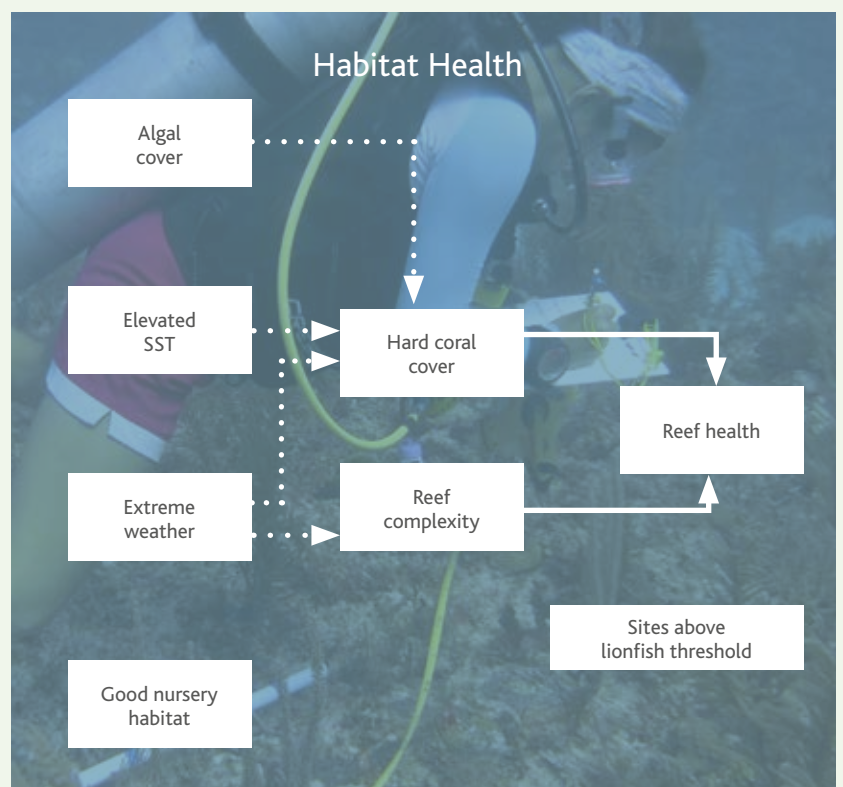
The *Consumers* cluster of the detailed SEF contains 10 nodes. All of these interactions between nodes are positive.

Tourists and the general public are separated as consumer groups because each group holds distinct norms and values, and is influenced by different management interventions. This diagram shows that an increase in the number of members of the general public who have heard about lionfish will lead to an increase in demand for lionfish from the general public. This demand and/or an increase in the average wealth of the general public will lead to an increase in their willingness to pay (WTP) for lionfish dishes.



The *Habitat Health* cluster of the detailed SEF contains eight nodes. Interactions between nodes are both positive (solid line) and negative (dotted line).

This diagram shows that increase in algal cover, sea surface temperature or frequency of extreme weather events will lead to a decrease in hard coral cover (negative relationships), which will lead to a decrease in overall reef health (positive relationship). The node *Good Nursery Habitat* refers to the extent of healthy, productive nursery habitat and does not interact directly with any nodes within the *Habitat Health* cluster (though referencing the complete detailed SEF shows that it does interact with nodes within *Native Reef Community* and *Management* clusters). The node *Sites Above Lionfish Threshold* refers to the proportion of sites that exceed the predicted density at which lionfish are expected to cause predation-induced declines in prey fish biomass; this node does not interact directly with any nodes within the *Habitat Health* cluster (referencing the complete detailed SEF shows that it interacts with nodes within *Native Reef Community* and *Lionfish Population* clusters).



## 2.6 Challenges of lionfish management

Traits of this invasive species, in particular rapid reproduction and high abundance beyond safe diving limits, make the possibility of eradication extremely unlikely and unrealistic [48]. Management focus has therefore shifted to lionfish population suppression [49], which requires regular and high volume lionfish extraction.

While fisheries-based extraction is considered the most effective, geographically scalable and financially sustainable approach to lionfish control [48], associated risks are that lionfish populations may not have the capacity to support a sustainable fishery that delivers long term economic benefits, and that a market-based approach may undermine control efforts through the creation of perverse incentives, e.g. for lionfish fattening or conservation. Furthermore, lionfish extraction by fishers can only occur in areas that fishers are able to physically or legally access – i.e. relatively shallow water environments outside of NTZs.

Lionfish control within NTZs is essential to maintain ecological integrity of these high priority conservation areas [50]. Uncontrolled lionfish populations within NTZs not only reduces their replenishment capability, but ironically, the protection afforded by MPAs may have the same positive effects on populations of alien species such as lionfish, counteracting control efforts in surrounding areas [51]. Strategies for control in NTZs must be developed so that they do not undermine existing conservation efforts, but to still confer adequate removal effort without adding a large financial burden on protected area managers.

The primary challenge for control in deep water environments is access; removals require expensive technical diving or submersibles, or the development of a trap that attracts lionfish, has an acceptable low proportion of by-catch, and does not cause physical damage to the environment.



### 2.6.1 Maximising socioeconomic benefit

Invasive lionfish populations have a direct, negative impact on native fish biomass and therefore, in the medium- to long-term, there is also a negative impact on traditional fisheries and the wellbeing of fishing communities. It is reasonable to consider that the suppression of lionfish populations reduces the likelihood of long-term negative socioeconomic impacts to fishing communities.

Lionfish population suppression is the first priority for the control strategy, preventing associated negative impacts to the wellbeing of fishing communities. However, the introduction of a new, alternative fisheries target for Belize's fishers is consistent with priorities identified within Belize's National Economic Alternative and Fisheries Diversification plan [16]. By anchoring lionfish control efforts in artisanal fisheries, small businesses, cottage industries and community-led initiatives, lionfish control activities can deliver new socioeconomic benefits.



## 2.7 Indicators for monitoring, evaluation and adaptive management

Twenty-one indicators have been prioritised for monitoring, evaluation and adaptive management. These were selected because of their relative importance (e.g. lionfish population density, number of restaurants serving lionfish) and feasibility (e.g. data already being collected through other programs). Description of methods for collecting and calculating these indicators are provided in *Chapter 3: Adopting A Coupled Human and Natural Systems Approach*.

### LIONFISH

#### N1. Lionfish Population

1. Average lionfish density (fish/ha)
2. Average lionfish size (cm)

#### H4. Lionfish Markets

3. Percent of restaurants that report serving lionfish
4. Percent of restaurants that report serving lionfish regularly (at least twice per month)
5. Median stated willingness to pay (WTP) for lionfish by restaurants (BZD/lb of fillet)
6. Percent of general public who have heard of lionfish
7. Percent of general public who have tried lionfish
8. Average WTP for lionfish by the general public
9. Average WTP for lionfish by tourists
10. Number of successful lionfish jewellers.

#### H5. Total Lionfish Catch

11. Total Lionfish Catch: Annual lionfish fishing mortality (F)

### FISHING

#### H3. Fishing Communities

18. Fishers' level of knowledge about the lionfish invasion, lionfish safe-handling, and lionfish buyers
19. Fishers' perceptions of lionfish markets
20. Description of fishers targeting lionfish for commercial use, subsistence use, or control (i.e. killing lionfish and leaving it on the reef)

### CONSERVATION AND ENVIRONMENT

#### N2. Coral Reefs

12. Prey fish biomass (hg/ha)
13. Mesopredator biomass (g/100 m<sup>2</sup>)
14. Lobster density (ind./ha)
15. Reef health (Reef Health Index score)
16. Percent of sites exceeding lionfish threshold density

#### N3. Traditional Fisheries

17. Lobster, Conch, and Finfish Landings (as reported through Managed Access programme)

### ECONOMY AND GOVERNANCE

#### H1. Management

21. Total catch by lionfish tournaments

#### H2. Economy and Tourism

No indicators identified for monitoring of this system in the SEF

# Adopting a coupled human and natural systems approach

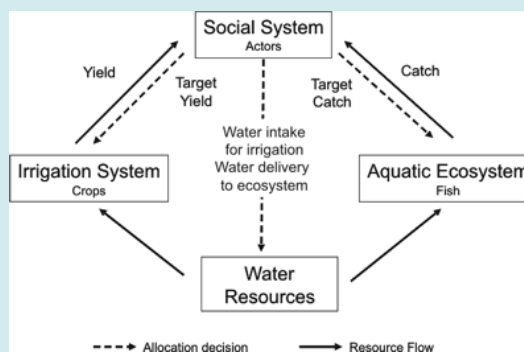
In this chapter, we explain the application of a Coupled Human and Natural Systems (CHANS) approach to lionfish management in Belize, including:

- An introduction to CHANS
- A description of the human and natural systems associated with lionfish management, and their interactions.
- Case studies demonstrating how these methods can be applied in practice.
- The use of a lionfish population dynamics model to project the results of different management actions.

## 3.1 What are coupled human and natural systems?

The interactions between human and natural systems are complex, and characterised by reciprocal feedback routes that can interact across local and global scales [46], [47]. Acknowledging this interdependency, and attempting to better understand these coupled human and natural systems (CHANS), is essential to successful natural resource management [52].

The CHANS approach, which involves both ecological and social science, has been increasingly used in conservation science [52]–[54], as it can expose indirect effects and non-linear relationships. Central to this approach is the construction of a conceptual framework (see: *Chapter 2.5, Socioecological Framework*) with an interdisciplinary team, enabling all stakeholders to view processes and challenges from different and new perspectives [47], [53]. These frameworks can range from extremely simple to highly complex.



*Figure 8: Example of an SEF, duplicated from Schlüter, M., and C. Pahl-Wostl 2007. Mechanisms of resilience in common-pool resource management systems: an agent-based model of water use in a river basin. Ecology and Society 12(2): 4.*

## 3.2 How do we understand each system?



### 3.2.1 Simplified and detailed SEF

The simplified SEF (*Figure 7*) provides a broad overview of key interactions between natural and human systems associated with lionfish management in Belize, showing three natural systems (N1-3) and five human systems (H1-5). The detailed SEF contains 97 nodes (representing unique indicators) that are grouped into 16 sub-systems known as clusters and four categories (*Appendix 2*). Interactions between nodes occur within, and between, clusters. In this chapter, each of the systems displayed in the simplified SEF is described in detail by referencing the clusters, nodes and indicators in the detailed SEF.

### 3.2.2 Natural systems associated with lionfish management

The simplified SEF (see *Figure 7, page 18*) shows us that there are three core natural systems associated with lionfish management: *N1. Lionfish Population*, *N2. Coral Reefs* and *N3. Traditional Fisheries*. As described in *Chapter 1, Ecological Effects of the Invasion*, lionfish predation can reduce abundance and species richness of native prey species, and compete with native species for food or shelter. These impacts to coral reef health directly affect the status of traditional fisheries, which depend upon healthy reefs with abundant populations of fishery target fishery species.

#### N1. Lionfish Population

The most important indicators associated with lionfish populations are density and average lionfish size.

- ⊗ Lionfish density is expected to increase with the abundance of fish recruits (attracted by prey) and reef complexity (lionfish tend to reside in overhangs and crevices), and decrease as lionfish catch rate increases.
- ⊗ An increase in lionfish density and lionfish average size is expected to lead to a decrease in mesopredators (through competition for prey) and lobster (through competition for shelter). This will also lead to an increase in the number of sites that exceed lionfish ecological threshold limits (see: *The Lionfish Ecological Threshold Model, page 27*).
- ⊗ An increase in lionfish density and lionfish average size is also expected to lead to an increase in the number of fishers who target lionfish to eat or sell.
- ⊗ An increase in lionfish density, regardless of lionfish size, is expected to lead to an increase in the number of fishers who kill lionfish and leave it on the reef. Fishers report killing lionfish and leaving them on the reef in order to reduce population density (see: *Case Study: Semi-Structured Interviews With Fishers, 2016, page 34*).

Both indicators (density and size) can be collected using the lionfish focused search (LFS) method [23], which involves systematically roving a large transect area (ideally 50 m x 10 m), and recording lionfish presence, behaviour and an estimate of total length (TL) (see *Appendix 4* for full description). A larger survey area provides better estimates due to lionfish's clumped distribution [22]. Traditional underwater visual census methods (e.g. fish belts) underestimate lionfish density [22] and therefore should not be used.

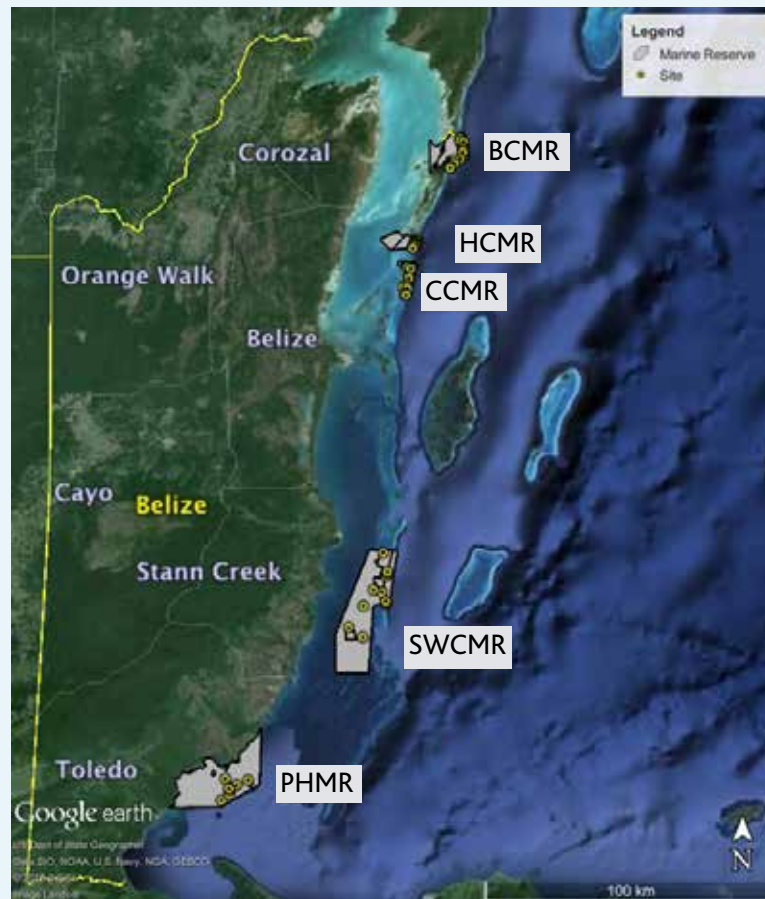
Lionfish size can also be monitored by measuring lionfish caught during culls (see *Appendix 3 for lionfish dissection guide*).

## N1 CASE STUDY

### LIONFISH POPULATION ASSESSMENT 2015

Between October and December 2015, data were collected using the LFS method at fifty coral reef sites, located within five MPAs: BCMR, CCMR, HCMR, PHMR and SWCMR. These five MPAs were chosen to be representative of the variable conditions, uses and intensity of coral reef use across Belize, and to include prioritised coral reef conservation areas [55]. All five are multiple use MPAs. For the purpose of this study, all zones were classified as either No Take Zone (NTZ), where no fishing is permitted, or General Use Zone (GUZ), where commercial fishing is regulated and all recreational activities are permitted.

A map of each reserve was populated with regularly spaced waypoints, made up of a combination of known reef monitoring sites and haphazardly assigned sites. Sites were then classified as either backreef or forereef, as well as either NTZ or GUZ, and then a total of fifty sites were randomly selected, ensuring effort was evenly spread across reef type and management zone.



*Figure 9: Map of survey sites for lionfish population assessment 2015.*

All forereef sites were spur-and-groove reefs, while backreef sites comprise of continuous backreef (behind the reef crest), patch reef and fringing reefs around mangrove cayes. Surveys were restricted to depth ranges 1-5 m or 8-15 m, except for some shallow forereef sites in SWCMR where transects were located in a shallower depth band, 6-9 m. In PHMR, which is behind the main barrier reef, all sites were classified as backreef.



**Results**

- Abundance generally low: only 22 lionfish were sighted in total; 11 of the 50 sites surveyed had lionfish present.
- Average lionfish density was  $10 \pm 4$  fish.ha<sup>-1</sup>.
- Mean size was  $21 \pm 2$  cm total length (TL), with body sizes ranging from 8-32 cm TL (Figure 11). 41% (n=9) were  $\geq 25$  cm TL.
- Excluding surveys at 5-8m (shallow forereef sites in SWCMR), lionfish density was significantly different between MPAs ( $p = 0.018$ ;  $DF = 4$ ;  $F = 3.4$ ).
- Lionfish density did not differ significantly between the two depth bands ( $p = 0.99$ ,  $DF = 1$ ,  $F = 0.001$ ) or protection status ( $p = 0.13$ ,  $DF = 1$ ,  $F = 2.37$ ).
- SWCMR had the highest lionfish densities, which were greater in shallow, backreef sites ( $29 \pm 20$  ind.ha<sup>-1</sup>) versus forereef sites ( $2 \pm 2$  ind.ha<sup>-1</sup>).
- Lionfish were absent from all surveys in PHMR, and very low or absent at sites within CCMR and HCMR (Figure 50).

**10** fish/ha  
the average lionfish density



The average lionfish size **21** cm

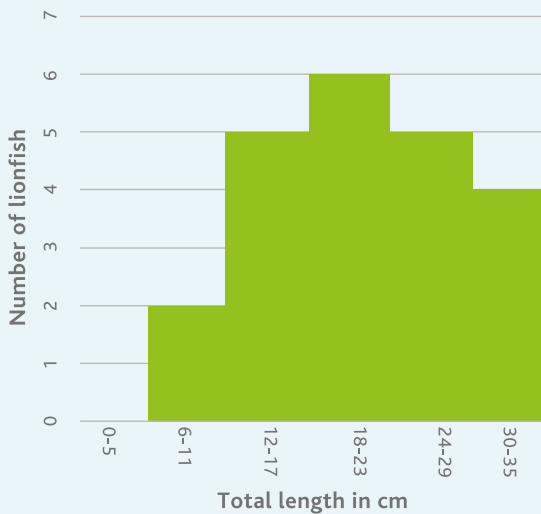


Figure 10: Distribution of lionfish total length (TL, to the nearest 1 cm; n=22) estimated visually during surveys.

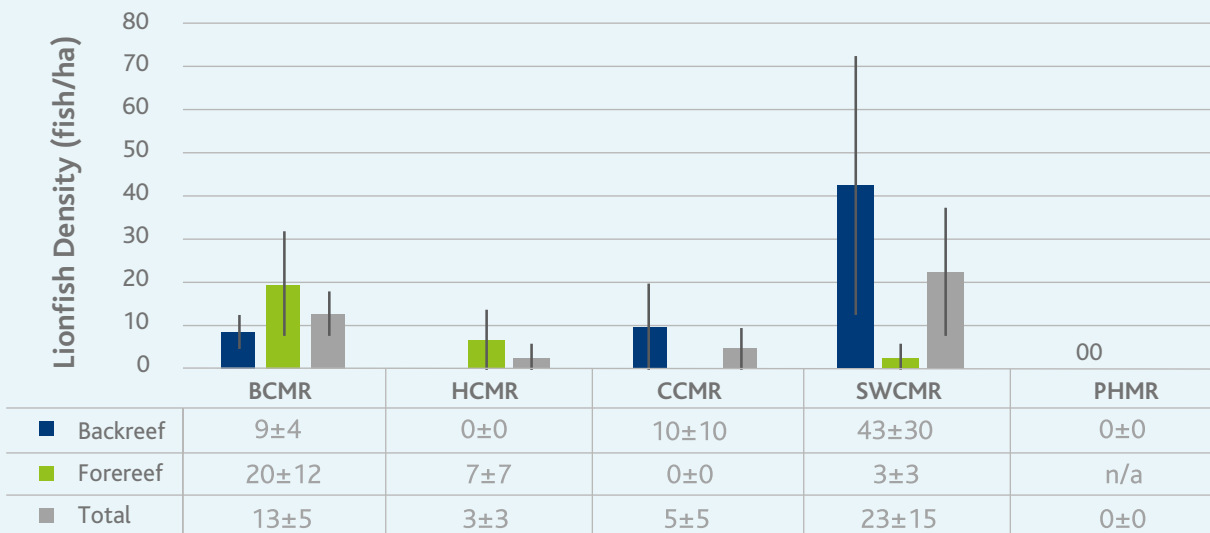


Figure 11: Mean lionfish density at five MPAs, presented by reef type. Error denotes standard error of the mean. Table under graph indicates number of surveys per habitat type in each region.

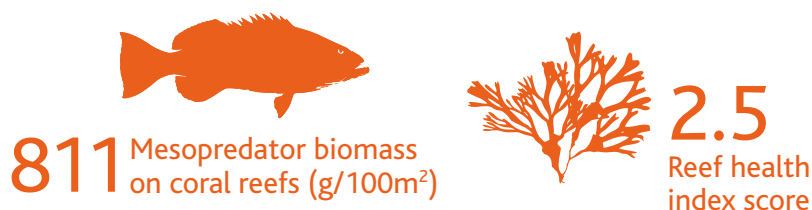
## N2. Coral reefs and associated species

For lionfish management, the most important indicators associated with coral reefs are coral reef health index, prey fish biomass (linked to juvenile fish abundance), mesopredator biomass, lobster abundance, and the percentage of sites that exceed lionfish ecological threshold limits.

- ✦ Coral reef health is influenced by a variety of factors, from extreme weather and coral bleaching events to the effectiveness of MPA and fisheries management. MPA and fisheries management activities can also increase populations of lobster and mesopredators.
- ✦ Healthy coral reefs support abundant juvenile fish, mesopredators and lobster populations. Juvenile fish abundance is also directly affected by the extent of good quality nursery habitat, such as seagrass beds and mangroves.
- ✦ As the abundance of prey fish increases, lionfish density and mesopredators biomass are expected to increase (attracted by prey).
- ✦ An increase in prey fish populations also confers increased resiliency to lionfish predation, raising lionfish ecological threshold limits (see: *The lionfish ecological threshold model, page 29*). Therefore, the number of sites exceeding lionfish ecological threshold limits will decrease.
- ✦ Increase in biomass of mesopredators such as snappers and groupers is expected to decrease juvenile fish abundance (through predation).
- ✦ An increase in lionfish density and lionfish average size is expected to lead to a decrease in mesopredator biomass (through competition for prey) and lobster abundance (through competition for shelter).
- ✦ Catch of live juvenile fish for the aquarium trade is expected to lead to a decrease in fish recruit abundance.
- ✦ Lobster and finfish catch is expected to lead to a decrease in lobster abundance and mesopredator biomass, respectively.
- ✦ An increase in mesopredator biomass and lobster abundance is expected to increase the number of fishers who choose to target those species.

Lobster populations are monitored through fisheries-independent surveys carried out by the Belize Fisheries Department and marine reserve co-management NGOs; these surveys have enabled comparison of lobster sighting frequencies between years and management zones within MPAs. A national indicator for abundance has not been developed.

Biennial reports by the Healthy Reefs Initiative provide national estimates for coral reef health and mesopredator biomass, evaluated using the Mesoamerican Barrier Reef System Synoptic Monitoring Program (MBRS-SMP) and Atlantic and Gulf Rapid Reef Assessment (AGRRA) methods. In 2015, the Reef Health Index score for Belize was 2.5 ('poor') and mesopredator biomass was 811 g.100-2 ('poor') [29].



Fish recruit abundance is also collected as part of MBRS-SMP and AGRRA methods, though these surveys focus on a subset of species. Given that lionfish are known to have a very wide diet, including high representation of fish families not captured by MBRS-SMP / AGRRA, a more thorough assessment of prey fish populations, following the method outlined in the LFS manual ([Appendix 4](#)), should be carried out when possible. The results of these surveys can also be used to calculate the percentage of sites exceeding lionfish ecological threshold limits ([Appendix 5](#)).

## The lionfish ecological threshold model

Given the broad distribution and depth range of lionfish, dispersal via pelagic larvae and high fecundity, it has become clear that the ongoing invasion of lionfish into Atlantic ecosystems is one that now occurs at a scale precluding complete eradication. Recognising this, focus has shifted to suppressing lionfish densities to levels that reduce their ability to cause severe ecological harm.

Experimental manipulation of lionfish densities on small patch reefs in the Bahamas demonstrated that maintained lionfish population suppression does allow native fish populations to recover [49]. The necessary level of suppression is unique to reef sites and depends upon native fish community structure and sea surface temperature. This so-called *lionfish threshold density* is the **tipping point between the rate at which lionfish consume prey and the rate at which new prey biomass is created** [49]. The rate at which lionfish consume prey (*lionfish consumption rate*) increases with lionfish size and water temperature [56]; *prey biomass production* is linked to both the amount of standing prey biomass at the site and the size structure of resident fish, with smaller bodied individuals generating new biomass at faster rates than larger bodied individuals [57] (Figure 12). Therefore, if lionfish density at a coral reef site exceeds its predicted lionfish threshold density, it is expected that the biomass of prey fish will decrease over time. If lionfish density at a coral reef site is below its predicted threshold density, it is not expected that lionfish will have a significant impact on prey fish biomass.

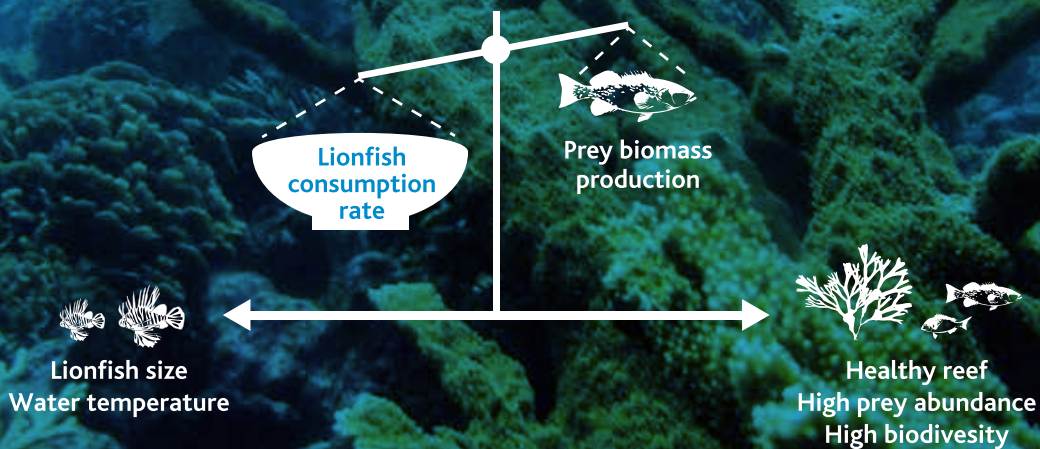


Figure 12: A coral reef's "lionfish threshold density" is the tipping point between the rate at which lionfish consume prey (*lionfish consumption rate*) and the rate at which new prey biomass is created (*prey biomass production*).

A coral reef's lionfish threshold density is predicted using an ecological model (*Appendix 5*) that simulates lionfish impacts on native fish populations based on data inputted by the user, and provides a range of probabilistic predictions for ecological threshold density [49].

Experimental manipulation of lionfish densities on patch reefs in the Bahamas tested this model: maintained suppression of lionfish population density below predicted thresholds was sufficient to maintain the standing biomass of native reef fish on coral reefs in the Bahamas, whereas on sites where densities remained above threshold values, prey species continued to decline [49]. This suggests that native fish populations can recover if the lionfish population is kept below site-specific threshold densities.

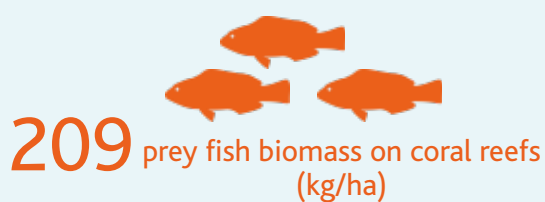
CASE STUDY

CALCULATING LIONFISH ECOLOGICAL THRESHOLD LIMITS 2015

Prey fish belts (10 m x 2 m) were conducted along the same transects as Lionfish Focused Search surveys (*Appendix 4*) during the Lionfish Population Assessment 2015. All fish encountered were identified to species level and tallied by size (total length, TL) to the nearest 1 cm. To perform these surveys, the researcher needed to have passed at least REEF Fish Identification Level 3 test<sup>5</sup>. Lionfish threshold densities for each site were then predicted using an ecological model (*Appendix 5*).

Results

- ▣ Average prey fish biomass in 2015 was 209 ± 31 kg.ha<sup>-1</sup>.
- ▣ Prey biomass was significantly different between MPAs (p = 0.019, DF = 4, F = 3.4), but did not differ between protection status (NTZ vs. GUZ) or depth (1-5 m vs. 8-15 m; p >0.3, DF = 1, F <1 for both tests). The small number of surveys conducted at 6-9 m were excluded from statistical analyses.
- ▣ The greatest prey fish biomass were encountered in shallow, backreef sites of SWCMR (459 ± 138 kg.ha<sup>-1</sup>) and PHMR (350 ± 129 kg.ha<sup>-1</sup>) (*Figure 52*)
- ▣ Lionfish threshold densities varied greatly across management zones within the five reserves, driven by differences in prey biomass production. Threshold densities were highest (i.e. reefs can withstand the greatest density of invasive lionfish) within PHMR. (*Figure 53*)
- ▣ In total, 22% of surveyed sites exceeded predicted threshold densities (i.e. lionfish are expected to have negative impacts on prey fish populations at these sites). The majority of sites exceeding threshold were located within NTZs (*Figure 54*), undermining the resiliency of these sites.



<sup>5</sup><http://www.reef.org/programs/volunteersurvey/experience>

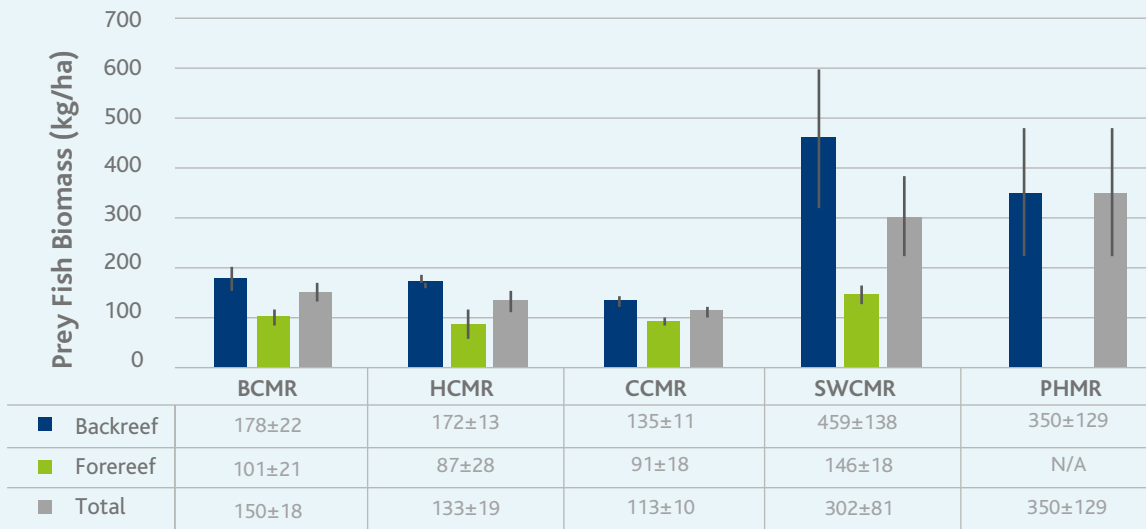


Figure 13: Mean prey fish biomass at five MPAs, presented by reef type. Error denotes standard error of the mean.

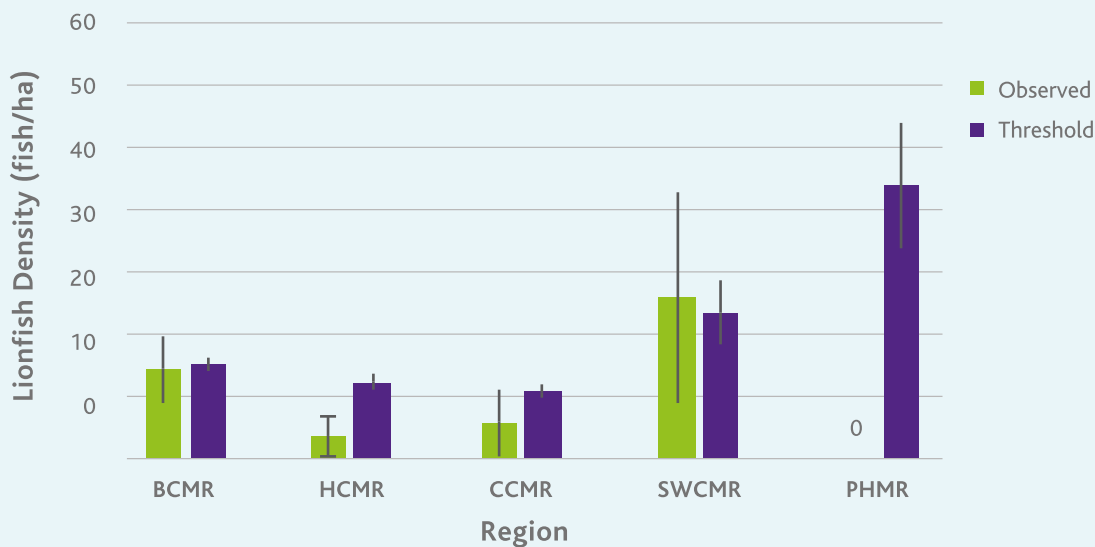


Figure 14: Mean observed lionfish density and predicted threshold density at five MPAs. Error denotes standard error of the mean.

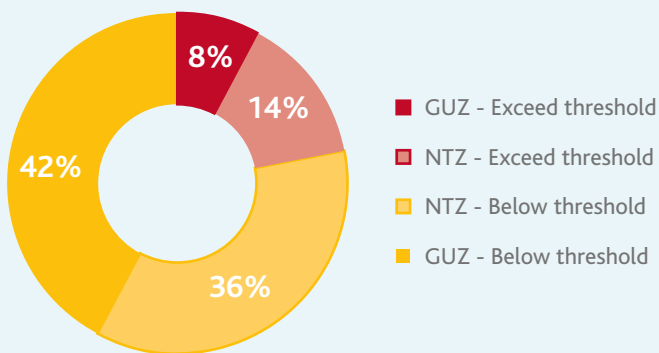


Figure 15: The percentage of sites exceeding and below threshold densities, presented by management zone (No Take Zone, NTZ; General Use Zone, GUZ).



### N3. Traditional fisheries

Belize's traditional fisheries targets are lobster, conch, and finfish (e.g. snapper, grouper).

- ✦ Finfish, conch and lobster inhabit different areas of the reef and are caught using different gear types. Therefore, total landings for each fishery is influenced by how many fishers choose to target that species, which is influenced by the status of in-water populations (density and size structure of each species) and fisheries management laws, such as seasonal closures and size limits.
- ✦ The total number of fishers choosing to target a certain species is also influenced by the total number of active fishers, which is itself influenced by the presence of economic alternatives in fishing communities.
- ✦ An increase in total landings for each fishery will lead to a decrease in poverty levels in fishing communities, but could also lead to a decreased status of in-water populations (density and size structure of each species).

The status of these fisheries can be monitored through in-water population monitoring (fisheries independent monitoring – see *N2. Coral Reefs*), or by monitoring fisheries landings (fisheries dependent monitoring). Both types of monitoring are essential for effective fisheries management. The introduction of catch logbooks in 2016 through the Managed Access programme will greatly improve fisheries independent monitoring in Belize (see *Chapter 2, Managed Access And Rights-Based Fishing*).

### 3.2.3 Human systems associated with lionfish management

The simplified SEF (see *Figure 7, page 18*) shows us that there are five core human systems associated with lionfish: *H1. Management, H2. Economy and Tourism, H3. Fishing Communities, H4. Lionfish Markets* and *H5. Total Lionfish Catch*.

Coral reef, fisheries and lionfish management activities are resource intensive and depend on funding availability, which is affected by the status of national and global economies, and can be enhanced by tourism – for example via entry fees to protected areas. Tourism can provide enormous benefits to coastal fishing communities through the introduction of economic alternatives, but poor tourism practices are also a legitimate threat to Belize’s coral reefs.

On the other hand, in the absence of livelihood alternatives, fishing communities are more likely to engage in unsustainable fishing practices. In general, community wellbeing depends heavily on healthy fisheries. Fair lionfish markets (i.e. that pay fishers an appropriate price for their catch) can provide opportunities for economic diversification in coastal communities, though the viability of these markets depends upon the availability of a regular, high-quality supply of lionfish. This total lionfish catch is influenced by the status of lionfish populations, the status of markets, and the types of lionfish management activities in place.

#### H1. Management

A number of management interventions are relevant to invasive lionfish, and have the potential to influence knowledge and perceptions about lionfish, the wellbeing of fishing communities, fishers’ decision-making, and the effectiveness of MPAs.

- ✉ Outreach activities raise awareness about lionfish amongst the general public and tourists, and provide opportunities for people to try lionfish meat for the first time.
- ✉ Lionfish safe-handling workshops increase confidence amongst fishers when handling lionfish.
- ✉ Lionfish tournaments or derbies to cull lionfish are an important vehicle for awareness-raising and also lead to the removal of a large number of lionfish from a small reef area over a single event.
- ✉ Programmes that help tour operators to establish lionfish-culling tours can lead to lionfish removals from visited sites – including within no take zone areas and deep coral reefs.
- ✉ Promotion of restaurants that serve lionfish raises awareness amongst restaurant, consumer and fishing community members about successful lionfish markets and can lead to the formation of positive attitudes towards lionfish exploitation.
- ✉ Programmes aiming to introduce economic alternatives in fishing communities, including lionfish jewellery initiatives, diversify household income and reduce dependency on fishing.
- ✉ MPA management activities can remove lionfish from reefs (e.g. lionfish culls by protected area managers) and improve the status of MPA conservation targets, such as coral reef health or mesopredator biomass (e.g. through the enforcement of regulations).
- ✉ Fisheries management laws, such as seasonal closures and size limits, and special licenses, such as permission to catch live, juvenile fish for the aquarium trade, influence fishers’ decisions about which species to target.

No indicators have been systematically monitored for this system, but a national database should be developed to monitor total catch from lionfish tournaments, and if possible lionfish tourism activities.

Approximately  
**1,398 lionfish**  
were caught through  
tournaments in 2015

## History of lionfish tournaments In Belize

In 2010, ECOMAR organised monthly lionfish tournaments resulting in the culling of over 8,000 lionfish across the Belize Barrier Reef [21]. Since 2011, tournaments have been organised independently in different areas of Belize (Table 4).

A crude estimate of the number of lionfish caught during tournaments in 2015 was calculated using available data: the average number of lionfish caught per tournament ( $699 \pm 131$  lionfish,  $n=5$ ) was multiplied by the number of tournaments held in 2015 ( $n=2$ ).

Table 4: Lionfish tournaments held in Belize, 2011-16. ND indicates that data were not available.

COMMUNITY	MARINE PROTECTED AREA	MONTH, YEAR	ORGANISER	LIONFISH CATCH (#)
Placencia	None	June, 2011	Southern Environmental Association (SEA)	ND
Placencia	None	June, 2012	SEA	979
Placencia	None	June, 2013	SEA	599
Placencia	None	June, 2014	SEA	1,027
Caye Caulker	Caye Caulker Marine Reserve (CCMR)	June, 2014	BFD	ND
Placencia	Gladden Spit and Silk Cayes Marine Reserve (GSSCMR)	June, 2015	SEA	ND
Placencia	GSSCMR	October, 2015	SEA	ND
Caye Caulker	CCMR	February, 2016	Sports Bar and BFD	546
San Pedro	HCMR	May, 2016	BFD	344
Placencia	GSSCMR, Laughing Bird Caye National Park	June, 2016	SEA	ND
Dangrigo	South Water Caye Marine Reserve	July, 2016	BFD	ND
San Pedro	Hol Chan Marine Reserve (HCMR)	2017	Belize Fisheries Department (BFD)	544
Average number of lionfish caught per tournament				673





## H2. Economy and tourism

Growth in Belize's tourism industry directly influences lionfish management and markets through providing an increased demand base for lionfish dishes in restaurants and lionfish jewellery, as well as more customers to participate in lionfish tourism activities. Tourism is itself influenced by the status of the global economy, as well as the status of natural resources and MPA management effectiveness.

No indicators for this system have been prioritised for monitoring.

## H3. Fishing communities

It is essential to fully understand the challenges that fishers face when fishing lionfish: if these are not overcome, fishers will not fulfil the desired lionfish catch rate in order to reduce lionfish populations. Development of a lionfish fishery opens the opportunity for fisheries diversification, supporting improved socioeconomic wellbeing in fishing communities, but only if the lionfish fishery is designed in such a way so as to support fishers' needs (e.g. price paid for lionfish matches fishers' expectations).

Whether a fisher decides to target lionfish is partially a result of their knowledge and perceptions of lionfish and lionfish markets, which can be influenced by activities in the *H1. Management cluster* (e.g. outreach, safe-handling workshops, and promotion of restaurants). Fishers' knowledge / perception of lionfish and/or lionfish markets is also influenced by personal connections with lionfish jewellers, the number of restaurants purchasing lionfish, and willingness to pay (WTP) for lionfish meat and fins by jewellers (*4B: Jewellery*), restaurants (*4C: Restaurants*), and consumers (*4D: Consumers*).

The status of lionfish populations (*N1. Lionfish Population*) and traditional fisheries (*N3. Traditional Fisheries*) also influences whether a fisher decides to target lionfish or other species. For example, during the conch season and when conch density is high, fishers' effort is primarily focused on seagrass beds and they are therefore less likely to encounter lionfish. However, if the conch season is closed or densities are low, fishers may divert their effort towards areas where lionfish are more abundant, such as deeper coral reefs. Similarly, as lobster density decreases and/or lionfish density increases, more fishers will choose to kill lionfish – though whether they choose to subsequently remove and use the lionfish (for subsistence or sale) is influenced by the size of the lionfish as well as the fishers' knowledge and perception of lionfish markets.

As more fishers choose to kill lionfish, lionfish density and average size will decrease, and if fishers choose to sell their lionfish catch, it can have a positive impact on economic wellbeing. It is also expected that less time will be spent fishing traditional targets if more time is spent fishing lionfish. This shift will lead to positive impacts on the status of coral reefs and traditional fisheries (as outlined in *N3. Traditional Fisheries*), and will benefit communities in the long term.

Prioritised indicators for this system are qualitative, and include level of knowledge and perceptions of the lionfish invasion, lionfish safe-handling and lionfish markets, as well as a description of fishers targeting lionfish for commercial use, subsistence use, or control (i.e. killing lionfish and leaving it on the reef). These indicators are best explored through semi-structured interviews<sup>6</sup>.

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<sup>6</sup>During a semi-structured interview, the interviewer follows a guide to ensure that key themes are covered, and uses open-ended questions so that the interviewee is able to express opinions without being restricted to a set of pre-determined answers. This method is particularly useful for exploring perceptions, as it allows respondents to raise opinions that may not have been considered by the interviewer. The data provided are qualitative.

CASE STUDY

SEMI-STRUCTURED INTERVIEWS WITH FISHERS, 2016

To explore fishers' attitudes and behaviour towards lionfish, semi-structured interviews were conducted between February and May 2016 with 46 fishers from three northern fishing communities (Sarteneja, n=26; Chunox, n=10; Copper Bank, n=10), using a snowball sampling method<sup>7</sup> until each community had been sampled to saturation. These interviews were repeated with five fishers from central and southern fishing communities (Belize City, n=3; Dangriga, n=1; Placencia, n=1) to attain additional information.

Interviews were conducted in either English or Spanish and lasted approximately 1 hour. The study was approved by Colorado State University's Research and Integrity & Compliance Review Office (IRB ID number: 053-17H). The interview outline can be found in [Appendix 6](#).

Calendar Mapping (Northern Belize Fishing Communities)

The first interviewee from each village participated in a seasonal calendaring exercise [58] during which information was compiled about a typical fishers' working year and the influences (e.g. timing of lobster season, weather conditions) that impact whether or not lionfish are targeted.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Open lobster season	█					█						
Open conch season	█					POTENTIAL EARLY CLOSURE					█	
Tourist season	█										█	
High capture												
Weather conditions												
Time at sea (trips)			EASTER									
Distance travelled	CLOSE		FAR	FAR	FAR	FAR	FAR			CLOSE	CLOSE	CLOSE
Good price (fish)	\$\$	\$\$	\$\$\$								\$\$	\$\$
More lionfish observed												
Sea cucumber fishing												
Captains service boats			█									
Potential lionfish capture												
Optimal lionfish capture	█											█

<sup>7</sup>This non-random sampling method involves one research subject nominating further potential research subjects to the researcher. The major advantage of this method is that it helps researchers to reach difficult-to-access populations. However, as there was no random selection of samples it is not appropriate to draw statistical inferences from data.

### Knowledge and perceptions

The level of knowledge about lionfish and lionfish safe-handling among all fishers was high. All respondents recognized that lionfish have become abundant throughout Belize’s reefs, and there was general consensus that lionfish are bad for the reefs.

*“They are a kind of fish that no one can do that [eliminate] and it is problem because this fish eat the good fish and when they reach a...rock and it have fish or lobster and lionfish reach there, it eat everything that is there and he take over the rock.” (F43, Copper Bank)*

Almost all fishers were confident handling lionfish (n=38), and most had learned to handle lionfish by themselves (i.e. intuition or trial-and-error, n=28) or from peers (n=7), versus only three who had learned during safe-handling workshops. Nevertheless, six fishers expressed a need for training in lionfish safe-handling, with five citing a lack of knowledge about safe-handling as the primary reason for not catching lionfish. Many (n=12) had low knowledge about the risks involved with lionfish envenomation, and were either unsure whether a lionfish sting could be fatal, or believed that it could be fatal.

*“If the spine goes deep, it can affect the person more and probably cause his death” (F14, Sarteneja)*

While many fishers (n=26) believed that lionfish were bad for Belize’s fishing industry, others were unsure and a small number from northern fishing communities (n=4) identified the potential economic benefits lionfish could bring.

*“I don’t think it will affect the fishing industry because it is now a product that the fishermen are working on to make money.” (F12, Sarteneja)*

In contrast, fishers from central/southern communities shared the general consensus that lionfish do not represent a valuable market and fishing lionfish is not worthwhile.

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Fishers have a high level of knowledge about lionfish and about safe-handling

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Fishers hold mixed perceptions of lionfish markets

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**Barriers**

During the first nine interviews with fishers from northern communities, barriers to lionfish fishing were explored. Using information from those interviews, a barrier-ranking exercise was included in subsequent interviews. A total of nine barriers were predetermined and a further two were later identified by interviewees and incorporated (Table 5). To ensure accessibility among fishers with varied levels of literacy, the ranking exercise comprised a series of pictures of known barriers, which participants were asked to rank in order of most to least important (Figure 17).

**Table 5: Barriers included in the barrier-ranking exercise with fishers from northern fishing communities during semi-structured interviews in 2016.**

STATED BARRIER	DETAILS
1. Low price for lionfish in the market	Pre-determined
2. Fear of envenomation	Pre-determined
3. Too time consuming to catch and prepare lionfish for sale	Pre-determined
4. Lack of familiarity with handling lionfish	Pre-determined
5. Lack of buyers	Pre-determined
6. Lionfish too small for restaurants to purchase	Pre-determined
7. Do not catch enough lionfish to make a profit	Pre-determined
8. Inadequate equipment	Pre-determined
9. Lack of first aid training	Pre-determined
10. Lionfish meat not staying fresh (compared to other finfish)	Incorporated by interviewee
11. Fear of lionfish sliding down the spear and causing a sting	Incorporated by interviewee

Economic and financial concerns were the most common primary and secondary barriers identified by participants. These were followed by a lack of knowledge of lionfish buyers (Figure 18).

Safety concerns (fear of envenomation, lack of knowledge of first aid for a lionfish sting, and lack of familiarity with handling lionfish) were also ranked as primary barriers. Only fishers from Chunox and Copper Bank cited lack of knowledge of lionfish first aid as an important barrier.

“If there was a constant sale for lionfish I would capture more. Sometime fishermen capture lionfish and cannot sell it because there is no one interested in buying it.”  
(F6, Sarteneja)

Question: “What would encourage you to catch more lionfish?” Answer: “A good price for the lionfish.”  
(F1, Sarteneja)

Low level of knowledge of lionfish buyers amongst fishers



Figure 17: Fishers were asked to rank barriers to lionfish fishing using a pin-board.

Secondary barriers included a lack of suitable equipment for lionfish fishing, the small size of lionfish, and that lionfish do not retain their freshness as long as other types of finfish.

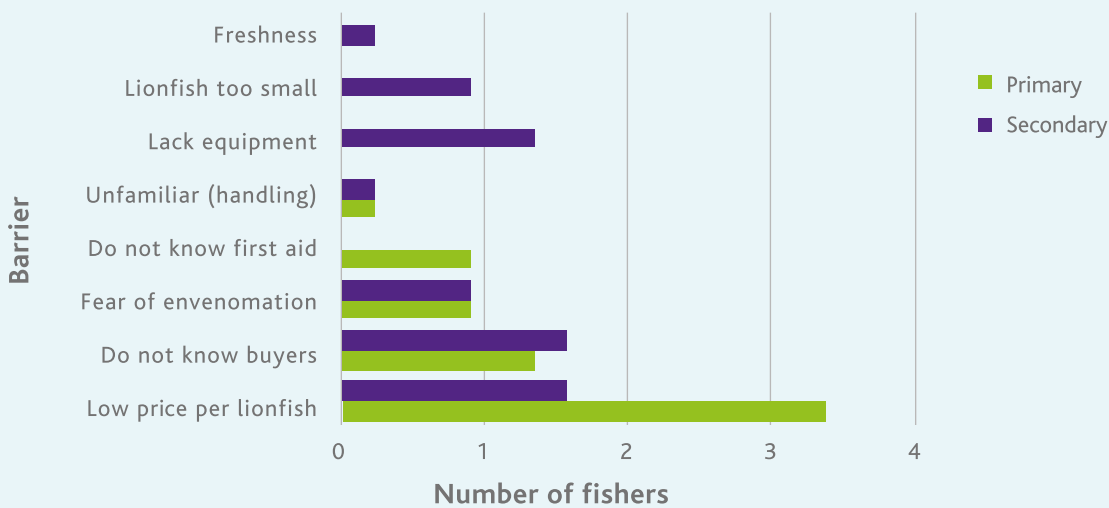


Figure 18: Stated primary and secondary barriers for not working, or not working more frequently, with lionfish.

“I wouldn’t want to pinch my hand for nothing right, ‘cause if I pinch my hand who will pay my day? Nobody.”

(F42, Copper Bank)

### Fisher behaviour

Of the 26 fishers interviewed in Sarteneja, almost all (n=25) speared lionfish, and over half (n=19) report selling it. Although nine of the ten fishers interviewed from Chunox speared lionfish, only three fishers noted that they had sold lionfish, and only one fisher reported that he currently sells lionfish. In both communities, fishers reported catching lionfish for subsistence. None of the fishers interviewed from Copper Bank, Belize City, Dangriga or Placencia had ever sold lionfish, and only two stated that they ate lionfish.

Fishers from Sarteneja and Chunox use lionfish for subsistence

"I don't kill a lot, I only kill them when I see them when I am catching lobster. I have a friend that work with me and he ask us when we see a lionfish we kill it and bring it for him to eat."

(F40, Copper Bank)

Fishers who sell lionfish primarily from Sarteneja

"Most know that the sailing boat fishers are the ones who work with it."

(F51, Placencia)

The majority of fishers kill lionfish and leave them on the reef

By comparison, only seven of the Sartenejan fishers interviewed would kill lionfish and leave them in the water, whereas over half (n=16) of the fishers from other communities reported killing lionfish and leaving them on the reef. The motives given for killing lionfish were linked to environmental benefit.

"As I reach in our coral where I know [I] always have lobster, now, now I could see the lionfish, and not the lobster in those corals. What I start doing is killing them, and push them back inside. As soon as I come back [in] 2 or 3 weeks, I could see a difference that there is lobster and there is not lionfish."

(F10, Sarteneja)

Due to the sampling method used (snowball) it was not possible to determine percentages of fishers who report selling lionfish, using lionfish for subsistence, and killing lionfish and leaving on the reef. If similar qualitative research were to be repeated, fishers should be randomly selected for participation and all communities sampled to saturation.



### Opportunity to add value

Four fishers from Sarteneja noted that they add value to their lionfish catch by selling normally discarded parts (e.g. fins and spines) that can be used to make jewellery.

### Willingness to accept

While fishers' stated willingness to accept (WTA) for lionfish varied between communities (Table 6), on average, WTA was 10 BZD/lb for lionfish fillet and 6 BZD/lb for whole lionfish.

**Table 6: Median stated willingness to accept for lionfish fillet and whole lionfish, with range.**

COMMUNITY	MEDIAN WTA FOR LIONFISH FILLET IN BZD/LB (RANGE, NUMBER)	MEDIAN WTA FOR WHOLE LIONFISH IN BZD/LB (RANGE, NUMBER)
Sarteneja	10 (8-14; n=23)	6.5 (5-9; n=18)
Chunox	8 (7-15; n=8)	5 (3-7; n=7)
Copper Bank	10 (6-16; n=7)	6 (5-10; n=4)
<b>Total</b>	<b>10 (6-16; n=38)</b>	<b>6 (3-10; n=29)</b>

#### H4. Lionfish markets

Since the introduction of the invasive alien lionfish, the biggest challenge facing Belize has been the development of financially sustainable control strategies. Once the high quality and palatability of lionfish meat was discovered, removal for human consumption was quickly touted as the solution to this invasive species [59].

Developing markets for lionfish meat provides an opportunity to diversify fisheries, making fishing communities more resilient to the impacts of changes in the status of traditionally targeted species. By establishing a financially attractive alternative target species, incentive for fishers to engage in illegal or unsustainable fishing practices is reduced, and community wellbeing is increased.

However, for lionfish markets to achieve this objective, the value of landed catch must be competitive. Catch value can be increased through improving supply chains (4A: Marketplace) or value-addition (4B: Jewellery). The market must also have steady and reliable demand (4C: Restaurants, 4D: Consumers) to achieve the desired consistent, high-volume removal rate necessary to achieve effective lionfish population control.



#### 3.2.4 Belioness – Belize Lionfish Jewellery

The Belize Lionfish Jewelry group “Belioness” is the first established women’s group in the country to use lionfish fins for the creation of jewellery to collectively address invasive lionfish and improve the livelihoods of their families and communities. Since 2015, Belioness has been working for the empowerment of its members and the protection of the reefs their families depend on, demonstrating that women’s community enterprises can support invasive species control, help overcome barriers to market development for lionfish, and support the development of a sustainable fishery.

Find out more: [www.facebook.com/belzelionfishjewelry](https://www.facebook.com/belzelionfishjewelry)



#### 4A: Marketplace

Where lionfish is bought and sold influences the attractiveness of the market to fishers and buyers alike. Fishing cooperatives have large membership, and primarily supply export markets; to be financially viable, high volume is essential [60]. Domestic markets – including restaurants, supermarkets and for home consumption – source seafood in a variety of ways, including through fishing cooperatives, private seafood distributors and directly from fishers. Informal transactions directly with fishers occur either through personal relationships or at fish markets; and as no operating costs have to be deducted, typically result in fishers being paid a higher price for their catch. However, the transaction is risky: both supply and demand is inconsistent, meaning that fishers may not find a buyer or vice versa. Cooperatives and private seafood distributors overcome this challenge by providing a reliable sales and purchasing point, however the price paid to fishers is typically lower than they could get at the informal market [60]. No indicators for this cluster have been prioritised for monitoring.

#### 4B: Jewellery

The use of fins and spines to create lionfish jewellery adds value to lionfish catch by commoditising a previously discarded part of the fish. Furthermore, the production and sale of lionfish jewellery increases awareness about the invasion. Success of lionfish jewellery businesses is expected to increase jewellers' willingness to pay for lionfish fins as well as improve fishers' perceptions of lionfish markets. In January 2016, there were twenty-two lionfish jewellers<sup>8</sup> in Belize, from eight coastal communities. Jewellers work independently or as part of a group.



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**22 lionfish  
jewellers**  
from 8 coastal  
communities

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#### 4C: Restaurants

Restaurants are currently the main buyers of lionfish in Belize, and therefore play a critical role in incentivising lionfish removals. The number of restaurants serving lionfish is influenced by availability of lionfish in the marketplace, as well as demand for lionfish from the general public and tourists. An increase in the number of restaurants serving lionfish, and therefore demand for lionfish from restaurants, will lead to an increase in restaurants' willingness to pay (WTP) for lionfish and improve fishers' perceptions of lionfish markets.

Besides providing fishers and divers a place to sell their lionfish catch, restaurants also play a role as awareness-raising platforms for the general public to learn about and taste lionfish for the first time. Prioritised indicators for this system are:

1. Percent of restaurants that report serving lionfish
2. Percent of restaurants that report serving lionfish regularly (at least twice per month)
3. Median stated willingness to pay (WTP) for lionfish by restaurants (BZD/lb of fillet)

These indicators are best explored through questionnaires.

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<sup>8</sup> Three independent and nineteen members of Belioness (who also work independently)

## CASE STUDY

### BELIZE RESTAURANT SURVEY, 2015

To evaluate restaurant indicators, as well as understand restaurateurs' (restaurant owners, managers or chefs) knowledge and perceptions of lionfish, questionnaires were conducted with restaurateurs in July-August 2015 (*Appendix 7*) in all district capitals as well as communities with a population greater than 7,500 people [61], or with more than 50,000 overnight tourist visitors per year [62].

In total, eight communities were sampled (Table 7) and for each a comprehensive list of restaurants was created by searching the Belize Yellow Pages and Trip Advisor. Each community was treated as an independent sample, the representative sample size for each was calculated<sup>9</sup>, and restaurants were randomly selected for participation. In total, 172 restaurants participated, 24 declined to participate, and 41 had permanently shut down or were closed due to low season (overall response rate = 62%). Nine restaurants were excluded because they could not be located or due to time limitations.

*Table 7: Details of the eight communities sampled in 2015 as part of the restaurant surveys.*

COMMUNITY	DISTRICT CAPITAL	POPULATION SIZE	TOURISTS / YEAR	TOTAL NO. RESTAURANTS	REPRESENTATIVE SAMPLE SIZE	NO. RESTAURANTS PARTICIPATED
San Pedro	No	11,765	144,821	94	79	56
Caye Caulker	No	1,763	83,361	39	36	25
Belize City	Yes	57,169	51,103	58	51	35
Corozal Town	Yes	10,287	13,243	14	13	8
Orange Walk	Yes	13,709	14,092	11	11	9
Dangriga	Yes	9,591	37,691	10	10	6
Punta Gorda	Yes	5,351	10,526	18	18	9
San Ignacio	Yes	10,489	70,288	29	28	24
<b>TOTAL</b>				<b>273</b>	<b>246</b>	<b>172</b>

### Knowledge and perceptions of respondents towards lionfish

While the majority (81%, n=139) of restaurateurs had heard of lionfish, only 29% (n=50) had tried eating it (*Figure 19*). Of the respondents who had heard of lionfish but never tried it (52%, n=89), almost half had simply never had the opportunity, while over a quarter stated that they were afraid to try it, despite knowing that it was safe to eat.

The restaurateurs who had tried lionfish were asked to rate its taste on a five-point scale (with 1 representing 'did not like it at all' and 5, 'loved it'): 82% rated lionfish highly (4-5). The majority (78%, n=39) said they would choose to eat lionfish in place of snapper, and more than half (56%, n=28) said they would choose lionfish over grouper.

<sup>9</sup><http://www.surveysystem.com/sscalc.htm>

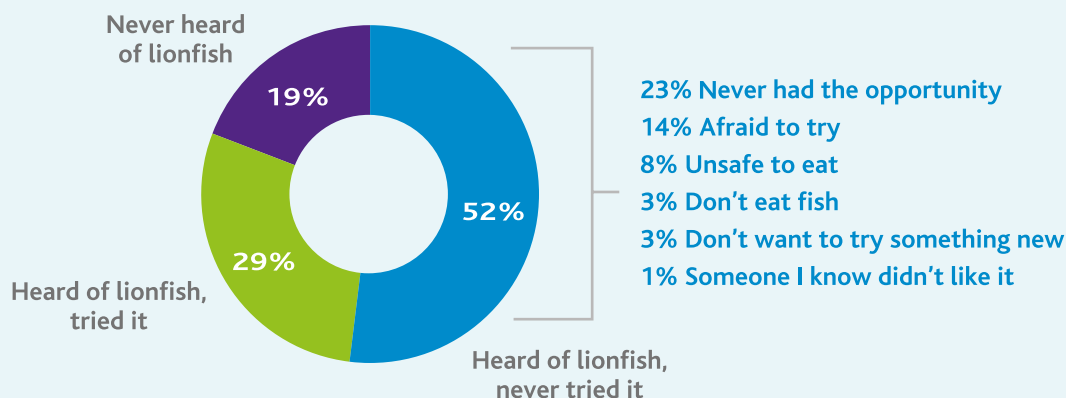


Figure 19: Percentage of restaurateurs who had heard of lionfish, and of those that had, how many had tried eating it before. Primary barriers to lionfish consumption displayed as bar.

### Restaurant indicators

In total, 20 restaurants (12% of all restaurants surveyed) reported that they had served lionfish before, however five of these reported that they did not continue to do so because:

- lionfish was served as a once-off, but there was no interest in changing their existing menu - it was either a special request from customers or their regular seafood supply was disrupted.
- difficulty in accessing regular supply.

9%  of restaurants that report serving lionfish

5% of restaurants served lionfish regularly (at least twice per month) in 2015

\$10  The median stated willingness to pay for lionfish by restaurants (BZD/lb of fillet)

All 20 restaurants that had served lionfish before were asked to rate the popularity of lionfish with customers: the majority (65%, n=13) said that lionfish was "very popular". Primary reasons given for serving lionfish were because it is "a good quality fish" (50%, n=10), "popular with customers" (40%, n=8), and "good for the environment" (35%, n=7).

In total, 9% (n=15) of all restaurants surveyed reported that they served lionfish, and eight of these (5% of all restaurants surveyed) reported that they served lionfish regularly (at least twice every month). The island communities of San Pedro and Caye Caulker had the greatest number of restaurants serving lionfish, and all but one of these restaurants included tourists as their target clientele.

### Barriers to lionfish use by restaurants

Difficulty accessing a reliable lionfish supply was the most frequently cited reason (33% of all restaurants, n=57) for not serving lionfish. Of these 57 restaurants, 23 (i.e. 13% of all restaurants surveyed) stated that a lack of supply was the only reason they did not serve lionfish.

The perception that lionfish would not be popular with customers was the second most commonly cited reason for not serving lionfish (n=47).

Restaurants that had purchased lionfish within the last year were asked the price paid per pound for lionfish fillet and whole lionfish. The median price paid for lionfish fillet was 10 BZD/lb (range: 6-12, n=13) while there was a standard 7 BZD/lb paid for whole lionfish. The selling price for lionfish dishes in restaurants varied: most charged either 16-20 BZD (n=6) or 26-30 BZD (n=6), and two charged over 35 BZD per lionfish dish.

### Estimating annual demand for lionfish from restaurants

Restaurants that had purchased lionfish within the last year provided estimates on lionfish purchasing, which were standardised to individual lionfish per month<sup>10</sup>. Some respondents had difficulty recalling how much lionfish they typically purchased, and not all respondents gave estimates. Median demand for lionfish was 109 (range: 11-1,920) lionfish per restaurant per month (n=12).

It was assumed that lionfish is served for eight months of the year, when fishers report catching lionfish and during the high tourist season. When scaled to the total number of restaurants per community, and considering the proportion of restaurants per community that served lionfish, this is equivalent to 21,795 lionfish per year for surveyed communities (Table 8).

**Table 8: Calculation steps to estimate the total number of individual lionfish bought by restaurants in surveyed communities in 2015.**

COMMUNITY	TOTAL NO. RESTAURANTS	% RESTAURANTS SERVING LIONFISH	NO. RESTAURANTS SERVING LIONFISH	NO. OF LIONFISH BOUGHT PER YEAR (109 LIONFISH/ RESTAURANT, 8 MONTHS / YEAR)
San Pedro	94	7%	6.7	5,843
Caye Caulker	39	24%	9.4	8,145
Belize City	58	9%	5.0	4,326
Corozal Town	14	0%	0.0	0
Orange Walk	11	0%	0.0	0
Dangriga	10	0%	0.0	0
Punta Gorda	18	22%	4.0	3,481
San Ignacio	29	0%	0.0	0
<b>Total no. lionfish bought by restaurants in surveyed communities</b>				<b>21,795</b>

Although communities of Placencia and Sarteneja were not included in the restaurant surveys, both are known to have restaurants that serve lionfish. Assumptions<sup>11</sup> for these communities brought the estimated total annual demand for lionfish from restaurants to 31,164 individual lionfish in 2015.

<sup>10</sup>Assumptions: fillet size of 2.5 oz. and whole, cleaned lionfish size of 11 oz., drawn from descriptions of lionfish catch given during fisher interviews (H3: Fishing Communities).

<sup>11</sup>Assumptions: (1) Placencia bought the average of Belize City, San Pedro, Caye Caulker, and Punta Gorda. (2) Sarteneja bought 245 lionfish per week for four months of the year (inferred from an informal interview with one restaurant in Sarteneja).

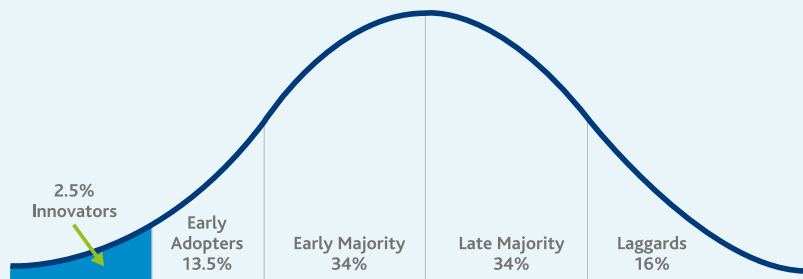
#### 4D: Consumers

Demand from consumers influences restaurant behaviour, and therefore lionfish markets (demand and willingness to pay). Consumers in Belize can broadly be classified into two groups – the general public and tourists – each with distinct cultural norms, preferences, and values, and influenced by different communication channels and peers. Consumer demand is dictated by individual preferences, knowledge, perceptions and familiarity, which can be influenced by activities in the *H1. Management cluster* (e.g. outreach and social marketing, see: *The Diffusion of Innovation (DOI) Theory*). As demand increases, so does willingness to pay for lionfish dishes, and therefore serving lionfish dishes becomes more attractive and financially viable for restaurants.

Prioritised indicators for this system are:

1. Percent of general public who have heard of lionfish
2. Percent of general public who have tried lionfish
3. Average WTP for lionfish by the general public
4. Average WTP for lionfish by tourists

These indicators are best explored through questionnaires.



**Figure 20: The diffusion of innovation curve, with adopter categories displayed. Adapted from Rogers (2010). Percentages denote the percentage of respondents making up each category.**

### 3.2.5 The Diffusion of Innovation (DOI) Theory

The DOI model [63] represents the rate of adoption of new ideas, products or practices over time within a culture, explaining how, why and at what rate behaviour is adopted by a population. Fundamental to the theory is the DOI curve (Figure 59), which divides the population into 'adopter categories'.

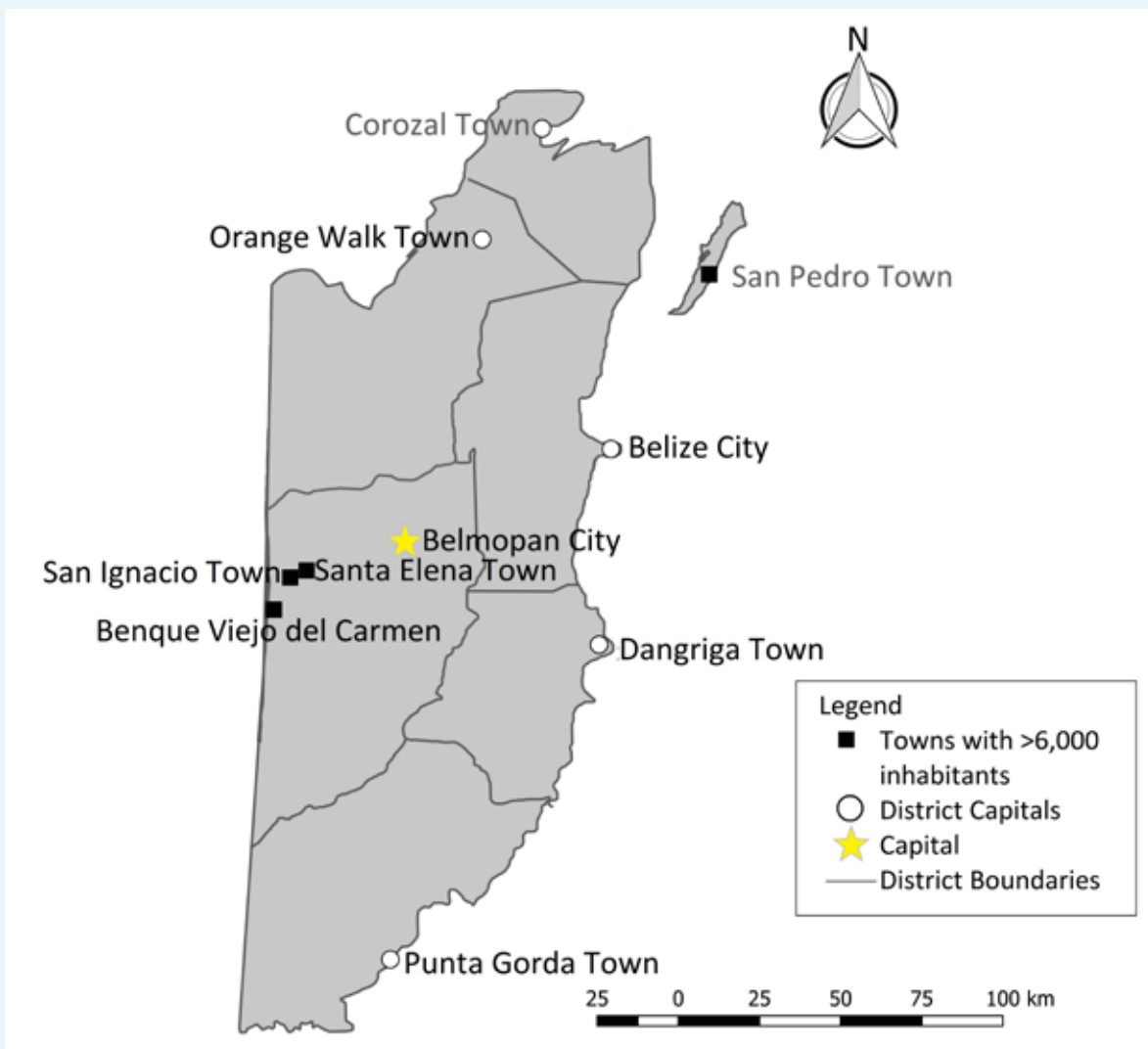
- 1. Innovators:** The first to adopt a new behaviour. Risk-takers that are financially wealthy with high social status, though are not opinion leaders nor are they very influential on the pragmatic majority. Willing to test new ideas that might ultimately fail.
- 2. Early adopters:** Colloquially known as trendsetters, this group is comprised of leaders with high social status and strong background in a specific field. Highly influential to the broader population, often more so than the media, which is most effectively used to reinforce behaviours of early adopters.
- 3. Early majority:** Above average social status and have contact with early adopters but do not hold positions of opinion leadership. May have very different interests and needs from early adopters, making the move from early adopter to early majority (a move known as "crossing the chasm" [64]) extremely challenging and the stage at which many innovations fail. The key to adoption of an innovation amongst the early majority is for it to be made as simple as possible for them to do so.
- 4. Late majority:** View innovations with a degree of scepticism, but fear being left behind. Share many of their fears as laggards. Seek reassurance that the innovation or behaviour is normal.
- 5. Laggards:** Will not adopt the behaviour until the alternative is no longer available or practically feasible. Seek to retain a high level of personal control when adopting a new behaviour.

CASE STUDY

CONSUMER SURVEY WITH THE GENERAL PUBLIC, 2015

Questionnaires (*Appendix 8*) were used to infer where Belize’s general public lies along the DOI curve, as well as their attitudes, beliefs, and knowledge of lionfish. These were piloted in Punta Gorda and Independence in mid-2015, and conducted between September and November 2015 in ten communities (*Figure 21*), including district capitals and towns with populations greater than 6,000 [61]. Systematic random sampling, using a skip-interval approach<sup>12</sup>, took place within each sampling location in high traffic areas such as open markets, bus terminals, water taxi ports, and public parks, until a representative sample was reached. Response rate was 61%.

All respondents had lived in Belize for at least one year and were ≥18 years of age. The study was approved by Colorado State University’s Research Integrity & Compliance Office (IRB no. 068-15H). Four hundred people were surveyed, and the sample population was representative of the population at large, based on 2010 census data [65].



*Figure 21: Map of Belize showing all ten communities included in consumer surveys, including district capitals (Corozal Town, Orange Walk Town, Belize City, San Ignacio, Dangriga, Punta Gorda) and towns with populations greater than 6,000 (San Pedro, Belmopan, Santa Elena, Benque Viejo del Carmen).*

The majority of respondents (92%, n=367) were seafood consumers. The most common reasons given for consuming seafood were health (37%, n=136), taste (28%, n=101, and personal preference (14%, n=51). Seafood consumption rates were highest at home: 61% (n=244) reported eating seafood at least once a week at home, compared to 15% (n=55) who reported eating seafood at least once a week at a restaurant.

<sup>12</sup>Every other individual passing a given point and perceived to be ≥18 years of age was invited to participate in the survey.

### Lionfish knowledge, perceptions and consumption

The majority (75%, n=300) of respondents had heard of lionfish. Level of knowledge about the lionfish invasion was subsequently tested through a series of seven true/false questions: 67% (n=200) attained at least four out of seven correct, representing a generally high level of knowledge about the invasion.

Overall, 11% (n=42) of respondents had tried eating lionfish – placing the Belizean general public in the “early adopter” category of the DOI process. Those who had tried lionfish were frequently repeat consumers, with the majority (81%, n=34) trying it on more than one occasion. Almost one third (31%, n=13) of respondents who had tried lionfish first tried it at home. The second most frequent location (26%, n=11) of first time lionfish consumption was a sponsored event, such as at a public outreach booth serving free lionfish samples.

Of respondents who had not tried lionfish (n=358), primary reasons were that it was not available to them (32%, n=115), they had never heard of lionfish (24%, n=85), or they believed it was dangerous (11%, n=41). Other reasons included lack of information to make a decision and preference (Figure 22).

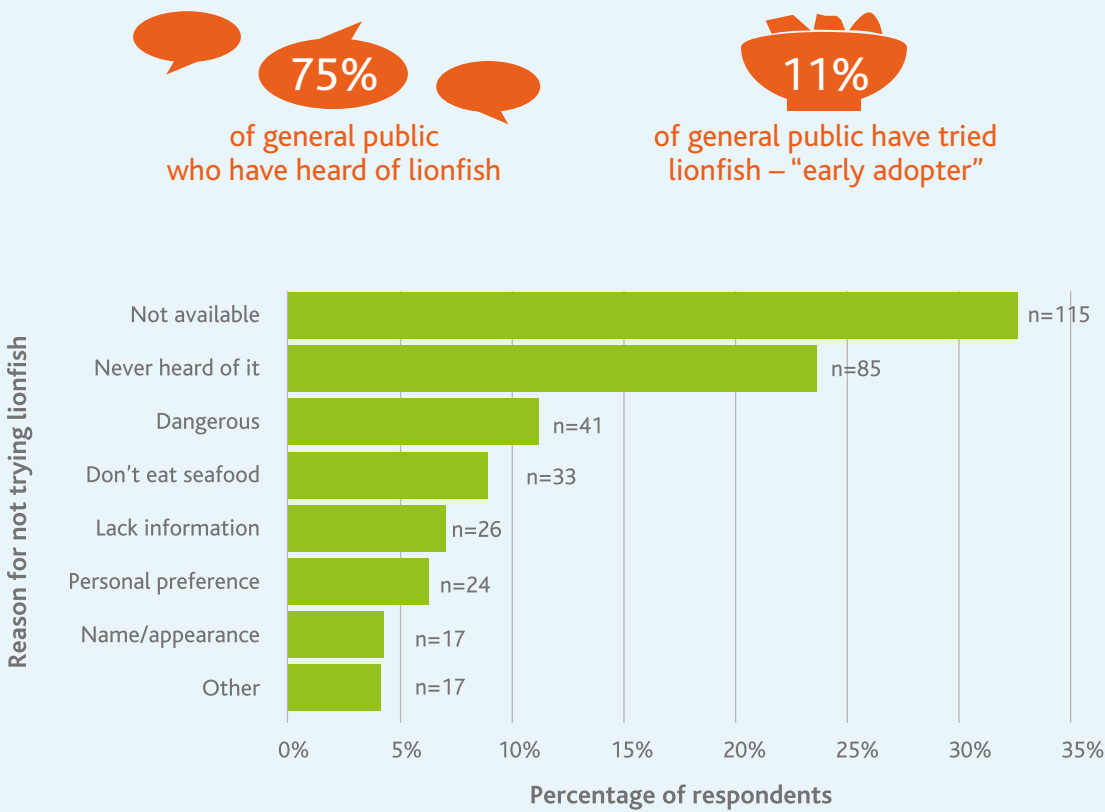


Figure 22: Reasons why the general public had not tried lionfish.

Of respondents who eat seafood and had heard of lionfish but who had not tried it (n=240), half (n=121) said they would be willing to try a sample if presented the opportunity, while 14% (n=33) remained undecided.

Limited access to lionfish and lack of knowledge about lionfish has prevented potential consumers from trying lionfish, however a considerable number of respondents were willing to consume lionfish given the opportunity, suggesting that with persistent awareness-raising efforts, the critical mass can be reached to advance along the DOI process from the early adopter category to the early majority.

### H5. Total lionfish catch

Understanding the catch rate, also known as fishing effort, is fundamental for assessing and managing fish stocks. Fishing effort is expressed in fisheries management by the Fisheries Mortality " $F$ ", which is simply the proportion of a species' population taken by fishing. Another way to think about it is the proportion of the population that is removed by people, and that does not die through natural causes. The proportion of the population to die through natural causes is called the Natural Mortality " $M$ ".

Total lionfish catch is comprised of the lionfish caught by artisanal fishers, recreational SCUBA divers and snorkelers, and by MPA managers. It could also potentially include lionfish caught for the aquarium trade. Small lionfish will not be caught for commercial or subsistence use, and therefore annual lionfish fishing mortality ( $F$ ) is comprised of  $F_{small}$  (Fisheries Mortality on lionfish less than 25 cm TL) and  $F_{large}$  (Fisheries Mortality on lionfish greater than 25 cm TL).

Annual lionfish fishing mortality ( $F$ ) is calculated by combining best available knowledge on current lionfish population density and lionfish removal rates.



### 3.2.6 Managed access logs will improve the estimate of $F$

At the time of research, no formal government monitoring systems were in place, and fishers were not obliged to declare lionfish landings. As of June 2016, as part of the Managed Access program, fishers are required to declare their catch, gear and effort in government-issued logbooks, which can be used to update catch estimates.

The creation of a centralised database for lionfish surveys and data from tournaments and tour operators would also improve the estimate of  $F$ .



**CASE STUDY**

**CALCULATING ANNUAL LIONFISH FISHING MORTALITY (F) 2015**

To calculate (F), best available current knowledge about lionfish is compiled. Calculations in this example were based on:

- ▣ Surveys of lionfish populations in Belize in 2015 (*Case Study: Lionfish Population Assessment 2015*)
- ▣ Semi-structured interviews with fishers in six fishing communities between February and May 2016 (*Case Study: Semi-Structured Interviews with Fishers, 2016*)
- ▣ Surveys of Belize restaurants in 2015 (*Case Study: Restaurant Survey, 2015*)
- ▣ Additional estimates and assumptions from key informants

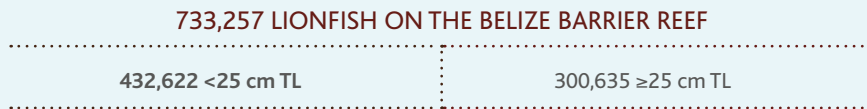
In this example, (F) does not include estimates of the number of lionfish killed by fishers and left in the water, as no reliable estimate for this could be ascertained. As it is known that many fishers do kill lionfish and leave them in the water, this is an important limitation of the estimate.

Other limitations to this estimate include a lack of data on:

- ▣ Frequency with which fishers go out fishing at different times of the year, the duration of each trip at different times of the year, and the average number of fishers per boat/trip.
- ▣ Frequency with which fishers catch lionfish at different times of the year.
- ▣ Average number of lionfish caught per fishing trip at different times of year.
- ▣ Number of lionfish caught for subsistence across the year.

**How many lionfish are in Belize?**

The lionfish population assessment (*Case Study: Lionfish Population Assessment 2015*) results were scaled using a detailed habitat map for Belize. Scaled, this gives a total lionfish abundance for Belize in 2015 of 733,257 (including the main barrier, backreef and atolls), of which 41% were  $\geq 25$  cm TL.



### Estimating lionfish catch by fishers

Interviews with fishers (*Case Study: Semi-Structured Interviews With Fishers, 2016*) show that lionfish is caught for eight months of the year, and that lionfish fishing behaviour is different in each community. To estimate lionfish catch, communities were placed into categories and based on the results of interviews, lionfish fishing behaviour was estimated. As the interviews did not use a random sampling approach, estimates are deliberately conservative.

#### 1. Sarteneja - 325 fishing licenses

Blue Ventures and the Sarteneja Fishermen Association (SFA) have both been actively involved in engaging consumers (community members), fishers and restaurants in Sarteneja with the benefits of fishing and eating lionfish. Engagement with the lionfish issue is anomalously high in this community compared to other fishing communities in Belize [66]. Based on interview responses:

- 38% of fishers use lionfish for subsistence
- 77% of fishers sell lionfish

#### 2. Low barrier communities - 612 fishing licenses

Freediving fishers using hooksticks, handslings and spearguns (predominantly from northern fishing communities<sup>13</sup>) require little behaviour change to target lionfish compared to fishers that use nets, handlines or traps. Tobacco Caye was included in this category as it is closely located to the reef, has some small demand for lionfish from tourism on the island, and has been engaged in lionfish outreach programs with the Tobacco Caye Marine Station. Estimates were based on averages of two assessed low barrier fishing communities, Chunox and Copper Bank.

- 35% of fishers use lionfish for subsistence
- 20% of fishers sell lionfish

#### 3. High barrier communities - 1653 fishing licenses

Fishers in all other communities were classified as "high barrier" as they are unlikely to encounter lionfish while fishing either due to low abundance (e.g. in Port Honduras Marine Reserve) or gear type used (e.g. handlines), where fishing has been largely replaced by more lucrative tourism livelihoods and therefore reduced the amount of time fishing license holders spend fishing, or where little lionfish outreach has taken place. It was assumed that no fishers from these communities target lionfish for subsistence or commercial use.

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<sup>13</sup>Caye Caulker, Chunox, Consejo, Copper Bank, Corozal, San Estevan, San Pedro

CALCULATION STEPS	ESTIMATE
<b>A. TOURNAMENTS</b>	
Number of lionfish caught in 2015 through tournaments (See: Box: History of Lionfish Tournaments in Belize, page 31).	94
Calculate proportion of population – all sizes targeted (1,398 / 733,257)	$F=0.002$
<b><i>F.small</i> = 0.002</b>	<b><i>F.large</i> = 0.002</b>
<b>B. DIVERS</b>	
How many groups? • Based on internet search and discussion with key informants, it was assumed that at least 15 groups conduct lionfish culling activities.	15 groups
How many lionfish caught per group each year? • ReefCI reported catching 4,199 in 2015 • Blue Ventures reported catching 202 lionfish in 2015 • Amigos del Mar reported catching 12-30 lionfish per week = 1,092 / year • Splash reported catching 3,500 lionfish per year	2,248 lionfish / group / year
How many lionfish are caught in total per year by divers?	33,724 lionfish
Calculate proportion of population – all sizes targeted (33,724 / 733,257)	$F=0.046$
<b><i>F.small</i> = 0.046</b>	<b><i>F.large</i> = 0.046</b>
<b>C. SUBSISTENCE</b>	
Assumptions • When a fisher brings home lionfish, they bring 2lbs fillet (6.4 lionfish) - Sarteneja fishers bring lionfish home twice per month (6.4*2*0.38*325) - Low barrier community fishers bring lionfish home once per month (6.4*1*0.35*612)	1,581 lionfish/month 1,371 lionfish/month
How many lionfish caught for subsistence each year? • Total catch (1,581 + 1,371) x 8 months of the year	23,616 lionfish/year
Calculate proportion – selective size target, only large lionfish (23,616 / 300,635)	$F=0.079$
<b><i>F.small</i> = 0.000</b>	<b><i>F.large</i> = 0.079</b>
<b>D. RESTAURANTS</b>	
Total annual demand for lionfish from restaurants in 2015 (See: Case Study: Restaurant Survey, 2015)..	31,164 lionfish
Calculate proportion – selective size target (large lionfish; 31,164 / 300,635)	$F=0.103$
<b><i>F.small</i> = 0.000</b>	<b><i>F.large</i> = 0.103</b>
<b>TOTAL ANNUAL LIONFISH FISHING MORTALITY F 2015</b>	
A+B+C+D	
<b><i>F.small</i> = 0.048 (20,766 lionfish)</b>	<b><i>F.large</i> = 0.230 (69,146 lionfish)</b>
Total lionfish catch = 89,912 lionfish	
<b><math>F = 0.123</math></b>	

Annual lionfish fishing mortality  
**(F) = 0.123**

### 3.3 Lionfish population dynamics model

To make informed decisions about invasive lionfish management, an age-structured population model for lionfish in Belize was developed. The model was structured to predict age-specific abundance and biomass through time. That is, by inputting annual lionfish fishing mortality  $F$  (See: [H5. Total Lionfish Catch](#)), the model provides annual estimates for total abundance and size structure of the in-water lionfish population as well as for the associated lionfish catch. Therefore, the relative impact of different management strategies over time can be predicted by modifying  $F$ .

The model uses data specific to lionfish in Belize where available, and makes assumptions based on information from other locations. This type of model was deemed appropriate because it can be easily updated and will provide higher quality output as new data become available in Belize. For a detailed model description, see [Appendix 9](#). To execute the population model code, ([Appendix 10](#)), use the statistical software R.



## CASE STUDY

### BUSINESS AS USUAL

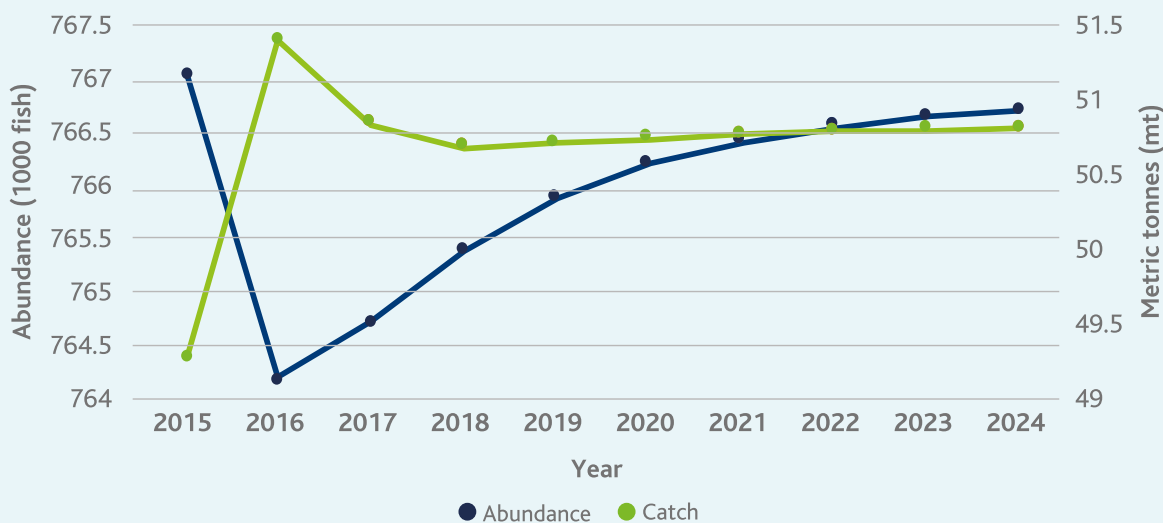
The model was set to run for ten years (2015-2024), using estimates of total lionfish abundance, *F.large* and *F.small* calculated for 2015 (Table 9).

Results show that under current conditions, total lionfish abundance is expected to slowly increase to approximately 767,000 individuals across Belize in 2024, and total lionfish catch is similarly expected to steadily increase to approximately 103 mt in 2024 (Figure 23). The initial decrease in lionfish abundance and associated increase in lionfish catch between years 2015-2016 is likely due to imperfect assumptions used to initiate the model.

The size structure of Belize’s lionfish population in-water as well as the size structure of lionfish catch are expected to be dominated by individuals  $\geq 30$  cm TL for all years.

**Table 9: Steps and values used to run the “Business As Usual” lionfish population model for Belize.**

STEPS	ESTIMATE
1. Using the R0 Model Code ( <i>Appendix 11</i> ), calculate parameters $R0^{14}$ and $N1.init^{15}$ . To do so, input estimates of total lionfish abundance ( $N.obs=733257$ ) <sup>16</sup> , <i>F.large</i> ( $F.large=0.230$ ) and <i>F.small</i> ( $F.small=0.048$ ) <sup>17</sup> to the model.	Result: [1] “The estimate of R0 is 252558” [1] “The estimate of initial recruits (N1.init) is 226815”
2. Input results of R0 model to Lionfish Population Model Code ( <i>Appendix 10</i> )	$F=0.103$
3. Choose number of years to run the model (nyrs)	Based on the result of the R0 Model Code: $R0=252558$ $N1.init=226815$
4. Set fishing pressure to estimated F values for the first two years that the model will run.	Chose 10 years: $nyrs=10$
5. Set fishing pressure to estimated F values for all subsequent years that the model will run (i.e. years 3+). This allows for a change in management approach to be predicted.	Used 2015 lionfish catch estimates: $F.large.2=0.230$ $F.small.2=0.048$



**Figure 23: Predicted total lionfish abundance (1000 fish) and catch weight (metric tonnes, mt) over ten years (2015-2024).**

<sup>14</sup>R0 parameter is asymptotic recruitment for age one fish in the population.

<sup>15</sup>N1.init is the estimated initial abundance of fish recruits in the population.

<sup>16</sup>See: Case Study: Lionfish Population Assessment 2015, page 26

<sup>17</sup> See: Case Study: Calculating Annual Lionfish Fishing Mortality F 2015, page 46

# Conservation Management

In this chapter, we explain the range of approaches to lionfish management, and provide details of their application in Belize.

- How to develop lionfish management targets
- The merits and challenges of different control actions and approaches, including lionfish outreach, lionfish tournaments, lionfish-based tourism, and lionfish traps.
- The value of adopting a participatory approach to conservation management.
- The results of participatory community consultations, including detailed SWOT analyses for each proposed management intervention.

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<sup>18</sup>Recruitment overfishing occurs when the adult (or 'parent') stock is depleted so dramatically that not enough juveniles (or 'fish recruits') are produced for the stock to maintain itself. [97]

## 4.1 Developing lionfish management targets

A coral reef's lionfish threshold density is the tipping point between the rate at which lionfish consume prey and the rate at which new prey biomass is created [49]; maintaining lionfish population density below the predicted lionfish threshold density provides the best opportunity for native fish populations to recover (see: *Chapter 3, Box: The Lionfish Ecological Threshold Model*).

Using the lionfish ecological threshold model, it is possible for managers to develop lionfish management targets at prioritised sites, such as within marine protected areas (MPAs). That is, a site's management target is to maintain lionfish population density below its predicted threshold density. Given lionfish's rapid reproduction and growth, reducing populations from current to desired densities requires high volume and regular removals: one lionfish population model predicted annual exploitation rates of 35-65% would be required to cause recruitment overfishing<sup>18</sup> [59], while another indicated that 27% of the adults in a lionfish population would have to be removed monthly for populations to stop growing [67].

Due to resource limitations, selecting sites for prioritising lionfish control actions should be based on social, economic and/or environmental importance. Effective control is most likely to be achieved through a strategic combination of various control actions and approaches, including lionfish fishery and market development, recreational culling by tourists and SCUBA divers, culling by MPA managers and lionfish culling competitions.



## CASE STUDY

### DEVELOPING LIONFISH MANAGEMENT TARGETS IN FIVE MARINE RESERVES

Lionfish Focused Search and prey fish surveys (*Appendix 4*) were conducted at fifty sites in five marine reserves in Belize between October and December 2015 (see case studies in *Chapter 3: Lionfish Population Assessment 2015* and *Case Study: Calculating Lionfish Ecological Threshold Limits 2015*). Lionfish threshold densities for each site were then predicted using an ecological model (*Appendix 5*).

#### 1. Bacalar Chico Marine Reserve (BCMR)

**Background:** Bacalar Chico Marine Reserve (BCMR), established in 1996, is one of the seven MPAs that forms part of the Belize Barrier Reef Reserve System UNESCO World Heritage Site [68]. This small MPA (6,280 ha, [69]) forms part of the Northern Belize Coastal Complex, a river-to-reef seascape of protected areas in northern Belize [70], and shares its northern border with the Mexican MPA, *Arrecifes de Xcalak*. BCMR includes barrier, fringing and patch reefs as well as coastal lagoons, mangroves and seagrass beds.

**Key Stakeholders:** The primary stakeholder communities of BCMR are San Pedro and Sarteneja. San Pedro Town is located one hour by boat south on Ambergris Caye, has a population of almost 12,000 [61] and has a high dependency on tourism, with almost 150,000 visitors per year [62]. San Pedro primarily uses BCMR for sport fishing tours, and occasionally for snorkelling and diving. Sarteneja, located one hour by boat north-west on mainland Belize, has a small population (approximately 2,000) that is primarily dependent on fishing [71]. Sarteneja uses BCMR to operate traditional beach traps on the leeward (non-reef) side of the reserve, and to fish for conch and lobster on the windward (reef) side of the reserve. Occasionally, Sarteneja operates snorkelling tours to BCMR [72].

**Management:** BCMR is a multiple-use MPA managed by Belize Fisheries Department (BFD), divided into three types of management zone: extractive fishing is permitted in General Use Zones (GUZ) by licensed fishers and with some gear restrictions (ban on gillnets, long lines and spear fishing), and the remainder of the reserve is either a Conservation Zone (CZ; no commercial or subsistence fishing of any kind, recreational use regulated by the Belize Tourism Board) or Preservation Zone (PZ; no commercial or subsistence fishing, tourism activities or boat access unless authorised). Two CZs and one PZ collectively represent the reserve's no-take zones (NTZ).

**Existing Lionfish Management Measures:** Lionfish management in BCMR primarily consists of the year-round removal of lionfish from within the NTZ and within the GUZ by conservation volunteers, coordinated by Blue Ventures [51], and occasional culls by BFD.



Figure 24: Map of Bacalar Chico Marine Reserve



### BCMR key results

Observed lionfish densities in BCMR’s NTZ and GUZ were approximately equal to predicted threshold densities (Figure 25); more effort is required to further reduce lionfish populations across the reserve.

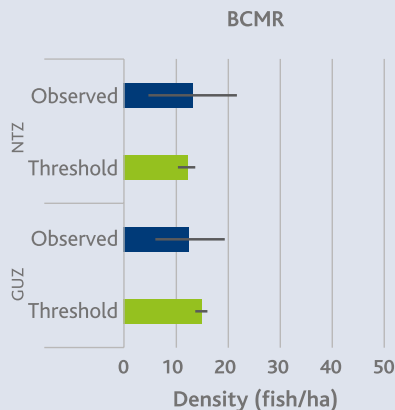


Figure 25: Average observed lionfish density and predicted ecological threshold density on coral reef sites in General Use Zones (GUZ) and no-take zones (NTZ) of Bacalar Chico Marine Reserve. Error bars denote standard error of the mean.

- ✦ Mean lionfish density was 13±5 fish/ha and mean threshold density was 14±2 fish/ha (n=11).
  - Similar lionfish densities were observed in the GUZ (13±7 fish/ha, n=6) and NTZ (13±8 fish/ha, n=5). These densities were approximately equal to corresponding mean lionfish predicted threshold densities, 15±1 fish/ha (GUZ) and 12±2 fish/ha (NTZ).
- ✦ Five of the surveyed sites (45%, n=11) had lionfish exceeding predicted ecological thresholds (Figure 26).
- ✦ Mean lionfish size was 22±2 cm (n=9).
- ✦ Mean prey fish biomass was 150±18 kg/ha (n=11).

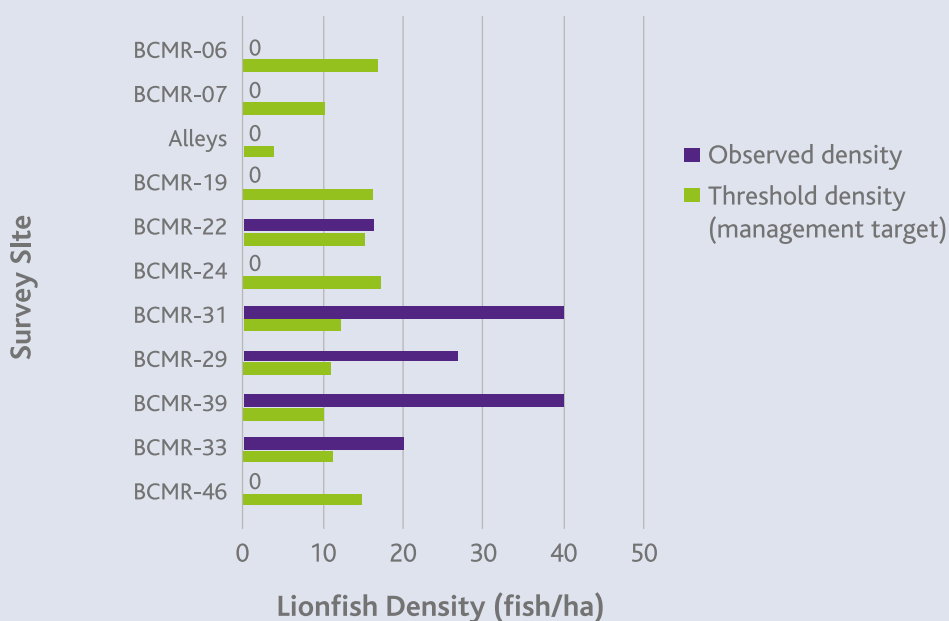


Figure 26: Observed lionfish density and predicted ecological threshold density on coral reef sites in Bacalar Chico Marine Reserve. Survey sites are displayed N-S along the axis.

## 2. Hol Chan Marine Reserve (HCMR)

**Background:** Hol Chan Marine Reserve (HCMR) is located off San Pedro on Ambergris Caye. It was established in 1987 as Belize’s first marine protected area. The reserve expanded to a total area of over 41,440 ha in 2015 to provide protection for sharks and rays, as well as mangrove cayes threatened by development [73]. HCMR lies in the centre of the Northern Belize Coastal Complex, a river-to-reef seascape of protected areas in northern Belize [70], and shares its western border with Corozal Bay Wildlife Sanctuary.

**Key Stakeholders:** HCMR is one of the main tourist destinations in Belize with many divers drawn to sites where they are able to sight sharks and rays. The primary stakeholders of HCMR are the communities of San Pedro, which has a population of almost 12,000 [61] and welcomes 150,000 visitors per year [62], and Caye Caulker, which has a population of almost 2,000 [61] and welcomes over 80,000 visitors per year [62]. Both communities were traditionally fishing communities, and high demand for seafood in San Pedro is met by locally-caught, as well as imported, seafood.

**Management:** HCMR is managed by the Belize Fisheries Department. Until 2015, HCMR was divided into Zones A-D, with Zone A functioning as a no take zone (NTZ). HCMR’s expansion in 2015 saw the addition of Zones E-H; portions of Zone E and all of Zone H add to the reserve’s NTZ. The remainder of the reserve permits regulated extractive fishing (General Use Zone, GUZ). Given the recent expansion of HCMR’s management zones at the time of surveying, this case study focuses only on Zones A-D.

**Existing Lionfish Management Measures:** Belize Fisheries Department performs lionfish culls and hosts occasional lionfish tournaments. Lionfish are also opportunistically speared by dive guides, and local fishers catch and sell lionfish to restaurants. High predator biomass exists in the reserve [29], which may help to prevent the establishment of large lionfish populations [74].

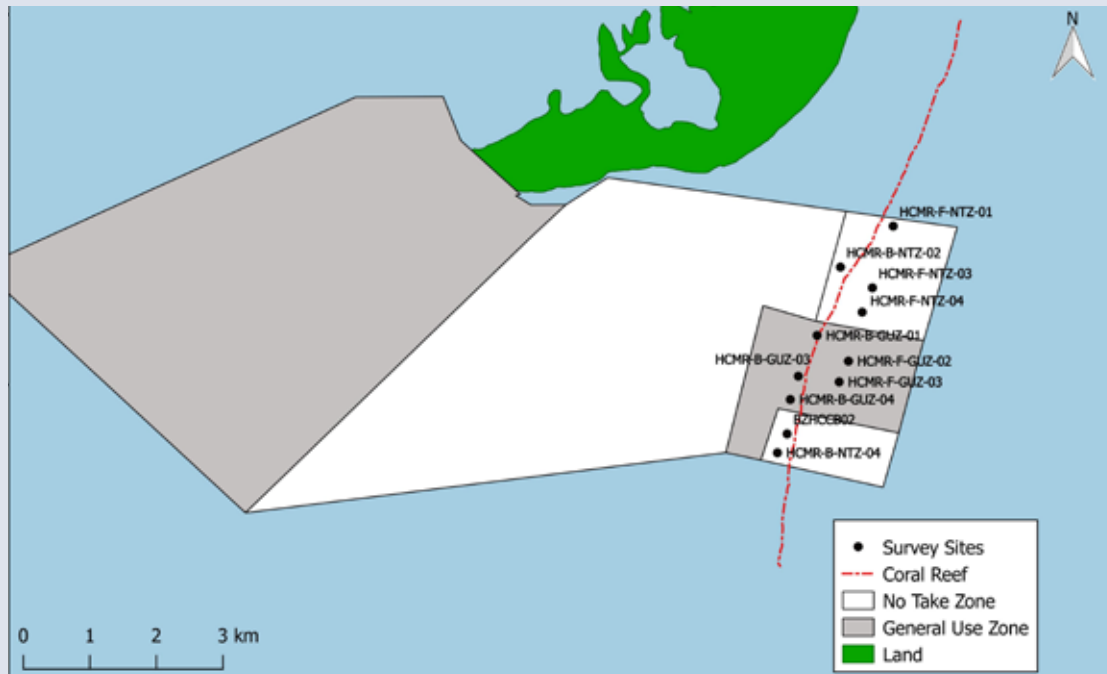
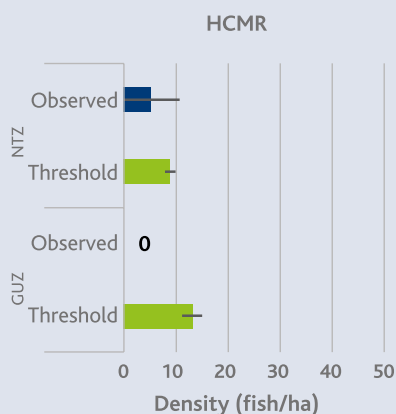


Figure 27: Map of Hol Chan Marine Reserve (Zones A-D)

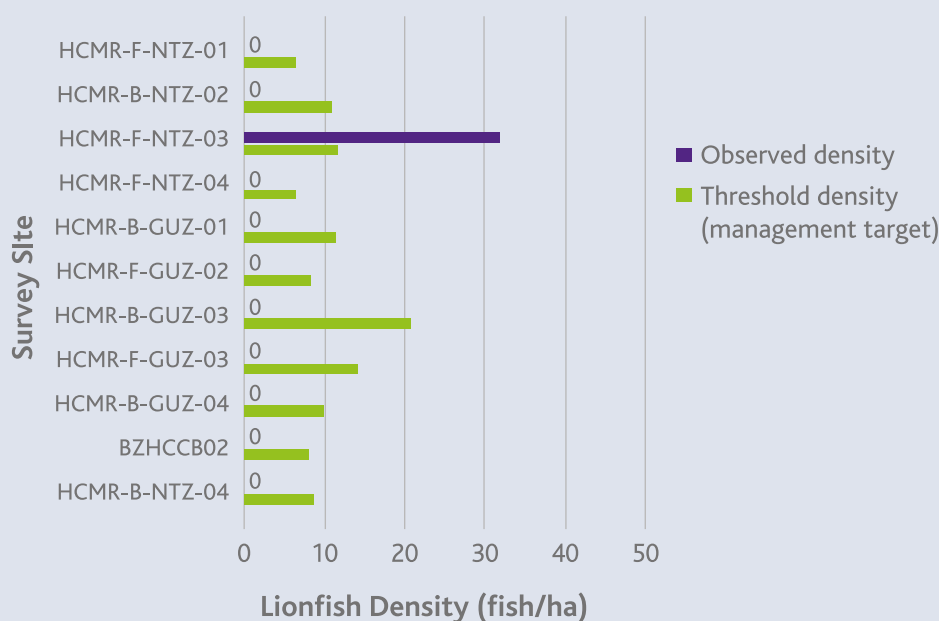
### HCMR key results

The density of lionfish observed in HCMR was among the lowest of the five surveyed MPAs. Despite low sighting frequency, average lionfish density in HCMR’s NTZ was approximately equal to predicted threshold densities (note overlapping error bars in Figure 28), suggesting that lionfish management should be prioritised in HCMR’s NTZs. Outside of NTZs, no lionfish were observed.



**Figure 28:** Average observed lionfish density and predicted ecological threshold density on coral reef sites in General Use Zones (GUZ) and no-take zones (NTZ) of Hol Chan Marine Reserve. Error bars denote standard error of the mean.

- ▣ Mean lionfish density was  $3 \pm 3$  fish/ha and mean threshold density was  $11 \pm 1$  fish/ha ( $n=11$ ).
- No lionfish were observed in the GUZ ( $n=6$ ), where mean lionfish threshold density was  $14 \pm 2$  fish/ha. Mean lionfish density in HCMR’s NTZ was  $6 \pm 6$  fish/ha ( $n=5$ ), approximately equal to the mean predicted threshold density of  $9 \pm 1$  fish/ha.
- ▣ Lionfish were recorded at only one site in the NTZ, where the observed density ( $33 \pm 7$  fish/ha) exceeded its predicted ecological threshold (12 fish/ha; Figure 29).
- ▣ One lionfish was sighted on surveys, measuring 15 cm total length (TL).
- ▣ Mean prey fish biomass was  $133 \pm 19$  kg/ha ( $n=11$ ).



**Figure 29:** Observed lionfish density and predicted ecological threshold density on coral reef sites in Hol Chan Marine Reserve. Survey sites are displayed N-S along the axis.

### 3. Caye Caulker Marine Reserve (CCMR)

**Background:** Situated within the Northern Belize Coastal Complex and along the main barrier of the reef, Caye Caulker Marine Reserve (CCMR) lies to the east of the popular island tourism destination, Caye Caulker, which itself lies 21 miles east of the mainland. The reserve was established in 1998 and covers 3,900 ha and five habitats: mangrove, littoral forest, lagoon marshland, seagrass and coral reefs [69].

**Key Stakeholders:** The primary stakeholder of CCMR is Caye Caulker Village, which has a population of almost 2,000 [61] and welcomes 80,000 visitors per year [62]. CCMR is one of the main tourist destinations in Belize, and Caye Caulker residents use CCMR primarily for touristic activities (e.g. snorkelling) and to a lesser extent small-scale and subsistence fishing (conch, lobster, finfish). The fishing village of Sarteneja is also a major stakeholder of the reserve, and uses CCMR to fish for conch, lobster and finfish [72]. High demand for seafood in Caye Caulker is met primarily by locally-caught seafood.

**Management:** CCMR is co-managed by the Belize Fisheries Department and the community based organisation Forest and Marine Reserves Association of Caye Caulker (FAMRACC). It is divided into three management zones: extractive fishing is permitted in General Use Zones (GUZ) by licensed fishers, and the remainder of the reserve is either Conservation Zone (CZ; non-extractive recreational use only, e.g. snorkelling) or Preservation Zone (PZ; access only permitted via a research permit). Two CZs and one PZ collectively represent the reserve's no-take zones (NTZ).

**Existing Lionfish Management Measures:** The Belize Fisheries Department organised one lionfish tournament in Caye Caulker in 2014. Small-scale commercial fishers catch lionfish in the waters surrounding Caye Caulker to supply restaurants on the island. Lionfish are also occasionally speared by dive and snorkel guides. After these surveys took place, The Sports Bar organised a lionfish tournament in 2016 and again in 2017.

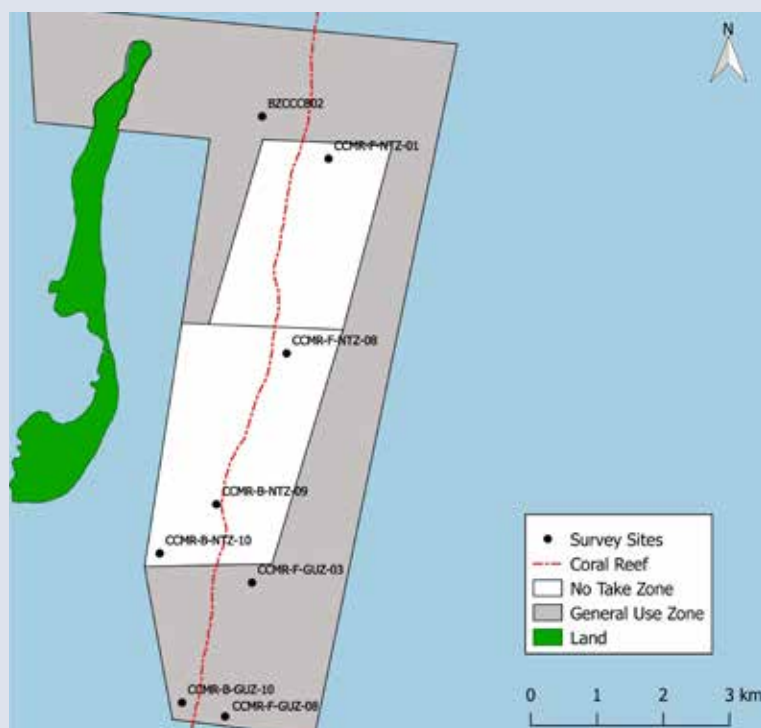
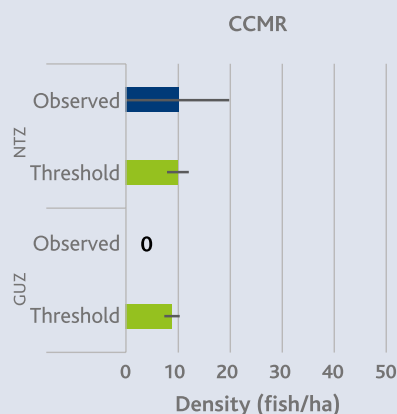


Figure 30: Map of Caye Caulker Marine Reserve

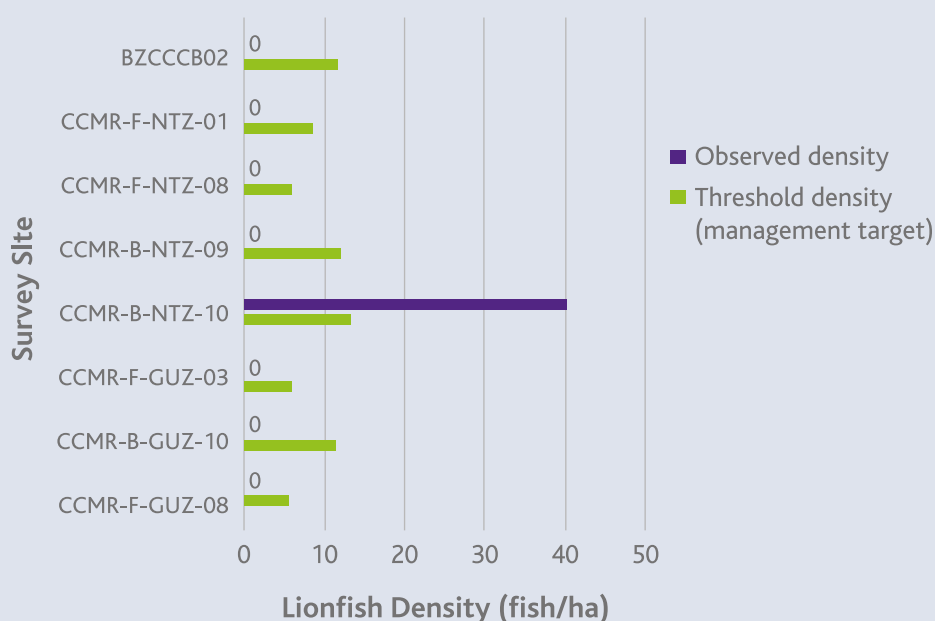
### CCMR key results

Much like HCMR, the observed density of lionfish was low and no lionfish were observed within GUZs. Nevertheless, average lionfish density in CCMR's NTZ was approximately equal to predicted threshold densities (note overlapping error bars in Figure 31). Managers should therefore err on the side of caution and continue to implement and closely monitor the results of management interventions in CCMR's NTZ.



**Figure 31: Average observed lionfish density and predicted ecological threshold density on coral reef sites in General Use Zones (GUZ) and no-take zones (NTZ) of Caye Caulker Marine Reserve. Error bars denote standard error of the mean.**

- ▣ Mean lionfish density was  $5 \pm 5$  fish/ha and mean threshold density was  $10 \pm 1$  fish/ha (n=8).
  - No lionfish were observed in the GUZ (n=4), where mean lionfish threshold density was  $9 \pm 1$  fish/ha. Mean lionfish density in CCMR's NTZ was  $10 \pm 10$  fish/ha (n=4), approximately equal to the corresponding mean predicted threshold density of  $11 \pm 1$  fish/ha.
- ▣ Lionfish were recorded at only one site in the NTZ, where the observed density ( $40 \pm 0$  fish/ha) exceeded its predicted ecological threshold (13 fish/ha; Figure 32).
- ▣ Mean lionfish size was  $23 \pm 8$  cm (n=2).
- ▣ Mean prey fish biomass was  $113 \pm 10$  kg/ha (n=8).



**Figure 32: Observed lionfish density and predicted ecological threshold density on coral reef sites in Caye Caulker Marine Reserve. Survey sites are displayed N-S along the axis.**

#### 4. South Water Caye Marine Reserve (SWCMR)

**Background:** SWCMR, established in 1996, lies off the coast of Dangriga and forms part of the Southern Belize Reef Complex. It covers 47,700 ha, and includes 9 km of almost unbroken barrier reef [69]. SWCMR encompasses a mosaic of coastal and marine habitats, and provides habitat for some endemic species of fish (social wrasse, *Halichoeres socialis*, and Maya hamlet, *Hypoplectrus maya*).

**Key Stakeholders:** The small community of Tobacco Caye is located within SWCMR and therefore is a primary stakeholder, using the reserve for commercial and subsistence fishing as well as tourism activities. The largest proportion of fishing licenses issued for Managed Access Area 3 (which includes SWCMR) in 2016 were from the communities of Sarteneja (172 licenses issued, 17% of all licenses issues for Area 3) and Dangriga (149 licences, 14%). Other major stakeholders of SWCMR, through fishing or tourism, are the communities of Hopkins, Sittee River, Placencia, and Riversdale/Seine Bight [72].

**Management:** SWCMR is a multiple-use MPA managed by Belize Fisheries Department, divided into three management zones: extractive fishing is permitted in General Use Zones (GUZ) by licensed fishers and with some gear restrictions (ban on gillnets, long lines and spear fishing), and the remainder of the reserve is either Conservation Zone (CZ; non-extractive recreational use only, e.g. snorkelling) or Preservation Zone (PZ; access only permitted via a research permit). Two CZs and one PZ collectively represent the reserve’s no-take zones (NTZ).

**Existing Lionfish Management Measures:** Sartenejan fishers who work in Managed Access Area 3 (which includes SWCMR) report catching lionfish (from *Case Study: Semi-Structured Interviews With Fishers, 2016*), and a few dive operators occasionally spear lionfish in the reserve. The Belize Fisheries Department organised the first lionfish tournament in SWCMR in 2016 (after these surveys took place).

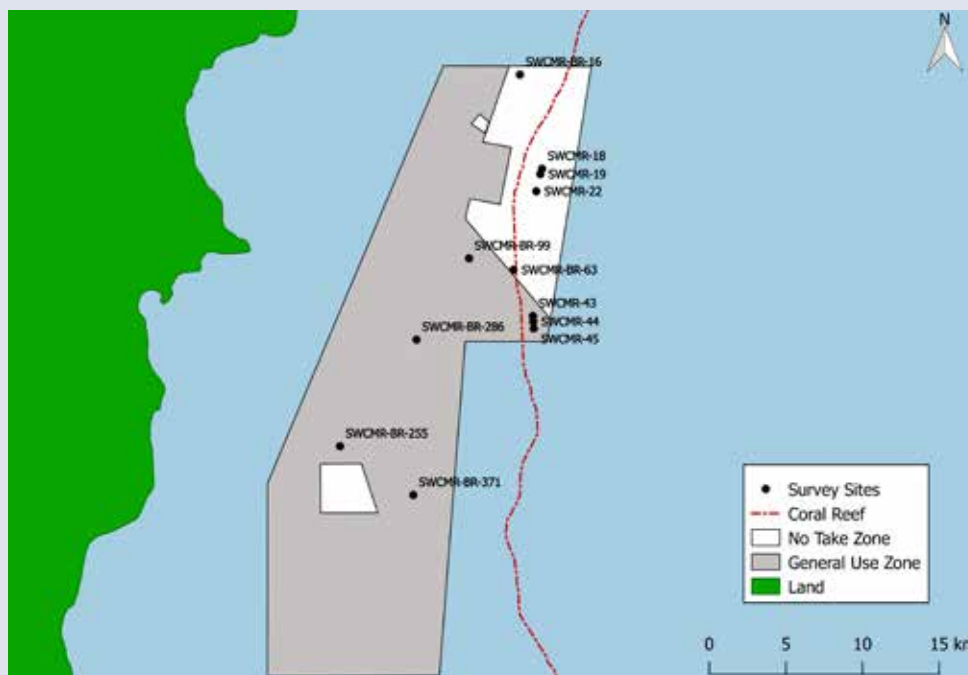


Figure 33: Map of South Water Caye Marine Reserve

### SWCMR key results

The predicted threshold density for SWCMR was one of the highest, given the high levels of prey fish biomass observed in the reserve, and observed density of lionfish within GUZs was well below levels predicted to cause predation-induced declines in prey fish biomass. However in NTZs, the observed density of lionfish far exceeded predicted threshold levels (Figure 34), indicating that urgent management to prevent loss of fish biomass and species richness is required in NTZ areas.



Figure 34: Average observed lionfish density and predicted ecological threshold density on coral reef sites in General Use Zones (GUZ) and no-take zones (NTZ) of South Water Caye Marine Reserve. Error bars denote standard error of the mean.

- Mean lionfish density was  $23 \pm 15$  fish/ha and mean threshold density was  $21 \pm 5$  fish/ha ( $n=12$ ).
- Mean observed lionfish densities in the NTZ ( $50 \pm 35$  fish/ha,  $n=7$ ) exceeded corresponding mean predicted threshold density ( $18 \pm 6$  fish/ha). Lower densities were observed in the GUZ ( $5 \pm 5$  fish/ha,  $n=5$ ), which were below corresponding mean predicted threshold ( $24 \pm 7$  fish/ha).
- Four of the surveyed sites (33%,  $n=12$ ) had lionfish exceeding predicted ecological thresholds (Figure 35).
- Mean lionfish size was  $21 \pm 3$  cm ( $n=10$ ).
- Mean prey fish biomass was  $302 \pm 81$  kg/ha ( $n=12$ ).

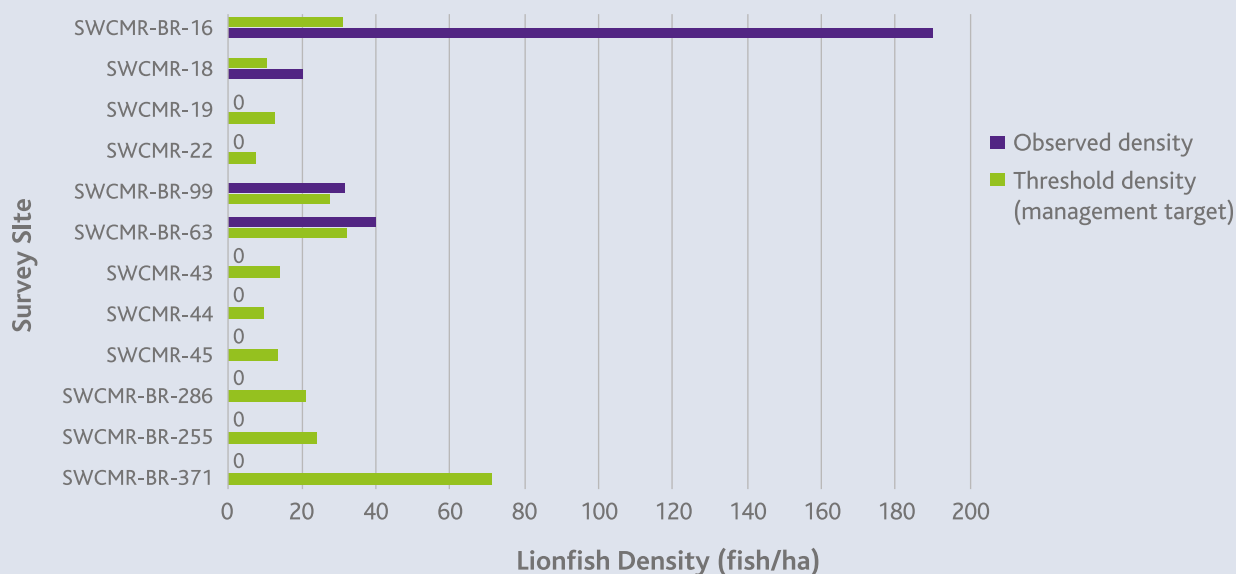


Figure 35: Observed lionfish density and predicted ecological threshold density on coral reef sites in South Water Caye Marine Reserve. Survey sites are displayed N-S along the axis.

### 5. Port Honduras Marine Reserve (PHMR)

**Background:** Port Honduras Marine Reserve (PHMR) is a nearshore MPA located in southern Belize and established in 2000. Covering an area of 41,400 hectares, PHMR’s environment is dominated by estuarine habitats, with freshwater input from three major rivers, and includes coral reefs in the waters surrounding the Snake Cayes [75]. PHMR plays a vital role in protecting the biodiversity and integrity of the barrier reef by providing nursery habitat for reef fish, including one of only three major nursery grounds for the critically endangered goliath grouper. It forms part of the Southern Belize Reef Complex as well as the Maya Mountain Marine Corridor.

**Key Stakeholders:** PHMR’s main stakeholder communities are Punta Gorda, Cattle Landing, Punta Negra and Monkey River. Community members primarily use PHMR for commercial fishing of conch, lobster and finfish, and for recreational uses such as swimming. There is some limited use for sport fishing tourism and to a lesser extent snorkelling/diving tourism to the Snake Cayes. Fishing incursions from Guatemala are frequently reported.

**Management:** PHMR is a multiple-use MPA co-managed by the Toledo Institute for Development and Environment (TIDE) and the Belize Fisheries Department. It is divided into three management zones: extractive fishing is permitted in General Use Zones (GUZ) by licensed fishers and with some gear restrictions (ban on gillnets, long lines and spear fishing). The remainder of the reserve is either Conservation Zone (CZ; non-extractive recreational use only, e.g. snorkelling) or Preservation Zone (PZ; access only permitted via a research permit), collectively representing the reserve’s no-take zones (NTZ). In 2011, Belize’s Managed Access (MA) fisheries management tool was introduced in PHMR as a pilot [76].

**Existing Lionfish Management Measures:** TIDE conducts lionfish culls on reefs when they are sighted.

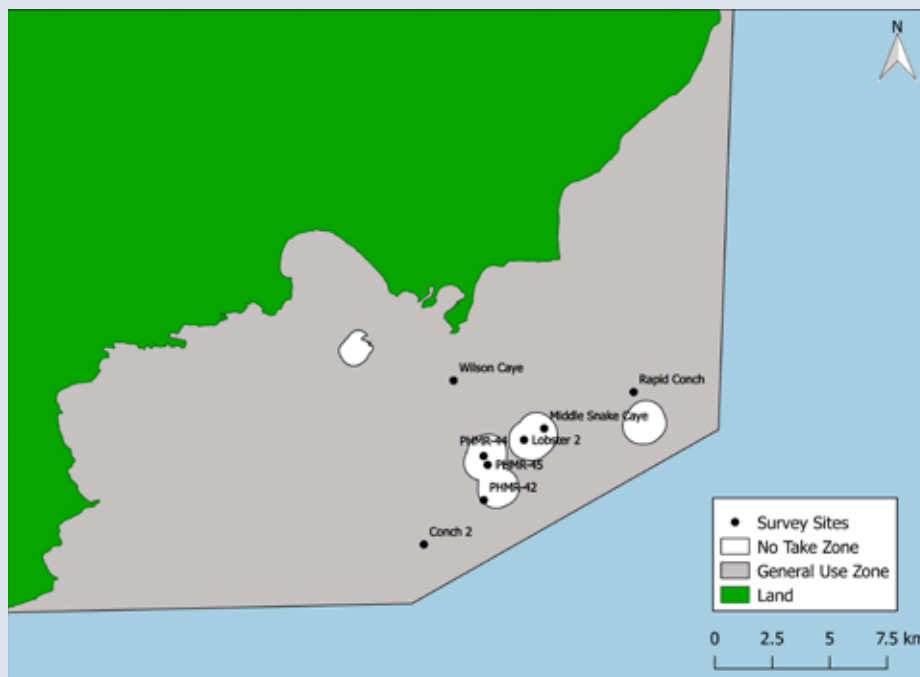


Figure 36: Map of Port Honduras Marine Reserve



### PHMR key results

The predicted threshold density for PHMR was the highest encountered of the five studied MPAs (Figure 37), given the high levels of prey fish biomass observed in the reserve. Lionfish were absent from all surveys of PHMR. A reassessment of prey fish and lionfish status is recommended after five years, as well as continuation of current control efforts.

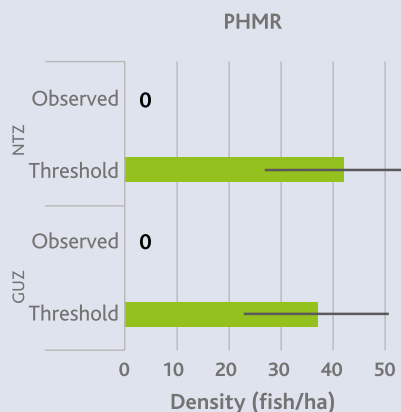


Figure 37: Average observed lionfish density and predicted ecological threshold density on coral reef sites in General Use Zones (GUZ) and no-take zones (NTZ) of Port Honduras Marine Reserve. Error bars denote standard error of the mean.

- Lionfish were absent from surveys in PHMR, and mean threshold density was  $40 \pm 9$  fish/ha ( $n=8$ ).
- GUZ ( $37 \pm 13$  fish/ha,  $n=3$ ) and NTZ ( $42 \pm 14$  fish/ha,  $n=5$ ) had similar mean predicted lionfish threshold densities.
- Mean prey fish biomass was  $350 \pm 129$  kg/ha ( $n=8$ ).

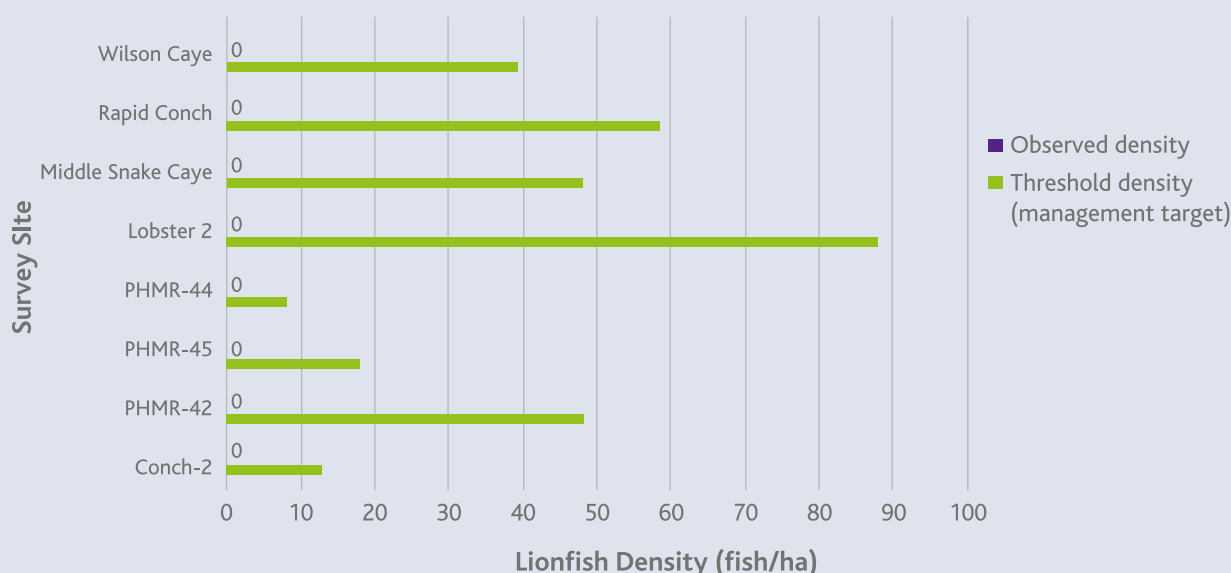


Figure 38: Observed lionfish density and predicted ecological threshold density on coral reef sites in Port Honduras Marine Reserve. Survey sites are displayed N-S along the axis.

## 4.2 Control actions and approaches

To support sustained lionfish control efforts as part of a wider lionfish management plan, a number of actions and approaches have been considered. The opportunities and challenges associated with different management approaches are discussed below.

### 4.2.1 Supporting lionfish market development

Lionfish have a high-quality, firm, mild flesh comparable to grouper, that is high in omega fatty acids [77] and therefore a desirable and marketable seafood product. Lionfish are also beautiful, with striped spines, tails and fins that offer opportunities to creative artisans (see: *Chapter 3, 4B: Jewellery*). Market development is generally thought to be the most effective management tool for managing the lionfish invasion, providing a long-term economic incentive for consistent removals [78].

Lionfish are relatively small when compared to traditional fishery targets such as grouper and snapper, and pose the risk of envenomation to fishers, which can lead to lost fishing time. For these reasons, fishers face a high opportunity cost when targeting lionfish in place of traditionally-fished species. This can be addressed in two ways: increase in the market price of lionfish through driving demand for lionfish products, and value-addition of lionfish through additional processing and/or the use of previously discarded parts.

The Sarteneja Fishermen Association evaluated the feasibility of a range of potential value-added products in 2013, including processed lionfish for retail, use of lionfish offal in aquaculture feed, and lionfish jewellery (using fins). The most feasible products were found to be lionfish burgers and lionfish jewellery [60].



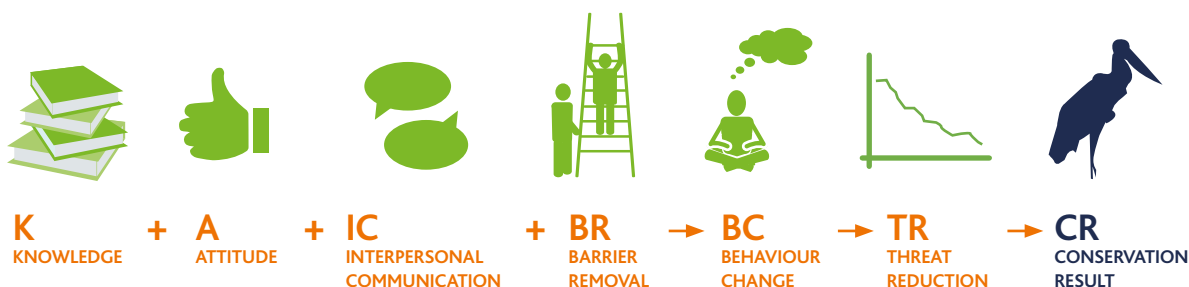
## 4.2.2 Awareness Raising and Social Marketing

In 2010, lionfish outreach workshops, each including a safe-handling demonstration, were held in twelve coastal communities countrywide [21]. Since, lionfish outreach and awareness-raising has been conducted by a number of organisations in coastal communities, at national events and trade shows, and in local and national media. Lionfish awareness-raising is a key aspect of lionfish management as level of knowledge about the lionfish invasion has been identified as the main driver for lionfish consumption by the general public in Belize [65]. Despite a generally high level of knowledge about lionfish amongst the general public, the myth that lionfish are unsafe to eat persists and fear remains a barrier to increased lionfish exploitation [65]. Images and messaging that use aggressive depictions of lionfish may inadvertently reinforce this fear, and should be avoided (Figure 39).



*Figure 39: The logo and slogan developed in response to fear association with negative and aggressive depictions of lionfish in previous campaigns. The slogan reflects that eating lionfish supports local laid-back, healthy, and environmentally-conscious values*

Within conservation organisations, social marketing tools and behaviour change theory are often used to design and develop campaigns that encourage a desired behaviour change. For example, Rare’s theory of change model (Figure 40), demonstrates how individuals move through a series of stages along the diffusion of innovation (DOI) curve [79]. A DOI curve depicts the process by which a new idea or concept is communicated over time among the participants of a social system, or study population (See *Chapter 3, Box: The Diffusion of Innovation Theory*).



*Figure 40: Rare’s theory of change model that depicts how their Pride social marketing campaigns are interventions designed to move through a series of stages along the diffusion of innovation curve [79].*

This theory and practice has been used in a campaign to stop destructive fishing in China and to engage communities in the management and enforcement of local protected areas in the Philippines [79]. Applying this to the lionfish market in Belize facilitates understanding of who to target with a social marketing intervention, and how to establish lionfish consumption as an accepted social norm.

CASE STUDY

DESIGNING A LIONFISH SOCIAL MARKETING CAMPAIGN

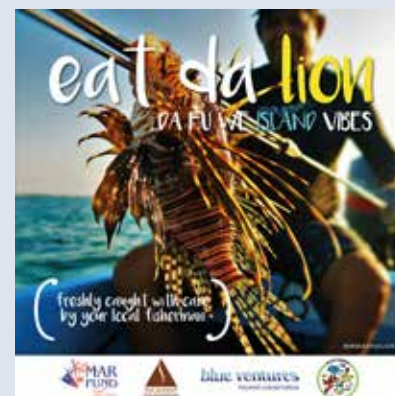
Questionnaires with restaurateurs in 2015 showed that 9% of Belize’s restaurants served lionfish, indicating that nationally, the restaurant community sat in the ‘early adopter’ stage of the DOI curve for lionfish exploitation (see *Chapter 3, Case Study: Restaurant Survey, 2015*). The community of Caye Caulker was identified as a positive deviant for lionfish consumption due to its fishing tradition (supply) and active restaurant community (demand).

As stated by the DOI theory, a new behaviour must have a relative advantage over the old behaviour and be compatible with existing values [79]. Serving lionfish at a restaurant represents many potential relative advantages (financial, reputation, environmental), but it is important that the campaign reflected values held in Caye Caulker. Semi-structured interviews were conducted to identify the motivations and concerns of Caye Caulker residents, to inform messaging used in the campaign (*Appendix 12*).

A changing way-of-life was a stated concern amongst all interviewees. While many valued tourism, respondents perceived their way-of-life to be threatened by fast development, including loss of access to shoreline and a faster pace (“rat race”). All of this was encapsulated in the idea that it is now harder to lead the subsistence/fishing lifestyle that Caye Caulker still values and for which Caye Caulker is renowned. Some tour guides identified declining fish stocks as being partly responsible for this, but a quickly changing society was more commonly blamed.

Many respondents valued their ability to make their living off the sea: while tourism was identified as a key means to achieve this, some respondents also had family members that continued to fish, and restaurants prided themselves on their commitment to serving the fresh, locally-caught seafood. Banners and other campaign content were developed to reflect three key themes:

1. Support local fishers and keep the reef healthy
2. Healthy, natural food and a subsistence lifestyle
3. Ecotourism, laidback vibe, island experience



*Figure 41: Banners designed and displayed for the social marketing campaign encouraging restaurants to serve lionfish. This messaging and imagery links to the emotional drivers of subsistence fishing culture that were found to be important to Caye Caulker restaurants.*

## Recommendations for future campaigns

- ✘ **Increase level of knowledge** among potential consumers. Those who are better informed about the lionfish issue and where to source it were more likely to consume it.
- ✘ **Overcome misconceptions** about the safety of lionfish consumption, educate people about how to safely prepare lionfish, and information about how to treat stings if they occur.
- ✘ **Organise lionfish tasting events** to engage with consumers who do not have family/friends in the fishing or tourism industries. Twenty-six percent of those who first tried lionfish reported doing so at a sponsored event (See: [Chapter 3, Case Study: Consumer Survey with the General Public, 2015](#)).
- ✘ **Consider gender-specific campaigns.** Men currently make up the majority of lionfish consumers and consume seafood more regularly in restaurants. In contrast, women were more likely to consume lionfish at home, and many of the women surveyed consumed seafood because of perceived health benefits. This message could be woven into lionfish campaigns targeting women [65].

### 4.2.3 SCUBA divers and tour operators

Involvement of recreational SCUBA divers and snorkelling/diving tour operators in lionfish control efforts provides an opportunity for consistent lionfish removal in frequented dive sites. This approach has had positive impacts elsewhere in the lionfish's invaded range, including Bonaire [80] and Honduras [81].

The main benefit of this approach is that SCUBA divers are potentially able to remove lionfish from sites that are inaccessible to fishers, such as deep coral reef sites or within NTZs. However, the major disadvantage of this approach is its limited geographic scope, as recreational divers typically frequent a limited number of coral reef sites.



#### Belize lionfish hunting license

SI 17 (1982) prohibits the harvest of marine life while using SCUBA gear. However, the Fisheries Administrator has granted special permission to dive guides to assist with the management of lionfish by permitting SCUBA divers to kill lionfish while diving using approved equipment (Hawaiian slings no longer than 26 inches (66 cm) which have 3 barbs). Prior to culling lionfish on SCUBA gear, SCUBA divers must present the device they will use to cull lionfish to the Fisheries Administrator in order to be issued a Lionfish Hunting License.

CASE STUDY

A FOCUS ON REEF CONSERVATION INTERNATIONAL

Based on Tom Owens Island in Sapodilla Cayes Marine Reserve (SCMR), Reef Conservation International (ReefCI) offers conservation-based diving holidays to guests of all ages who are keen to learn about, and contribute to, coral reef conservation in Belize. In 2009, when lionfish were first sighted in SCMR, ReefCI recognised the potential for its guests to contribute to lionfish management efforts. Throughout the year, ReefCI’s guests now assist in locating and removing lionfish during recreational dives.

ReefCI’s divers and snorkelers take lionfish spears on most dives, allowing for consistent removal of lionfish from SCMR. On a typical dive, 30-50 lionfish are removed, varying with the experience of current guests. With the help of guests, 7,084 lionfish were removed from SCMR in 2014, and 5,587 lionfish were removed from SCMR in 2015. In 2016, a dive instructor removed a record 120 lionfish in a single dive.

Approximately 40 of the lionfish that are caught each week are dissected to record prey items, and the remainder are served to ReefCI’s guests during evening meals. The organisation is developing a lionfish recipe book to encourage others to cook with the fish. The inedible tails and fins of speared lionfish are provided to women, trained by ReefCI, to make lionfish jewellery. Finished products are bought back by ReefCI to sell to guests. To raise awareness of the lionfish issue outside of the dive centre, ReefCI also conducts lionfish outreach and provides lionfish tasters and information at regional seafood festivals.

The experiences of ReefCI clearly demonstrates that dive operators have the potential to contribute to lionfish monitoring and removal efforts. With appropriate training and supervision, recreational divers can offer a sustainable and consistent source of income and manpower to contribute to lionfish management efforts.

CASE STUDY

PLACENCIA LIONFISH TOURNAMENT, SOUTHERN BELIZE

The Placencia Lionfish Tournament has been held annually since 2011, and focuses on removing lionfish from within the Gladden Spit and Silk Cayes Marine Reserve (GSSCMR). The tournament has two objectives:

1. Lionfish control within the MPAs that Southern Environmental Association (SEA) manages – Laughing Bird Caye National Park and Gladden Spit and Silk Cayes Marine Reserve (GSSCMR)
2. Awareness raising across a wide audience – booth with information about lionfish and tasters made from lionfish caught manned during the tournament at Placencia’s Lobsterfest

In 2014, surveys before, during and after the Placencia Lionfish Tournament were carried out to evaluate the tournament’s effectiveness. Results showed that the tournament did not have a significant impact of the mean density, mean size, or size distributions of lionfish within the GSSCMR. However this is likely to have been because there was no defined competition area, leading to divers capturing lionfish outside the reserve. As of 2015, SEA introduced the rule that every team must conduct at least one dive within the reserve, in order to target lionfish populations that would not be captured via commercial fishing and to prevent tensions between commercial and recreational fishers.

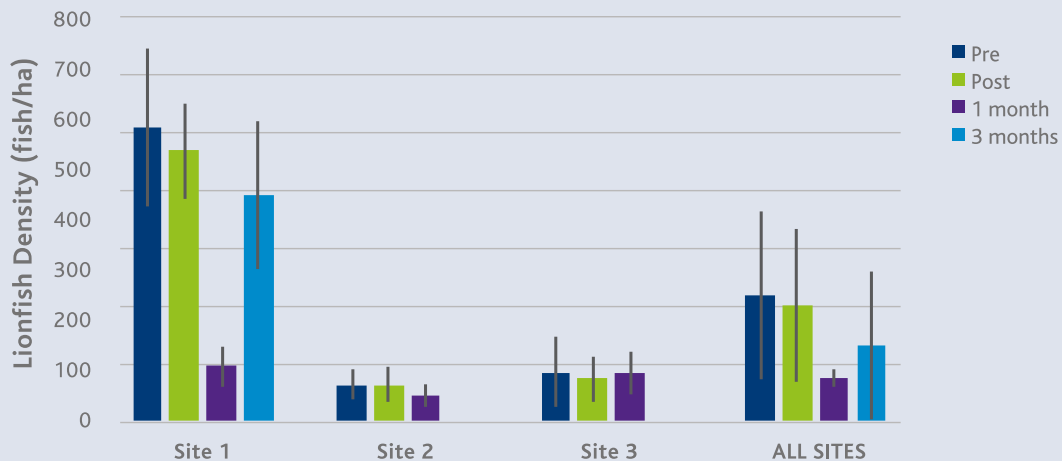


Figure 42: Lionfish density in Gladden Spit and Silk Cayes Marine Reserve before, immediately after, one month after and three months after the Placencia Lionfish Tournament in 2014. Site 1 is a reef wall >18 m deep, sites 2 and 3 are spur and groove reefs 8-15 m deep.

## 4.2.4 Lionfish tournaments

One-day lionfish tournaments have taken place in Belize since 2010, with increasing numbers of coastal communities taking part each year. During a tournament, teams of recreational SCUBA divers are challenged to spearfish as many lionfish (of all sizes) as possible with the objective of controlling lionfish populations, engaging coastal communities with the lionfish issue, and providing high numbers samples from which to collect biological information (e.g. prey choice, lionfish body size) with which to monitor the impacts of the lionfish invasion.

Tournaments offer an opportunity to catch lionfish in areas that are inaccessible to local fishers, such as deep reef sites (>30 m) which require SCUBA equipment to access and in NTZs<sup>19</sup>. They also provide an incentive to catch all sizes of lionfish with prizes typically awarded for the total number of lionfish caught as well as maximum and minimum sizes. In contrast, commercial fishers typically target larger size classes. Tournaments therefore complement the existing lionfish control efforts being made by commercial fishers, averting tensions between recreational and commercial fishers.

### The benefits of lionfish tournaments

Although long-term, broad-scale research into the effectiveness of tournaments is limited, available evidence from Florida and the Bahamas suggests that tournaments can result in a >60% reduction in local lionfish density within the tournament area, compared to pre-tournament densities [82].

As well as offering a means of suppressing local, and less accessible, lionfish populations, tournaments provide an opportunity to raise awareness of lionfish invasions among tourists, coastal communities, the media, restaurants and the fishing industry; they can also provide a source of funding (via tournament entrance fees) to reinvest in lionfish management and an opportunity to perform safe-handling demonstrations with restaurants and individuals, encouraging them to eat and sell lionfish.



<sup>19</sup> Spearfishing on SCUBA and within NTZs is illegal in Belize except when special permission is granted by the Belize Fisheries Department.

## 4.2.5 Lionfish traps

Due to depth limitations of fisher- and diver-led lionfish control, lionfish traps have been discussed as a supplementary means of capturing and removing lionfish in the Caribbean. Traps show promise as a cost-effective and efficient means of capturing multiple lionfish with minimal effort, particularly in sites that are inaccessible to divers (e.g. unappealing dive sites; those that are difficult to reach because of currents; and those that are too deep for recreational diving) [83].

Commercial lobster fishers are reportedly eager to develop and implement a lionfish trap fishing program in Florida [84], while in Bermuda, fishers joined forces with the Bermuda Lionfish Taskforce to participate in a lionfish trapping pilot<sup>20</sup> during the summer season (i.e. outside lobster season). These examples suggest that fishers could be involved in deploying traps, and that traps may offer a safer means of lionfish capture for those fishers who are currently deterred from spearing or handling lionfish for fear of envenomation.

However traps are not yet without limitations. For example, little is known about the level of bycatch they capture and the survival of bycatch, existing designs are not practical for reef wall habitats as they require a flat seabed to sit upon and heavy traps require boats with a winch to deploy which may not always be available [83].

A number of trap designs are currently being piloted, ranging from simple adaptations of traditional lobster traps to remote controlled robots that stun lionfish with an electric current.

1. Funnel traps have a similar design to lobster traps, with a rectangular or ring-shaped funnel that allows lionfish to enter the trap but prevents larger fish such as groupers from entering the trap. Escape slots allow small fish to escape, but retain lionfish. The development of this trap is subsidised by the Bermuda Lionfish Taskforce and traps are currently being trialled by fishers at depths of 45-50 m outside of lobster season [83].
2. Robots in Service of the Environment are in the process of designing a remote-controlled lionfish killing robot<sup>21</sup> that operates at depths far beyond safe recreational SCUBA diving limits. Operated from a nearby boat, the robot uses an electric current to stun lionfish before it is sucked into a cage and removed. To avoid bycatch, the robot relies on the fact that lionfish tend to remain static in the water column when approached, while other species of fish tend to swim away.
3. NOAA has tested a novel trap design that makes use of lionfish's tendency to aggregate around structure. Purse and dome traps<sup>22</sup> have a simple design: a net curtain attached to PVC piping and a surface marker buoy and laid on the seabed around a fish aggregating device (FAD). When retrieved, the PVC piping closes around the FAD and the entire structure is lifted to the surface. Initial trials have been associated with high lionfish catch and low bycatch.

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<sup>20</sup><http://bernews.com/2016/06/commercial-experimental-lionfish-trapping>

<sup>21</sup><https://robotsise.com>

<sup>22</sup><https://sanctuaries.noaa.gov/news/feb17/sanctuary-scientist-fights-invasive-lionfish.html>



## 4.3 Scenario planning

Given the complexity of interactions and feedbacks, Coupled Human and Natural Systems (*CHANS* – see *Chapter 3, What are Coupled Human and Natural Systems*) are dynamic and adaptive. Scenario planning allows researchers adopting a CHANS approach to consider plausible futures based on best available knowledge in the face of unpredictability and uncertainty [85]. Given that shocks to the system are inevitable, the best management strategy is one that enhances the ability of the CHANS to adapt, without reducing the functioning of any of its components [46], [86].

### 4.3.1 Developing lionfish management scenarios for Belize

Using the lionfish population dynamics model developed for Belize (see *Chapter 3, Lionfish Population Dynamics Model*), five scenarios were tested:

1. Stop all lionfish control
2. Establish a lionfish processing facility that provides a reliable sales point and pays a fair price to fishers
3. Double the number of lionfish tourism providers
4. Double the number of lionfish tournaments per year
5. Combined: introduce a facility, double the number of tourism providers and tournaments held per year

As for the “Business As Usual” scenario (see *Chapter 3, Case Study: Business As Usual*), the model was set to run for ten years (2015-2024) using estimates of total lionfish abundance, *F.large* and *F.small* calculated for 2015 for the first two years (*F.large.1* and *F.small.1*). To simulate a change in management in year three, new values for *F.large* and *F.small* were calculated for each scenario and inputted to the model (*F.large.2* and *F.small.2*, Table 10).

Using the socioecological framework (SEF) of social and environmental factors associated with the lionfish invasion in Belize (see *Chapter 2, Socioecological Framework*), the impacts of lionfish population and catch predictions to human and natural systems associated with the lionfish invasion were then qualitatively interpreted using the SEF, following an “if-then” iterative process.



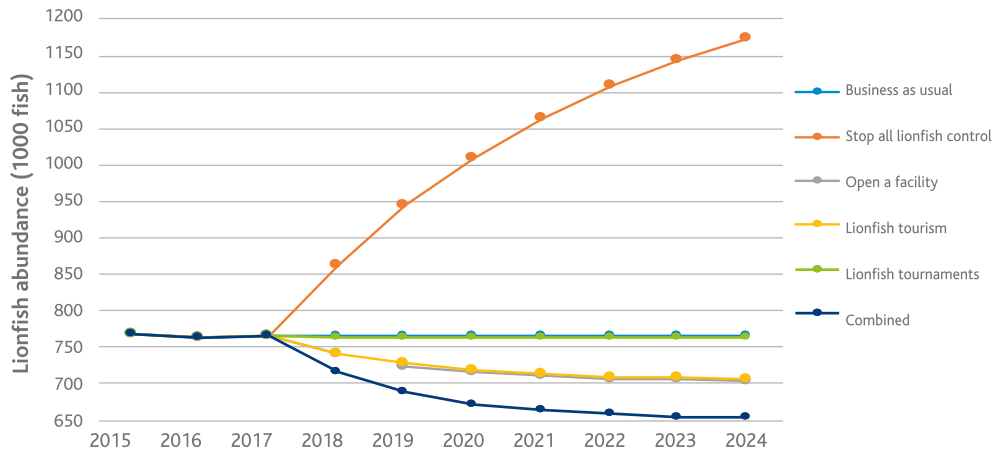
**Table 10: Calculation steps and assumptions used to develop estimates of F.large and F.small used in lionfish management scenarios.**

SCENARIO	DETAILS	F.LARGE ESTIMATE		F.SMALL ESTIMATE	
Business as usual	See Chapter 3, Case Study: Calculating Annual Lionfish Fishing Mortality F 2015	A. Tournaments	0.002	A. Tournaments	0.002
		B. Divers	0.046	B. Divers	0.046
		C. Subsistence	0.079		
		D. Restaurants	0.103		
		<b>F.large.1</b>	<b>0.230</b>	<b>F.small.1</b>	<b>0.048</b>
Stop all lionfish control	Model cannot handle absolute zero value	<b>F.large.2</b>	<b>1x10<sup>-11</sup></b>	<b>F.small.2</b>	<b>1x10<sup>-11</sup></b>
Lionfish facility	Introducing a facility that paid a fair price for lionfish would make commercial lionfish fishing attractive to more fishers <sup>23</sup>	A. Tournaments	0.002	A. Tournaments	0.002
		B. Divers	0.046	B. Divers	0.046
		C. Subsistence	0.079		
		D. Restaurants	0.181		
		<b>F.large.2</b>	<b>0.308</b>	<b>F.small.2</b>	<b>0.048</b>
Lionfish tourism	Provide promotional materials and incentives for tour operators, aiming to double the number of lionfish tourism providers	A. Tournaments	0.002	A. Tournaments	0.002
		B. Divers	0.092	B. Divers	0.092
		C. Subsistence	0.079		
		D. Restaurants	0.103		
		<b>F.large.2</b>	<b>0.103</b>	<b>F.small.2</b>	<b>0.092</b>
Lionfish tournaments	Double the number of lionfish tournaments per year	A. Tournaments	0.004	A. Tournaments	0.004
		B. Divers	0.046	B. Divers	0.046
		C. Subsistence	0.079		
		D. Restaurants	0.103		
		<b>F.large.2</b>	<b>0.232</b>	<b>F.small.2</b>	<b>0.050</b>
Combined	Introduce all changes	A. Tournaments	0.004	A. Tournaments	0.004
		B. Divers	0.092	B. Divers	0.092
		C. Subsistence	0.079		
		D. Restaurants	0.181		
		<b>F.large.2</b>	<b>0.356</b>	<b>F.small.2</b>	<b>0.096</b>

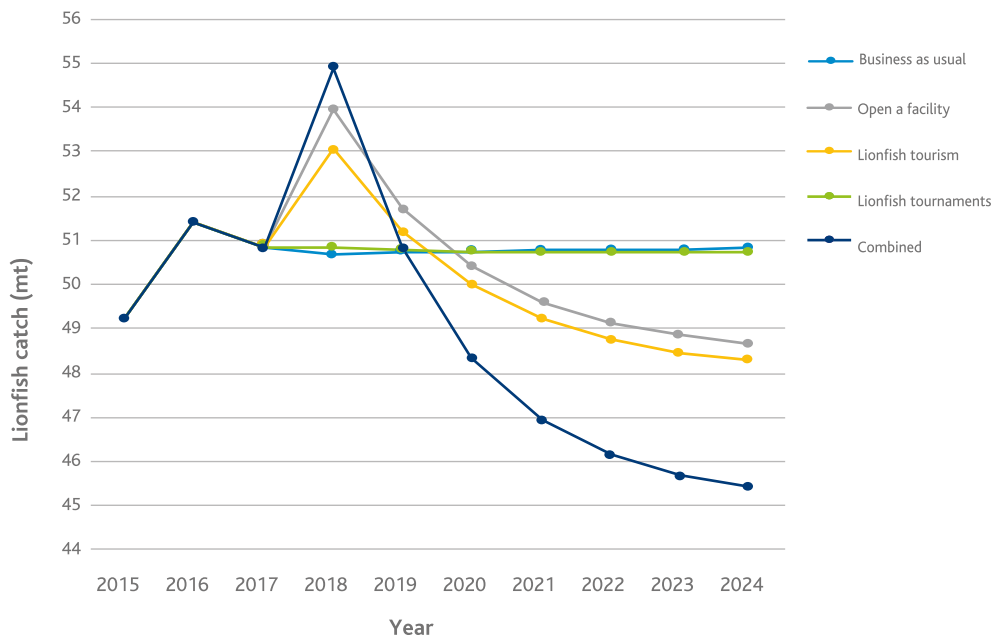
<sup>23</sup>Estimates derived from surveys (Chapter 3, Case Study: Semi-Structured Interviews With Fishers, 2016): 35% of Sartenejan fishers and 5% of fishers from "low barrier" communities cite market barriers as the only reason they do not catch and sell lionfish. Therefore, introducing a facility that paid a fair price for lionfish would make lionfish fishing attractive to 145 fishers, catching an average of 10 lionfish per fisher per trip. Average stated number of lionfish caught per fisher per trip = 10. Assuming two trips per month for eight months of the year, this increase current estimated catch for sale to restaurants (D) by 23,200 fish (selective size target, only large lionfish).

### Population dynamics model results

Under the "Stop All Lionfish Control" scenario, total lionfish abundance is expected to rapidly increase, reaching 1,174,000 individuals across Belize by 2024. All other scenarios are expected to cause a decrease in total lionfish abundance (Figure 43), though this decline is barely detectable in the lionfish tournament scenario. The size structure of Belize's lionfish population in-water is expected to become dominated by individuals'  $\geq 30$  cm TL for all years under all scenarios except "Combined", for which average lionfish size is expected to decrease.



**Figure 43: Predicted total lionfish abundance (1000 fish) over ten years (2015-2024) for "Business As Usual" and five scenarios effective from year three of the model – "Stop All Lionfish Control", "Lionfish Facility", "Lionfish Tourism", "Lionfish Tournaments" and "Combined".**



**Figure 44: Predicted catch weight (metric tonnes, mt) over ten years (2015-2024) for "Business As Usual" and four lionfish management scenarios ("Lionfish Facility", "Lionfish Tourism", "Lionfish Tournaments" and "Combined").**

Total annual lionfish catch is expected to be approximately stable (at 50 metric tonnes, mt) under the "Business As Usual" scenario, and to very slowly decrease under the "Lionfish Tournaments" scenario. For all other scenarios ("Lionfish Facility", "Lionfish Tourism" and "Combined"), total lionfish catch is expected to initially increase and subsequently decrease annually (Figure 45). This total annual lionfish catch is expected to stabilise at 48 mt for "Lionfish Facility" and "Lionfish Tourism" scenarios, and at 45 mt for the "Combined" scenario.

### 4.3.2 Impact of scenarios on the socioecological framework



Figure 45: Artistic representation of the current status of socioecological systems associated with lionfish, by Chuy Arts, Sarteneja

#### Continue with business as usual

Over ten years, continuing with “business as usual” (BAU) is expected to lead to a decrease in overall coral reef health and declining status of traditional fishery targets. This is expected to have a negative impact on fishing community wellbeing. However, continuation of awareness-raising efforts, including lionfish tournaments, is expected to increase demand for lionfish from the general public and restaurants.

CATEGORY	WHAT IS HAPPENING
<b>Natural Systems</b> <ul style="list-style-type: none"> <li>- N1. Lionfish Population</li> <li>- N2. Coral Reefs</li> <li>- N3. Traditional Fisheries</li> </ul>	<p>Lionfish abundance increases very slowly (almost negligible), which means that the number of sites exceeding lionfish threshold densities remains approximately the same. It is expected that prey fish, mesopredator (e.g. snapper and grouper) and lobster abundance will decrease. Decrease in the abundance of traditional fishery targets will lead to a decrease in landings for those species, leading to reduced wellbeing in fishing communities.</p>
<b>Human Systems</b> <ul style="list-style-type: none"> <li>- H1. Management</li> <li>- H2. Economy and Tourism</li> <li>- H3. Fishing Communities</li> <li>- H4. Lionfish Markets</li> <li>- H5. Total Lionfish Catch</li> </ul>	<p>Outreach activities by NGOs, lionfish jewellery businesses and awareness-raising through the two lionfish tournaments held each year increase awareness about lionfish amongst the general public, as well as the proportion of the general public who has tried lionfish. This increases demand for lionfish, and therefore increases restaurants’ demand and willingness to pay (WTP) for lionfish.</p> <p>Due to a decrease in traditional fishery status, restaurants buy more lionfish to meet demand which encourages fishers to catch and sell more lionfish.</p>

## Lionfish facility

Introducing a lionfish facility will lead to a decrease in lionfish abundance and improved coral reef health. It also removes the barrier of unreliable lionfish supply and demand, supporting fishers' and restaurants' needs. More fishers will catch and sell lionfish, and more restaurants will buy and serve lionfish. Increase in demand and willingness to pay for lionfish, together with improved traditional fishery target status, is expected to have a positive impact on fishing community wellbeing.

CATEGORY	WHAT IS HAPPENING
<b>Natural Systems</b> <ul style="list-style-type: none"><li>- N1. Lionfish Population</li><li>- N2. Coral Reefs</li><li>- N3. Traditional Fisheries</li></ul>	Lionfish abundance decreases, and therefore it is expected that prey fish, mesopredator (e.g. snapper and grouper) and lobster abundance will increase. This improves the resiliency of coral reefs, as well as the catch per unit effort of traditional fishery targets, leading to improved wellbeing in fishing communities.
<b>Human Systems</b> <ul style="list-style-type: none"><li>- H1. Management</li><li>- H2. Economy and Tourism</li><li>- H3. Fishing Communities</li><li>- H4. Lionfish Markets</li><li>- H5. Total Lionfish Catch</li></ul>	<p>The introduction of a lionfish facility removes the primary barrier to lionfish fishing and exploitation stated by fishers and restaurants – reliable supply and demand. Increase in lionfish supply will increase the number of restaurants selling lionfish (20% of restaurants state lack of supply is the only barrier).</p> <p>Demand from restaurants will be further increased due to increased demand from the general public, stimulated by continuation of outreach activities by NGOs, lionfish jewellery businesses and lionfish tournaments, as per the BAU scenario.</p> <p>Overall, introduction of a facility leads to an increase in demand and WTP for lionfish from restaurants, which means that more fishers target lionfish to sell – leading to an increase in total lionfish commercial catch, supporting improved fishing community wellbeing.</p>

## Double the number of lionfish tourism providers

More divers removing lionfish of all sizes decreases lionfish abundance, especially within deep reef sites and no take zone areas. This leads to improved coral reef health and traditional fishery status, which in turn has a positive impact on fishing community wellbeing. Continuation of existing awareness-raising efforts, including tournaments, is expected to increase demand and WTP for lionfish from restaurants.

CATEGORY	WHAT IS HAPPENING
<b>Natural Systems</b> <ul style="list-style-type: none"><li>- N1. Lionfish Population</li><li>- N2. Coral Reefs</li><li>- N3. Traditional Fisheries</li></ul>	Lionfish abundance decreases, and therefore it is expected that prey fish, mesopredator (e.g. snapper and grouper) and lobster abundance will increase. This improves the resiliency of coral reefs, as well as the catch per unit effort of traditional fishery targets, leading to improved wellbeing in fishing communities.
<b>Human Systems</b> <ul style="list-style-type: none"><li>- H1. Management</li><li>- H2. Economy and Tourism</li><li>- H3. Fishing Communities</li><li>- H4. Lionfish Markets</li><li>- H5. Total Lionfish Catch</li></ul>	<p>Increased lionfish tourism (to approximately 30 lionfish tourism providers) will lead to an increase in total lionfish catch, especially from deep reef sites and within no take zone areas.</p> <p>Demand from restaurants will be increased due to increased demand from the general public, stimulated by continuation of outreach activities by NGOs, lionfish jewellery businesses and lionfish tournaments, as per the BAU scenario.</p>

## Double the number of lionfish tournaments

Doubling the number of lionfish tournaments is not expected to lead to a significant increase in lionfish removal rate, and therefore it is expected that overall coral reef health will decrease, and so will the status of traditional fishery targets. This is expected to have a negative impact on fishing community wellbeing. However, increase in awareness about lionfish is expected to increase demand for lionfish from the general public and restaurants.

### CATEGORY

### WHAT IS HAPPENING

#### Natural Systems

- N1. Lionfish Population
- N2. Coral Reefs
- N3. Traditional Fisheries

Lionfish abundance decreases very slowly (almost negligible), which means that the number of sites exceeding lionfish threshold densities remains approximately the same. It is expected that prey fish, mesopredator (e.g. snapper and grouper) and lobster abundance will decrease. Decrease in the abundance of traditional fishery targets will lead to a decrease in landings for those species, leading to reduced wellbeing in fishing communities.

#### Human Systems

- H1. Management
- H2. Economy and Tourism
- H3. Fishing Communities
- H4. Lionfish Markets
- H5. Total Lionfish Catch

An increase in the number of lionfish tournaments has a strong influence on demand for lionfish from the general public, and encourages more restaurants to buy and serve lionfish. Demand from restaurants will also be stimulated by continuation of outreach activities by NGOs, lionfish jewellery businesses, as per the BAU scenario.



Figure 46: Artistic representation of the status of socioecological systems associated with lionfish after doubling the number of lionfish tournaments held every year, for 10 years. By Chuy Arts, Sarteneja

## 4.4 Participatory community consultations

The history of the use of participatory methods dates back to the 1970s with the introduction of the 'rapid rural appraisal' (RRA) approach, which emerged in recognition of the need for conservation planners and scientists to have a better understanding of local context [87]. However, the RRA approach received criticism as it was primarily focused on data-gathering and retained a top-down approach that excluded local communities from decision-making and planning [87]. In the late 1980s, the RRA approach was modified into a 'participatory rural appraisal' (PRA), reflecting a move from top-down to bottom-up participatory conservation planning and management, as it includes community members as active participants throughout the process, from appraisal through action to monitoring and evaluation [88].

Community consultation workshops form a critical component for adopting a PRA approach, and in order to have successful engagement, the workshop needs to have a clear goal, objectives and purpose that is properly communicated to participants [89]. This will allow for the collaboration between the participants to create better results, bring multiplicity of views and recommendations. Most importantly, consultations need to have a strategic and integrative approach to make people feel comfortable and willing to collaborate. Finally, it is vital to share all information with participants once it is ready.

### 4.3.3 Holding participatory consultations for Belize's lionfish management strategy

#### Method

Consultation workshops were held in six coastal communities (Sarteneja, San Pedro, Caye Caulker, Belize City, Dangriga and Placencia) in August 2017. Each community was visited one month before the consultation date to disseminate information about the workshop and to finalise logistics. Promotional materials included a document to inform key stakeholders in each community about the consultation's main objectives, and flyers providing information on the date and location (*Appendix 13*).

The World Café<sup>24</sup> method was used to obtain active participation and create a participatory atmosphere in order to formulate and share ideas. This method utilises a structured conversational process, where groups of people from diverse backgrounds can discuss a topic on different tables. The main guidelines for this process are to: clarify the purpose of the discussion, create a hospitable space, explore questions that matter, encourage everyone's contribution and to connect diverse perspectives or ideas in order to create valuable group discussion [90]. Participants were divided amongst four tables, each with a facilitator present to encourage full participation, promote mutual understanding, foster inclusive solutions and cultivate a shared responsibility between participants [91]. The goal was to ensure that all participants felt comfortable and included.

Each consultation opened with an introduction and welcome by the Belize Fisheries Department, followed by a presentation by Blue Ventures' staff. This presentation summarised results of all surveys that were carried out in 2015-16, which collectively aimed to improve understanding of the systems associated with invasive lionfish in Belize (see *Chapter 3: Adopting A Coupled Human and Natural Systems Approach*). Presentations were prepared according to the stakeholder context (i.e. made to be geographically relevant), presenters avoided using technical terms, and bilingual (English and Spanish) facilitators were strategically positioned around the room to assist as necessary.

Following the presentation, participants were invited to discuss proposed lionfish management scenarios – "Lionfish Facility", "Lionfish Tourism" and "Lionfish Tournaments" (see *Developing Lionfish Management Scenarios for Belize*). Participants were asked to focus their discussion on the pros and cons associated with each scenario, and to consider unmet opportunities or hidden pitfalls. These data were later analysed using a SWOT (Strengths, Weaknesses, Opportunities and Threats) framework.

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<sup>24</sup><http://www.theworldcafe.com/key-concepts-resources/world-cafe-method/>

## SWOT Analysis

A SWOT Analysis is an analysis of the strengths, weaknesses, opportunities and threats (SWOT) of a particular project, subject or discussion. The major advantage for using this type of analysis is that it is not necessary for everyone in the group to reach a consensus, but rather for everyone to participate and give their opinion so all ideas can be recorded. As participants often find it difficult to distinguish between opportunities and strengths and between weaknesses and threats [92], discussion points can be placed into these categories post-consultation:

- Strengths: characteristics of the project that give it an advantage over others
- .....
- Opportunities: elements in the environment that the project could exploit to its advantage
- .....
- Weaknesses: characteristics of the project that place it at a disadvantage relative to others
- .....
- Threats: elements in the environment that could cause trouble for the project

After reviewing the proposed management scenarios, time was allocated for participants to provide recommendations for alternative management scenarios. Once all management scenarios had been shared with the entire group, participants were asked to vote for the scenario that they would most like to see being implemented. Alternative scenarios were later placed into categories to enable comparison of votes across communities. After each consultation, evaluation forms were shared, lionfish tasters were provided and a raffle of lionfish-themed prizes was held.

## 4.5 Results of the consultations

### 99 participants

26 female and 73 male attended six community consultations in August 2017

These participants were represented by

35% fishing industry

21% tourism industry

18% non-governmental organisations

7% local government

1% food industry

All other participants (17%) did not identify with any of the aforementioned categories (e.g. educator, media, retail).



### 4.5.1 Lionfish facility

In general, participants felt that the establishment of a lionfish facility would benefit fishers, though many expressed concerns regarding the financial viability of such a venture. General consensus was that the facility would only be viable if it traded in multiple species, not just lionfish, and/or that lionfish should be introduced to existing seafood distributors/cooperatives rather than opening a new facility. An additional benefit of the facility expressed by participants was that it would raise awareness about lionfish, and one participant stated that to establish a facility would represent shift from the “doom and gloom” perspective of invasive lionfish to adopting a perspective that focuses on potential benefits. A large number of participants stated that there is a need to enable commercial fishing of lionfish from within NTZ areas, however there was no consensus reached on this point and one participant explicitly stated that they did not want to “see reserves opened for lionfish fishing” (*Table 11*).

Two enabling factors were identified for the success of this scenario:

- ▣ Hold more safe-handling workshops with fishers
- ▣ Make lionfish fishing gear (e.g. gloves and spears) more easily available to fishers



**Table 11: Points raised about the “Lionfish Facility” scenario, as discussed by participants during community consultations, presented using a SWOT framework.**

## STRENGTHS

- Supports fishers
  - Set location to deliver lionfish
  - Introduces a set price for lionfish (no need for haggling)
  - Certain buyer – reduces risk for fishers to not find a buyer
  - Employment opportunities in the facility
  - Increase awareness of market opportunities for lionfish
  - Economic benefits to fishers through new target species
- Support restaurants
  - Reliable supply
  - Introduces a set price for lionfish (no need for haggling)
- Decrease in lionfish numbers on the reef
- Increase awareness about lionfish

## WEAKNESSES

- Business feasibility
  - Not financially viable if only a lionfish facility
  - High maintenance and operating costs
  - Domestic lionfish market is dependent on tourism seasons (not year round)
  - Many people still have the misperception that lionfish is poisonous, reducing domestic market viability
  - Lionfish has low catch per unit effort (CPUE; due to being relatively small-bodied and low density) and therefore calls for a high price to make it attractive to fishers
  - Requires business and marketing support
  - Competition with the informal domestic market (facilities would need purchase for lower price than restaurants, so supply from fishers would be unreliable)
- Regulatory barriers, e.g. access and spear use, and enforcement issues in MPAs
- One landing station would only support a subset of fishers
- Lack of equipment to access lionfish on deep reefs, where they are more abundant
- Market only demands large fillet – therefore only remove large lionfish

## OPPORTUNITIES

- Establish through existing cooperatives or businesses
  - Avoid extra costs
  - Increase economic sustainability of cooperatives through diversification
- Sell lionfish internationally
  - Increase foreign exchange
- Engage more stakeholders
  - Engage with lobster trap fishers as well as freediving fishers
  - Facility could purchase lionfish from tour guides as well as fishers
  - Locate multiple receiving stations across the country and create collaboration between these facilities
- Lionfish market development
  - Bring lionfish to other outlets such as supermarkets
  - Further processing of lionfish could increase financial viability (value-added)
  - Certify lionfish in high quality packaging
  - Buy and sell spines for lionfish jewellery
- Government subsidy to fishers catching lionfish and/or to support facility operating costs
- Modify fishery regulations related to lionfish
  - Provide more consistency or standards for control of lionfish licenses
  - Permit commercial lionfish fishing on SCUBA
  - Provide fishers with controlled access to NTZ: “it is better if fishers’ access to high priority conservation areas is legally and managed, rather than illegally and unmanaged... protected areas are here for the fishers”
  - Introduce as a pilot project in a managed access area
  - Special license to fishers who complete managed access log books correctly (incentive)
  - Establish strict guidelines to outline proper gear types
- Invest in research to introduce traps to catch lionfish in deep waters

## THREATS

- Lack of transparency in financial management of cooperatives
- Long-term feasibility of business/fishery
  - Change in lionfish behaviour and/or availability over time may decrease CPUE to the point that it is no longer a viable fishery
  - Change in lionfish behaviour over time may decrease accessibility of lionfish (e.g. more scarce / deeper)

## 4.5.2 Lionfish tourism

Liability and safety concerns for tour operators, tour guides and tourists and concerns of reef damage due to improper spear handling were raised in all consultations. Some participants felt that the risks associated with lionfish tourism were too great, and that lionfish management in protected areas should be carried out only by NGO and government entities. Others felt that specialised training provided to tour guides would be sufficient to overcome these concerns, and that speciality lionfish tourism should be managed through a formal certification process. Certification of lionfish speciality tourism providers may boost Belize's reputation in the international tourism market, providing new economic opportunities. Although population modelling shows that increased lionfish tourism will lead to a decrease in lionfish population abundance, given that tourism is seasonal and geographically limited, the strategy is unlikely to result in lionfish population control at a national level. (Table 12)

Three enabling factors were identified for the success of this scenario:

- ▣ Hold safe-handling workshops with tour guides
- ▣ Make lionfish fishing gear (e.g. gloves and spears) more easily available for purchase
- ▣ Requires additional enforcement investment from Belize Fisheries Department



**Table 12: Points raised about the “Lionfish Tourism” scenario, as discussed by participants during community consultations, presented using a SWOT framework.**

## STRENGTHS

- Increase awareness about lionfish
- Avenue for promoting lionfish consumption in local restaurants to tourists
- Remove lionfish from NTZs and deep reefs
- Collaboration between tour operators and fishers around a common conservation threat
  - Division of labour: tour operators tackle lionfish populations in NTZ while fishers in GUZ

## WEAKNESSES

- Tour operators risk staff/guests being stung
  - Tour guides spearing lionfish cannot provide the sufficient level of supervision to their guests, increasing chance of accident
  - Divers use more air while culling lionfish, increasing the chance of accident
- Tourists with minimal diving experience may damage the reef
- Does not result in effective, sustained lionfish control nationally
  - Geographically limited to areas with high tourism visitation rates
  - Many sites are too far away (expensive to reach)
  - Removal activities will decrease during tourism slow season
- Lack of access to lionfish culling equipment
- Unfair to provide tour guides with access rights for lionfish fishing that fishers do not have
- Some tourists dislike killing wildlife, even if it is invasive

## OPPORTUNITIES

- Create job opportunities in tourism sector
  - Fishers can provide training to tour operators / tourists about lionfish culling and safe-handling
  - Train fishers to lead lionfish tours
- New specialty tourism for Belize, and/or in areas with low visitation rates, e.g. Dangriga
  - Raise profile in international tourism markets
  - Certification with high standards for tour operators to make it an exclusive activity
  - Involve cruise ship tourists (large number, high demand)
  - Involve students via study abroad programmes
- Remove lionfish from non-reef habitats, e.g. mangroves
- Tour operator involvement in lionfish management
  - Data collection and monitoring
  - Coordination of culling efforts through good communication of lionfish status at frequently visited sites
  - Explore new sites with high lionfish densities
  - Tour operators/guides conduct awareness-raising, safe-handling and/or safe-spearing training to tourists
  - Avenue for information dissemination about lionfish management priorities and lionfish status
- Tour operators can sell lionfish they catch to generate further funds, helping to cover additional gas costs of distant sites
- Certified tour operators can charge higher prices for lionfish tours
- Have a seasonal opening for lionfish e.g. once a month or by area in protected areas
  - Independent licensing mechanism for lionfish hunting in NTZs
  - Tour operators register to enter MPA before going to ensure enforcement presence

## THREATS

- Poorly managed lionfish tourism will threaten MPAs more than help them
  - Risk of poor tourism practices, e.g. feeding lionfish to wildlife
  - Risk of illegal fishing: tour operators may target other species in NTZs
- Over time, the availability of large lionfish may decrease, affecting fishers who depend on lionfish fishing
- Low interest from tourists to participate in lionfish tours

### 4.5.3 Lionfish tournaments

In all consultations, lionfish tournaments were viewed positively due to the opportunities they present for awareness-raising amongst the general public and to deliver economic benefits to the host community. General consensus was that tournaments tend to be poorly organised and do not fulfil their potential to deliver these benefits, partially due to weak sponsorship. Some participants also complained that the rules surrounding tournaments were too strict; it was suggested that lionfish tournaments place less focus on lionfish control, and instead focus on community benefits. In all consultations, the idea of converting the tournament into a "LionfishFest" (in keeping with other successful community-based food festivals, e.g. LobsterFest) was proposed. (Table 13)

One enabling factor was identified for the success of this scenario:

- ✦ Improved sponsorship, such as better prizes or funds to cover participants' fuel costs, to increase participation



**Table 13: Points raised about the "Lionfish Tournaments" scenario, as discussed by participants during community consultations, presented using a SWOT framework.**

### STRENGTHS

- Increase awareness about lionfish
  - Provide tasters and reduce misperception that lionfish is poisonous
  - Engages with a large number of people
  - Increase demand and willingness to pay for lionfish by restaurants and general public
- Target lionfish of all sizes
- Increase social cohesion and community pride over involvement in lionfish management

### WEAKNESSES

- Resource intensive (money and time) to organise and host
  - Lack of sponsors
  - Cost of participation is too high compared to the prizes that are offered
  - Value of lionfish on the market is greater than prize money
  - Low participation
  - Rules are too strict, decreases participation
- Does not result in effective, sustained lionfish control nationally
  - Geographically limited to a small area
  - Infrequent removal
  - Mostly targets large lionfish
  - No legal access to NTZs limits impact
- No direct benefit to fishers
- Does not provide a steady supply to lionfish market

### OPPORTUNITIES

- Economic benefits to host community
  - Promote internationally to increase tourism to the area, especially during slow tourism season
  - Make bigger, focus on business benefits and market as "Lionfish Fest"
  - Tour operators can offer a package enabling visitors to participate
  - Restaurants and artisans can sell lionfish products
- Lionfish caught during tournaments can be donated to feeding programs
- Focus on education and outreach benefits more than lionfish control
- Support lionfish management
  - Discover new sites with high lionfish densities
  - Provide special permission for lionfish hunting in NTZs during a tournament
  - Hold more frequent lionfish tournaments each year (e.g. quarterly)
- Sell lionfish caught during tournaments to generate funds for tournament organizers and/or participants
- Schedule tournaments to increase participation from fishers

### THREATS

- Unfavourable interaction with lionfish fishing / tourism industries
  - Temporary decrease in lionfish numbers may negatively impact these industries
  - Fishers / tour operators removing lionfish prior to tournaments may make the tournament unsuccessful
- Poor organisation leads to ineffective use of funds and efforts
- Risk of illegal fishing: participants may target other species during tournament

## 4.5.4 Alternative scenarios

At each consultation, participants made suggestions for lionfish control activities that had not been discussed. These suggestions were subsequently placed into five categories to enable comparison across communities:

1. Access to NTZ
2. National and international collaboration
3. Education and outreach
4. Diversified marketing
5. Improved gear and equipment

The feasibility of each scenario was discussed with the Belize Fisheries Department in a meeting in October 2017 (*Table 14*).

**Table 14: Justification and feasibility of alternative scenarios suggested by participants of community consultations, grouped categorically.**

SCENARIO CATEGORY (NUMBER OF VOTES)	ALTERNATIVE SCENARIO (COMMUNITY)	JUSTIFICATION (BY PARTICIPANT)	FEASIBILITY (ASSESSED BY BFD)
<b>Access to NTZ</b> (9 votes)	A. Allow fishers to cull inside NTZs (Sarteneja, Caye Caulker), e.g. via a seasonal opening during lobster closed season (Placencia).	A. To catch lionfish, under supervision of fisheries staff, providing opportunity for additional income. Fisheries Department can enforce the area.	A. There is a need for management of lionfish in NTZ and that needs to be explored within the realms of the purpose of NTZ, to ensure that the long-term objective is maintained. Any intervention should not at the risk of undermining the initial purpose for the NTZ establishment.
	B. Allow fisher to use spear guns in MPAs (Sarteneja).	B. Help increase lionfish catches by having proper gear and enforcement in these areas.	B. Through a lionfish strategy, a provision for special gear use in MPAs may be made, however this will not be for commercial fishing.
	C. Hire / organise removal teams, managed by NGOs (Caye Caulker, Belize City).	C. Control lionfish in NTZs.	C. Channel through Lionfish Working Group.
<b>National and international collaboration</b> (6 votes)	A. More government involvement in lionfish management (Sarteneja).	A. Provide resources (e.g. equipment), improve enforcement to reduce illegal fishing, and support the creation of a proper price for lionfish. Consult with fishers more and play a greater role in awareness-raising about lionfish and direct management of lionfish.	A. Government already provides resources for lionfish management, and works with partners. Future control activities will be based on recommendations of this strategy. Government has no influence over market price.
	B. Lionfish Working Group (Sarteneja, Belize City)	B. Include representatives of all stakeholders, prioritise and facilitate control activities, shared use of resources and knowledge.	B. Establish a formal Lionfish Working Group.
	C. Knowledge exchange with other countries (Caye Caulker, Dangriga).	C. Shared learning, involve international partners in events.	C. Feasible

**Table 14 (continued): Justification and feasibility of alternative scenarios suggested by participants of community consultations, grouped categorically.**

SCENARIO CATEGORY (NUMBER OF VOTES)	ALTERNATIVE SCENARIO (COMMUNITY)	JUSTIFICATION (BY PARTICIPANT)	FEASIBILITY (ASSESSED BY BFD)
<b>Education and outreach (5 votes)</b>	A. LionfishFest (Sarteneja, Dangriga)	A. Attract more people during high tourism season, could be hosted in more than one location. A way to involve the general public and tourists.	A. Contributes to broader lionfish program – good for awareness raising, sensitization, more people active.
	B. Education to tour operators (Sarteneja).	B. Training on lionfish handling can reduce liability issues.	B. Concerns pertaining to liability/safety issues and potential damage to coral reefs of poorly managed lionfish tourism, must be adequately addressed, under the guidance of the LWG and intergrated into training of tour guides that is underway.
	C. Engage fishers from southern Belize (San Pedro).	C. Close the gap between northern and southern fishers, share techniques and resources.	C. Feasible.
	D. Involve universities and promote more lionfish studies (Caye Caulker, Belize City).	D. Direct and encourage academic institutions and international students to do lionfish research in Belize.	D. Channel through Lionfish Working Group.
	E. Education and outreach with multiple audiences (Caye Caulker, Dangriga, Placencia, Belize City).	E. Increase awareness; Subject should be included in school curriculums, including marine biology in general and lionfish; use more techniques such as dissections and safe-handling demonstrations; Place information in hotels to inform tourists; Use social media, TV and radio to can target wider audiences; Involve more cultural activities in campaigns and activities.	E. Feasible.
	F. Create online lionfish portal (Placencia).	F. Share information about lionfish sightings, data, ideas and articles.	F. Channel through Lionfish Working Group.
<b>Diversified marketing (2 votes)</b>	A. Find a market for small lionfish, e.g. aquarium (Caye Caulker, Dangriga).	A. Improve market viability and incentivise removal of juvenile lionfish.	A. Approach seafood distributors to discuss viability; may be feasible through existing channels. Government has no influence over market price.
	B. Lionfish certification for hotels, restaurants and tour operators (Placencia).	B. Encourage businesses to support lionfish control activities.	B. Include in the Fish Right Eat Right programme to stimulate a local niche market.
	C. Use lionfish by-products (Placencia).	C. Increase lionfish catch value.	C. See Sarteneja Fishermen Association economic viability assessment of lionfish value added products [60].
<b>Improved gear and equipment (1 vote)</b>	A. Lionfish aggregation device and/or traps (Dangriga, Placencia).	A. Improve lionfish catch per unit effort; Remove lionfish from deep sites.	A. Use research to evaluate feasibility of lionfish traps, ensuring that there is no negative impact.
	B. Make lionfish fishing equipment more available (Dangriga, Placencia, San Pedro).	B. Improve access to lionfish culling and safe-handling equipment, possibly via tax breaks or official endorsement.	B. Little opportunity for government to give tax breaks, but there is opportunity to work with suppliers in terms of certifying a specific gear. The LWG may seek grant funding to increase accessibility and/or reduce the cost of lionfish culling devices approved by the Belize Fisheries Department



### 4.5.5 Scenario voting

In Sarteneja, there were a total of 27 votes submitted anonymously by participants, indicating that some participants voted more than once. The voting method was modified after this consultation to prevent participants from submitting more than one vote.

A total of 98 votes were gathered after the community consultations, of which ten were void due to illegibility or voting for multiple scenarios (Figure 46). The scenario to receive the most votes was lionfish facility, followed by lionfish tourism and tournaments.

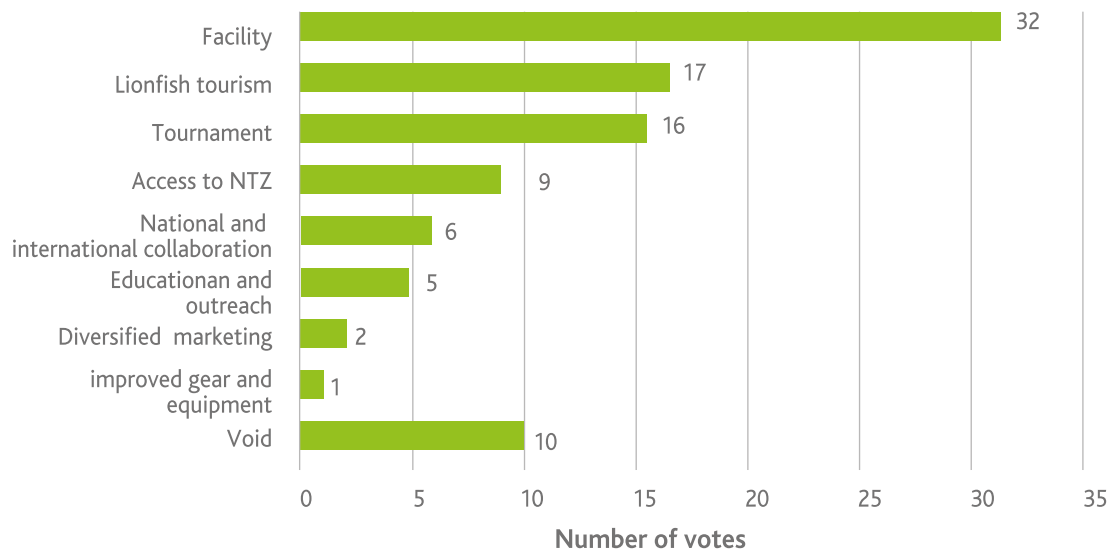


Figure 46: Total votes for lionfish management scenarios, with alternative scenarios pooled by categories, gathered during six community consultations in August 2017.

#### Evaluation and lessons learned

Handing out flyers and visiting communities one month ahead of consultations, and delivering reminders about the workshops on social media immediately before each consultation, was an effective strategy to secure participation in some communities, where the number of participants made it difficult to ensure that all participants were actively involved. However, there was very poor turnout in other communities and food industry stakeholders were under-represented in all consultations. To address these issues:

- ✘ Advertise the consultation via multiple avenues, including visiting communities, flyers, radio, TV, newspaper and social media, one month in advance. Follow up these advertisements with frequent reminders the week before the consultation is scheduled to take place.
- ✘ Consultations all took place in the evening (after normal working hours) to facilitate the participation of stakeholders. However, food industry stakeholders are typically busy during these hours and a different time should be targeted to facilitate their participation.
- ✘ Have at least one bilingual facilitator present per four participants to support everyone's involvement.

Each consultation concluded with a raffle of lionfish-themed items as well as free lionfish tasters, both of which were well received by participants.

After each consultation, the team of presenters, facilitators and note-takers met to review the consultation, share notes and collectively evaluate process. In this way, the approach to consultations was adaptive. For example, the scenario voting mechanism was modified after the first consultation.

Of a total of 80 participants who completed evaluation forms at the end of the workshops:

- ✘ 88% said that facilitation was either "very good" or "excellent".
- ✘ 73% said that they felt comfortable and included.
- ✘ 75% said that they felt that their ideas were heard.

The majority of participants (n=76) stated that were interested in being actively involved in lionfish management.

# Recommendations for the next five years

In this chapter, we summarise recommendations for lionfish management, including:

- Objectives from the regional lionfish strategy that have yet to be addressed
- Data gaps for lionfish management
- A review of prioritised indicators and methods for monitoring and evaluation of the effectiveness of lionfish control efforts
- Prioritised actions

## Introduction

The formal adoption of this strategy secures lionfish population suppression as the core objective over the next five years, and provides sufficient time to address knowledge gaps and to develop policy instruments to prevent the establishment of perverse incentives.

Broad, negative long-term impacts are associated with ineffective lionfish control, and it is clear that ongoing action based on available knowledge is essential. However, given that this is a relatively unique and new invasive species, immediate action is not without risk. Addressing knowledge gaps and frequently evaluating the status of indicators, using standardised methods, provides conservation managers with the necessary tools for adaptive management, and to change the approach should it prove to not lead to the desired outcome.

It is unlikely that lionfish markets alone can deliver effective lionfish population suppression, however the introduction of lionfish as a fisheries target can deliver long term, sustained economic benefits, particularly to fishing communities. Other coral reef stakeholders, in particular coastal community members and marine tourism providers, have expressed a strong interest in being involved in lionfish management. Participatory discussions with stakeholders about a number of different possible management interventions have exposed strengths and weaknesses, as well as opportunities and threats. Through this strategy, recommendations are made to engage a wide range of reef stakeholders in lionfish management, leveraging interest and capacities of multiple groups, proactively addressing threats, whilst capitalising on opportunities.

## 5.1 Mesoamerican reef regional lionfish strategy

In 2014, following a meeting between conservation and fisheries management bodies from Belize, Guatemala, Honduras and Mexico, the Regional Strategy for the Control of Lionfish in the Mesoamerican Reef was published [33]. Belize has been successful in achieving many of the agreed objectives – some of which have been achieved through the production of this national lionfish management strategy. For example, this strategy promotes standard survey methods for monitoring of indicators, and presents the first assessment of lionfish status using standardised methods. It also provides a detailed overview of the socioeconomic aspects of lionfish invasion, and identifies lionfish control methods for marine protected areas (MPAs), in fishing zones and for the deep sea.

However, some objectives remain unaddressed. Specific actions outlined in the regional strategy that have not been addressed in Belize are:

- ⊠ Create a mechanism to promote the coordination of lionfish control and management in each country through existing national organisations: create/strengthen national committees, determine functions and roles of committee members, identify two representatives to sit on MAR Lionfish Committee, monitor implementation of strategy at the national level.
  - At present, the Belize Lionfish Working Group is a sub-committee of the National Coral Reef Monitoring Network. Given the interest and capacities of a wide range of stakeholders in lionfish management, a Lionfish Working Group will be established as an independent entity with broader membership and the specific mandate to oversee and monitor the implementation of Belize’s National Lionfish Management Strategy.
- ⊠ Promote and support research seeking technical solutions for lionfish control: assimilate lionfish landings data, develop mechanisms for monitoring with local artisanal fishers, develop a study on use of lionfish in regional aquarium trade, research lionfish genetics and connectivity, promote research into the use of lionfish for medical purposes, and develop studies related to the consumption of lionfish (nutrition/food science, ciguatera)
  - Lionfish landings data has been estimated in this strategy but there is no precise monitoring programme in place. The introduction of Managed Access logbooks will provide lionfish landings data eventually, though fishery-based extraction is only one component of total lionfish catch. A national monitoring system and database for recording lionfish catch by divers and through tournaments should be established.
  - Independent or visiting researchers interested in studying lionfish in Belize should be directed towards investigating the potential for lionfish use as part of the aquarium trade, lionfish genetics and connectivity, medicinal use of lionfish, and lionfish consumption (health and hazards).
- ⊠ Review policy and legislation related to invasive marine species and develop specific legislation to regulate the use of lionfish as an ornamental species.
- ⊠ Create microloan schemes and targeted subsidies or grants for effective lionfish control.
- ⊠ Raise funds for site-specific management of lionfish in prioritised conservation areas.
- ⊠ Create database for lionfish monitoring, and an official platform for disseminating information.

## 5.2 Data gaps

During the production of this strategy, social and ecological data related to invasive lionfish were collected. Nevertheless, it was not possible to gather all desired indicators. Additional data gaps should be addressed (*Table 15*) in addition to continued monitoring of indicators described in *Chapter 3: Adopting A Coupled Human and Natural Systems Approach*. Whilst reviewing these data needs, in-country capacity to properly conduct and analyse surveys should be considered, as well as the risk of survey fatigue for social research. To avoid survey fatigue, any social research should be conducted following consultation with the Social Science Working Group<sup>25</sup>.

**Table 15: Data gaps associated with lionfish management in Belize**

DATA GAP	DETAILS
Lionfish landings: fishery, tourism, tournaments	Monitoring of lionfish landings will make it possible to calculate indicators for <i>H1. Management</i> as well as improve the estimate of <i>H5. Total Lionfish Catch</i> .
Lionfish focused search (LFS) data: atolls, unassessed MPAs, coral reefs outside of MPAs	Data collected through these surveys can be used to develop improved indicator estimates for <i>N1. Lionfish Population</i> , and <i>N2. Coral Reefs</i> . It can also be used to improve the Lionfish Population Dynamics Model, as initial (year 0/current) abundance was estimated per reef type from LFS surveys, and then scaled nationally. As atolls were not represented in LFS surveys, and LFS surveys only took place in five of Belize's MPAs, this estimate would be improved by conducting research on lionfish populations on the atolls, in other MPAs as well as outside of MPAs. Further, data used to estimate population demographics and model parameters were sourced from a five-year dataset of lionfish sightings in BCMR. These estimates would be improved through use of national level data.
National fisheries landings data	Indicator for <i>N3. Traditional Fisheries</i> . These data are being collected through Managed Access logbooks as of July 2016.
Qualitative indicators for central/southern fishing communities	Indicator for <i>H3. Fishing Communities</i> . The case study presented in this strategy document focused on three northern fishing communities.
Quantitative indicators for fishing communities	Currently, only qualitative indicators have been developed for <i>H3. Fishing Communities</i> . For example, the number of fishers targeting lionfish for commercial or subsistence purposes is a qualitative indicator within this system in the Socioecological Framework. These could also be used to improve the estimate for <i>H5. Total Lionfish Catch</i> , which does not include estimates of the number of lionfish killed by fishers and left in the water. This in turn would improve the Lionfish Population Dynamics Model.
Willingness to pay for lionfish by the general public and tourists	Unassessed indicators in <i>H4. Lionfish Markets</i> . Data for each of these has been collected as part of the case studies presented in this strategy document, however analysis of results is outstanding.
Belize lionfish aging study	The Belize lionfish population size structure was converted to an age structure using an age-length key constructed from age-length data of lionfish from North Carolina. Lionfish aging studies are needed in Belize to obtain a Belize-specific age-structure of the population. Once an aging study has been completed, the model can be updated. Growth parameters (asymptotic length, $L_{\infty}$ ; metabolic coefficient, $K$ ; theoretical age at size 0, $t_0$ ) used to initialize the model were those from North Carolina <sup>26</sup> . This was done so that the growth parameters aligned with the age-length key used. These should be updated as part of the lionfish aging study.

<sup>25</sup>To discuss social research, contact the Environmental Research Institute, University of Belize

<sup>26</sup>Unpublished data of J. Potts (NOAA)

## 5.3 Monitoring and evaluation

Whilst all indicators outlined in *Chapter 3: Adopting A Coupled Human and Natural Systems Approach* should ideally be monitored, this may not always be realistic. Ten indicators have been identified as essential for adaptive management (Table 16).

**Table 16: Indicators and associated monitoring methods for evaluation of lionfish management.**

INDICATOR	MONITORING METHOD
1. Average lionfish density (fish/ha)	Lionfish focused search (LFS) method ( <i>Appendix 4</i> ), carried out as part of Belize's National Biodiversity Monitoring Program [93].
2. Average lionfish size (cm)	Average lionfish size can also be assessed using data from dissections ( <i>Appendix 3</i> ).
3. Average prey fish biomass (kg/ha)	
4. Percent of sites exceeding threshold density	
5. Percent of restaurants that report serving lionfish	Questionnaires with restaurateurs ( <i>Appendix 7</i> ).
6. Median stated willingness to pay (WTP) for lionfish by restaurants (BZD/lb of fillet)	
7. Percent of general public who have heard of lionfish	Questionnaires with the general public ( <i>Appendix 8</i> ).
8. Annual fishing mortality (F) for lionfish	To calculate F, best available current knowledge about lionfish is compiled. The indicator in this strategy was calculated using data from LFS surveys, restaurants questionnaires and semi-structured interviews with fishers ( <i>Appendix 6</i> ). Improved monitoring of lionfish landings will dramatically improve the estimate of this indicator.
9. Mesopredator biomass on coral reefs (g/100m <sup>2</sup> )	Assessed annually using MBRS-SMP method and biennially using AGRRA method. Reported biennially by the Healthy Reefs Initiative in reef health report cards.
10. Coral Reef Health Index score	

## 5.4 Prioritised actions

Recommended actions have been prioritised based on a compilation of all views and data gathered throughout the production of this strategy, as well as through reference to the previous Belize Lionfish Management Plan and the Regional Strategy [21] for Lionfish Control in the Mesoamerican Reef [33] (*Table 17*). All actions are to be coordinated through a multi-stakeholder Lionfish Working Group.

**Table 17: Objectives and recommended actions for lionfish management in Belize, 2019-2023.**

OBJECTIVE	ACTION
1. A multi-stakeholder Lionfish Working Group (LWG) has been established in 2019 and coordinates lionfish management, monitoring and evaluation.	1. Convene meeting with interested parties, representing MPA management authorities, conservation practitioners, fishing stakeholders, tourism stakeholders, and food industry stakeholders.
	2. Establish LWG memorandum, articles, guidelines and agreement.
	3. Nominate executive committee and representatives for MAR Lionfish Committee.
	4. Prepare action plan (2019-2023) based on recommendations in Belize Lionfish Management Strategy and capacities of group members.
2. At least one seafood processing facility purchases lionfish from fishers by 2020.	1. Organise fisher exchange between northern, central and southern fishing communities, highlighting safe-handling and making lionfish-specific fishing gear available.
	2. Conduct business plan for an independent facility that processes lionfish.
	3. Approach private seafood distributors to explore interest in establishing lionfish handling.
3. A lionfish tourism certification scheme that adequately addresses associated risks, supports the needs of marine tour operators, and supports lionfish management priorities, has been established by 2020.	1. Prepare a guiding framework for lionfish tourism by reviewing highlighted weaknesses and threats, through a meeting with tourism and protected area management authorities, tour operators and conservation practitioners.
	2. Formalise guiding framework for lionfish tourism via regulatory bodies and instruments.
	3. Hold workshops with tour guides to explain lionfish tourism guidelines and regulations.
	4. Establish a formally-recognised lionfish tourism training and certification programme.
	5. Liaise with fishing and diving gear outlets to make lionfish fishing gear (e.g. gloves and culling devices) more easily available for purchase.
4. By 2021, all lionfish tournaments are registered with the LWG, raise awareness about the lionfish invasion, provide economic benefits to host communities, and record data to national database.	1. Establish national database for lionfish caught through lionfish tournaments.
	2. Organise an exchange programme for representatives of the LWG to learn about lionfish tournaments that successfully generate economic benefits and attract good sponsorship (for example, see [94]).
	3. Create national guidelines for lionfish tournaments.

## OBJECTIVE

## ACTION

5. Lionfish control in Belize's no take zones (NTZ) has been implemented by 2021.

1. LWG provides recommendations for lionfish control within NTZs.
2. Conduct a national assessment to determine lionfish density and target (threshold) density on coral reefs in NTZs.
3. Prioritise sites within NTZs for lionfish management.
4. Train MPA staff on lionfish survey methods, SCUBA diving and lionfish safe-handling, so that they can include lionfish monitoring in their work plans, and identify sites where lionfish are close to or exceed threshold.
5. Implement control activities.

6. Conduct consistent education and outreach programmes about lionfish with a wide range of stakeholders.

1. Prepare lionfish educational materials for dissemination via tour operators, hotels, etc.
2. Hold lionfish educational programmes in schools.
3. Carry out lionfish social marketing to increase domestic demand for lionfish.
4. Communicate to fishers in all communities where restaurants that buy lionfish are located.
5. Place advertisements on varied media to inform the public about lionfish.
6. Create an online lionfish portal that shares information about lionfish and hosts the national lionfish database.

7. Increase the value of lionfish catch through diversified product markets.

1. Provides guidelines for the establishment of lionfish value-added product line(s), such as packaged fillets or burgers for sale in supermarkets.
2. Investigate the market potential of lionfish as part of Belize's aquarium fish export trade.
3. Promote lionfish jewellery businesses.

8. Conduct research and monitoring to fill identified knowledge gaps about lionfish ecology, management and markets, and evaluate lionfish control actions.

1. Finalise and implement National Lionfish Monitoring Program, a component of the National Biodiversity Monitoring Program (ERI-UB).
2. Conduct questionnaires with restaurants and the general public every three years to update the status of indicators.
3. Independent or visiting researchers interested in studying lionfish in Belize should be directed towards investigating the potential for lionfish use as part of the aquarium trade, lionfish genetics and connectivity, medicinal use of lionfish, and lionfish consumption (health and hazards).
4. Review policy and legislation related to invasive marine species and develop specific legislation to regulate the use of lionfish as an ornamental species.
5. Conduct research on the impacts of lionfish traps in deep water environments (by-catch, native fish community assemblage, physical damage).

9. Ensure adequate funding is available for consistent implementation of lionfish control activities, as well as monitoring and evaluation.

1. Raise funds to support the activities of the Lionfish Working Group.
2. Create microloan schemes and targeted subsidies or grants for effective lionfish control.

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# Contributors

Strategy document outline preparation: Jennifer Chapman and Daniela Bueso

Strategy Review and Approval: Adriel Castañeda

Compilation and editing of chapters: Jennifer Chapman

Chapter reviews: Frances Humber, Lucy Anderson, Cecilia Guerrero and Ben Honey

Chapter content contributors, as detailed below:

## Chapters 1 and 2

- ✦ Writing: Lucy Anderson, Jennifer Chapman, Stephanie Green and Fanny Tricone
- ✦ Three-day strategic planning and socioecological framework development meeting attended by Jennifer Chapman, Marc Fruitema, Tyrell Reyes (Blue Ventures), Ramon Carcamo (Belize Fisheries Department), Jennifer Solomon and Julie Sabattis (Colorado State University), Alexander Bogdanoff (North Carolina State University / National Oceanographic And Atmospheric Association), Stephanie Green (University of Alberta), Leomir Santoya (Sarteneja Fishermen Association, day one), Nigel Martinez (Belize Federation of Fishers, day three)

## Chapter 3

- ✦ Writing: Jennifer Chapman, Lucy Anderson, Marc Fruitema and Julie Sabattis
- ✦ Lionfish Focused Search surveys designed and data analysed by Jennifer Chapman and Stephanie Green. Data collected by Julia Rubin, Anna Simmons, Anouk Neuhaus, Jennifer Chapman, Marc Fruitema, Daniela Escontrela, and Blue Ventures Expeditions volunteers (Blue Ventures), Elias Cantun, Henry Brown and Ali Cansino (Belize Fisheries Department), Eli Romero (Belize Audubon Society), Ellen McRae (FAMRACC), Tanya Barona, Fernando Rabateau and Genevieve Ramirez (TIDE)
- ✦ Social research surveys were designed, carried out and analysed by:
  - Fisher interviews: Tyrell Reyes, Julie Sabattis and Jennifer Solomon
  - Restaurant questionnaires: Marc Fruitema and Jennifer Chapman
  - Consumer (general public) questionnaires: Julie Sabattis, Phil Krening and Jennifer Solomon
- ✦ Lionfish population model was developed by Alexander Bogdanoff and Kyle Sherzer
- ✦ Total lionfish catch calculation: Jennifer Chapman, Daniela Bueso, Jennifer Solomon, Alexander Bogdanoff, and Marc Fruitema

## Chapters 4 and 5

- ✦ Writing: Lucy Anderson, Jennifer Chapman, Marc Fruitema, and Daniela Bueso
- ✦ Data analysis: Stephanie Green and Jennifer Chapman
- ✦ Lionfish management scenario planning: Jennifer Chapman, Marc Fruitema and Daniela Bueso
- ✦ Participatory Community Consultations (PCC) team: Daniela Bueso (Colorado State University), Jennifer Chapman, Cecilia Guerrero, Tyrell Reyes, Bairon Flores (Blue Ventures), Vanessa Figueroa (Belize Fisheries Department)
- ✦ Meeting to develop recommendations using PCC outputs: Blue Ventures (Jennifer Chapman and Cecilia Guerrero) and Belize Fisheries Department (Beverly Wade and Vanessa Figueroa)

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## Design

Elaine Odlin Design  
info@elaineodlindesign.co.uk

Blue Ventures Conservation  
digital@blueventures.org

## Glossary

- BAS – Belize Audubon Society  
BCMR – Bacalar Chico Marine Reserve  
CCMR – Caye Caulker Marine Reserve  
FAMRACC – Forest and Marine Reserves Association of Caye Caulker  
FOOSC – Friends of Swallow Caye  
GUZ – General Use Zone  
HCMR – Hol Chan Marine Reserve  
MPA – Marine Protected Area  
NTZ – No Take Zone  
PHMR – Port Honduras Marine Reserve  
PRA – Participatory Rural Appraisal  
RRA – Rapid Rural Assessment  
SACD – Sarteneja Alliance for Conservation and Development  
SEA – Southern Environmental Association  
SFA – Sarteneja Fishermen Association  
SWCMR – South Water Caye Marine Reserve  
TIDE – Toledo Institute for Development and Environment  
TL – Total Length

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Blue Ventures  
Omnibus Business Centre,  
39-41 North Road, London, N7 9DP, UK

REGISTERED CHARITY 1098893

Tel: +44 (0)207 697 8598  
Email: [info@blueventures.org](mailto:info@blueventures.org)  
[www.blueventures.org](http://www.blueventures.org)

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