



NOAA National Marine Sanctuaries Lionfish Response Plan (2015-2018)

Responding, Controlling, and Adapting to an Active Marine Invasion

U.S. Department of Commerce
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About the Marine Sanctuaries Conservation Series

The Office of National Marine Sanctuaries, part of the National Oceanic and Atmospheric Administration, serves as the trustee for a system of 14 marine protected areas encompassing more than 170,000 square miles of ocean and Great Lakes waters. The 13 national marine sanctuaries and one marine national monument within the National Marine Sanctuary System represent areas of America's ocean and Great Lakes environment that are of special national significance. Within their waters, giant humpback whales breed and calve their young, coral colonies flourish, and shipwrecks tell stories of our maritime history. Habitats include beautiful coral reefs, lush kelp forests, whale migrations corridors, spectacular deep-sea canyons, and underwater archaeological sites. These special places also provide homes to thousands of unique or endangered species and are important to America's cultural heritage. Sites range in size from one square mile to almost 140,000 square miles and serve as natural classrooms, cherished recreational spots, and are home to valuable commercial industries.

Because of considerable differences in settings, resources, and threats, each marine sanctuary has a tailored management plan. Conservation, education, research, monitoring and enforcement programs vary accordingly. The integration of these programs is fundamental to marine protected area management. The Marine Sanctuaries Conservation Series reflects and supports this integration by providing a forum for publication and discussion of the complex issues currently facing the sanctuary system. Topics of published reports vary substantially and may include descriptions of educational programs, discussions on resource management issues, and results of scientific research and monitoring projects. The series facilitates integration of natural sciences, socioeconomic and cultural sciences, education, and policy development to accomplish the diverse needs of NOAA's resource protection mandate. All publications are available on the Office of National Marine Sanctuaries Web site (<http://www.sanctuaries.noaa.gov>).

NOAA National Marine Sanctuaries Lionfish Response Plan (2015-2018)

Responding, Controlling, and Adapting to an Active Marine Invasion

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Cover

Lionfish at the East Flower Garden Bank. Photo Credit: Amanda Sterne, Texas A&M University Galveston

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Summary

The explosion of the Indo-Pacific lionfish (*Pterois volitans* and *Pterois miles*) is a serious threat to Atlantic, Gulf of Mexico, and Caribbean coral reefs, with potential long-term consequences affecting native fish communities and habitats. Lionfish are well-known for their venomous spines, rapid colonization rate, and generalist preferences for both habitat and diet. Invasive lionfish are capable of causing significant impacts to biodiversity and recovery of coral reefs, a result of their high densities and predation rates on native fish communities.

The National Marine Sanctuary Act resource protection mandate aims to “maintain the natural biological communities in the national marine sanctuaries, and to protect, and, where appropriate, restore and enhance natural habitats, populations, and ecological processes.” As it relates to the lionfish invasion, the goal of NOAA’s National Marine Sanctuaries Lionfish Response Plan is to minimize ecosystem degradation in affected sanctuaries so that benthic habitat does not degrade and sanctuaries continue to serve as refuges for native reef fish species. Lessons learned from the lionfish invasion will make managers better capable of dealing with future invasions by other species, should they occur.

This plan aims to identify critical actions needed to minimize the impact of this unprecedented marine invasion. Four national marine sanctuaries have been invaded by lionfish – Gray’s Reef, Florida Keys, Flower Garden Banks, and Monitor. The plan recommends science, service, and stewardship activities for the first three sanctuary sites, as activities at the Monitor are much more limited and will only be discussed briefly. Prior actions by the sanctuaries to deal with lionfish, as well as future activities, rely on collaborations among agency programs and offices, as well as partners outside NOAA, including international collaborations around the wider Caribbean.

This response plan summarizes information on the scope and status of the lionfish invasion, the threats posed to national marine sanctuaries, and the challenges to managing the invasion. It also summarizes current activities taking place, as well as calls for actions to be planned, coordinated, and supported nationally or regionally and actions specific to the individual marine sanctuaries within the invaded range. All actions are directed at management measures that will minimize impacts caused by the invasion, specifically in the areas of monitoring, control, research, and education and outreach. These actions are consistent with those called for in the National Ocean Policy Implementation Plan and other local, regional and national plans specific to the lionfish invasion.

Key Words

Invasive species, lionfish, Gray’s Reef National Marine Sanctuary, Florida Keys National Marine Sanctuary, Flower Garden Banks National Marine Sanctuary, NOAA

Acronyms

ANSTF	Aquatic Nuisance Species Task Force
BOEM	Bureau of Ocean Energy Management
CFP	Ciguatera Fish Poisoning
CRCP	Coral Reef Conservation Program (NOAA)
FDA	Food and Drug Administration
FGBNMS	Flower Garden Banks National Marine Sanctuary (NOAA)
FKNMS	Florida Keys National Marine Sanctuary (NOAA)
FWC	Florida Fish and Wildlife Conservation Commission
GIS	Geographic Information Systems
GREAT	Gulf Reef Environmental Action Team
GRNMS	Gray’s Reef National Marine Sanctuary (NOAA)
KAP	Knowledge, Attitudes, and Perception
MEERA	Marine Ecosystem Event Response and Assessment
MNMS	Monitor National Marine Sanctuary (NOAA)
NCCOS	National Centers for Coast Ocean Science (NOAA)
NCRMP	National Coral Reef Monitoring Program
NGO	Non-Governmental Organization
NMSA	National Marine Sanctuaries Act
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NSU	Nova Southeastern University
ONMS	Office of National Marine Sanctuaries
REEF	Reef Environmental Education Foundation
ROA	Research Only Area
ROV	Remotely Operated Vehicle
SEGOM	Southeast and Gulf of Mexico Region
SPA	Sanctuary Preservation Area
TAMUCC	Texas A&M Corpus Christi
TAMUG	Texas A&M Galveston
TER	Tortugas Ecological Reserve
TNC	The Nature Conservancy
UNCW	University of North Carolina at Wilmington
USGS	U.S. Geological Survey
UTB	University of Texas Brownsville

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Chapter 1. About this Plan

1.1 Purpose

The purpose of this plan is to guide national marine sanctuaries and their partners in addressing the invasion of the lionfish in national marine sanctuaries within the southeast region of the United States. The plan is the guiding document for protecting national marine sanctuary resources and is intended to facilitate collaboration in national marine sanctuaries by:

- Implementing **monitoring** activities to track the invasion and evaluate effectiveness of management actions,
- **Controlling** invasive lionfish populations where possible, using coordinated and effective methods,
- Establishing **research** priorities to guide investigators by identifying highest priority research questions and science needs,
- Using **education and outreach** approaches that generate public support and foster stewardship,
- Providing mechanisms for **collaboration** among regional sanctuary staff and partners, and
- Adapting **management** actions in response to information learned from monitoring, research and control activities.



Figure 1. Lionfish are invasive species native to the Indo-Pacific region. Photo: FGBNMS/Schmahl.

This plan acts as a guide for lionfish management at national marine sanctuary sites in the southeast region of the United States, and complements existing response plans, including the Regional Strategy for the Control of Invasive Lionfish in the Wider Caribbean (Gomez Lozano et al. 2013), the National Invasive Lionfish Prevention and Management Plan (Invasive Lionfish Control Ad-hoc Committee of the Aquatic Nuisance Species Task Force, 2015), the NOAA Invasive Lionfish Action Plan (Morris and Harmon, *in prep*), the National Park Service Lionfish Response Plan (McCreedy et al. 2012), and the Invasive Lionfish Control and Management Action Plan of Florida Keys National Marine Sanctuary (NOAA 2011). While this plan specifically applies to national marine sanctuaries, it is recognized that close coordination and cooperation with

other organizations and agencies across both domestic and international boundaries and jurisdictions is essential for success.

1.2 Rationale

Two species of Indo-Pacific lionfish (Red Lionfish, *Pterois volitans* and Devil Firefish, *Pterois miles*) have become established on continental shelf areas throughout the southeast United States, the Caribbean Sea, and much of the Gulf of Mexico. The range of these invasive predators is still expanding, and they are expected to reach areas as far south as Uruguay (Morris and Whitfield 2009).

While these are not the first invasive marine fish species to be documented in the region, they are the most successful (Schofield et al. 2009). The Indo-Pacific lionfish invasion may become one of the top transformative human impacts to occur on Atlantic coral reefs. It follows on the heels of recent acute stressors such as several high impact coral disease and bleaching events since the late 1970s and the mass die-off of the long-spined sea urchin (*Diadema antillarum*) in the early 1980s; some of these stressors are also correlated to changing climate and ocean conditions. The lionfish invasion also exacerbates the impacts of historical and ongoing overfishing. Each of these stressors has unmistakably and dramatically altered reef communities and their interactions may compound to produce irreversible ecological and economic damage to reef communities of the Atlantic.



Figure 2. Confirmed lionfish sightings throughout the Atlantic, Gulf of Mexico, and Caribbean. Map: USGS, 2015.

Lionfish eradication is considered impractical with current knowledge and technology given the species' high densities, broad depth distribution (surface to 300 m), and rapidly growing populations. However, controlling lionfish densities at the local scale (e.g., individual reef up to hundreds of square kilometers) can be successful and may lead to the recovery of biodiversity and ecosystem services (Frazer et al. 2012; de León et al. 2013; Green et al. 2014). As it relates to invasive species, the Office of National Marine Sanctuaries aims to prevent marine sanctuary ecosystem degradation within the invaded range so that they continue to serve as refuges for native species. Interagency

collaboration across the entire invaded range will be required for successful large scale control of the invasive species.

1.3 Scope

The Office of National Marine Sanctuaries serves as the trustee for a network of 14 marine protected areas encompassing more than 170,000 square miles of marine and Great Lakes waters. The network includes a system of 13 national marine sanctuaries and the Papahānaumokuākea Marine National Monument.



Figure 3. Map of the National Marine Sanctuary System. Map: NOAA/ONMS.

The area targeted by this plan is the southeast region within the national marine sanctuary system. The current sites of specific concern include:

- Gray's Reef National Marine Sanctuary, 57 km², 32 km off Sapelo Island, Georgia
- Florida Keys National Marine Sanctuary, 9,933 km² area surrounding the Florida Keys archipelago
- Flower Garden Banks National Marine Sanctuary, 146 km², 110-170 km southeast of Galveston, Texas

A fourth marine sanctuary, the Monitor, has also reported lionfish, but there are no specific plans to respond to the invasion, as it is not expected to affect the value or quality of maritime heritage artifacts on the Monitor, or the shipwreck site itself. That site, therefore, is not included in this plan. It is worth noting, however, that the sanctuary issues permits for diving on the Monitor, and requests that permittees report and provide images or video of lionfish, if seen. Furthermore, lionfish could affect access to the wreck, as they pose an acute safety threat to divers, including recreational divers, sanctuary staff, and researchers. Sanctuary staff currently discusses the lionfish problem

at outreach events as a way of informing the public about on-going ocean conservation and safety issues. An action plan for the Monitor sanctuary will be developed, and for any newly designated marine sanctuary sites in the region, if a decision is made that the invasion significantly threatens sanctuary resources or safety, and specific activities are needed to address it.

1.4 Issues, Concerns, and Threats

With the globalization of commerce and trade, invasive species have become a concern in virtually all marine ecosystems. Transportation of goods by larger and faster ships, international trade in live animals and plants, and changing ocean conditions caused by pollution and climate change, for example, all put ecosystems at greater risk of invasions. This is particularly true for ecosystems already under pressure from local sources of pollution, overuse, climate change, and other stressors (Albins and Hixon 2011).

The lionfish invasion in the northwest Atlantic Ocean occurred slowly after the initial discoveries around 1985, then rapidly after 2000 (Schofield 2009). Primary reasons for the invasion's success include prolific breeding and an apparent lack of Atlantic predators or other controls (Mumby et al. 2011; Hackerott et al. 2013). The invasion is resulting in declining native fish biomass in certain places because of extremely high predation rates by lionfish on native species, and rapidly growing populations that occur over a wide depth distribution (Albins and Hixon 2008; Green et al. 2012). This disrupts food webs and alters critical ecosystem functions, thus reducing an ecosystem's resilience (the capacity for maintenance and self-renewal) (Lesser and Slattery 2011). The high abundance and lack of effective tools and techniques to remove lionfish from deep water make eradication impractical.

The first evidence of invasion in Gray's Reef National Marine Sanctuary was in 2007, Florida Keys National Marine Sanctuary in 2009, and Flower Garden Banks National Marine Sanctuary in 2011. Concern over the ecological effects of lionfish in marine sanctuaries has increased as new findings have emerged. Ecological impacts are expected to occur mainly through the reduction of native reef fish and invertebrate populations caused by lionfish predation. Consumption of juveniles of large native reef fish may also hamper stock recovery of key economically and ecologically important species (Morris and Whitfield 2009). It has become clear that the integrity of reef ecosystems in national marine sanctuaries of the southeast Atlantic and Gulf of Mexico region is at considerable risk from the lionfish invasion (Albins and Hixon 2011; Ruttenberg et al. 2012).

Though the lionfish invasion represents a major ecological threat to national marine sanctuaries, there are also short and long-term social and economic consequences for communities that depend on sanctuary resources and the ecosystem services they provide. Some of these include *provisioning* services, like food and ornamental species; *regulating* services, such as biodiversity; and *cultural* services, like tourism, recreation, science, and education (Gittings et al. 2013). Lionfish represent a safety risk to recreational divers, snorkelers, swimmers, and anglers because of their venomous spines. In some areas,

lionfish may also contribute to the decline of commercially and recreationally important fish and invertebrates, including species caught for local consumption (Green et al. 2012, 2014). Tourism is also potentially affected by the reduction in biodiversity, which can lead to declines in popularity of dive destinations. Thus, controlling the impacts of lionfish is among the higher priorities for sanctuary management in this region.

National marine sanctuaries are focal areas for research, education and outreach, and enforcement, all of which could facilitate lionfish control. They also allow for adaptive management, whereby action plans can be developed and altered to address emerging threats. Sanctuaries serve as sentinel sites, where sustained observations of ecosystem conditions allow for a greater understanding of underlying drivers of change, as well as an early warning capacity to enable rapid response and intervention. Together, the high ecological value, iconic status, and existing capabilities make national marine sanctuaries priority areas for conservation in the face of this significant threat to reef communities of the northwest Atlantic Ocean and Gulf of Mexico.

1.5 Challenges Hampering Effective Lionfish Control

Science and conservation communities, including national marine sanctuary staff, have worked to understand, track, and respond to the lionfish invasion. To date, the affected national marine sanctuaries have implemented activities that could lead to effective controls of lionfish populations, but additional and sustained efforts are required for long-term success. Competing priorities and a lack of capacity have hindered control efforts through 2015. For example, the lack of techniques available for lionfish removal below no-decompression diving depths and challenges involving logistics and funding in remote locations have hindered large-scale implementation of control measures.



Figure 4. Lionfish observed during a ROV survey over deep coralline algae reefs on banks in the Northwestern Gulf of Mexico at approximately 120 meters. Photo: FGBNMS/UNCW-UVP.

In addition, there are still many unanswered questions about what approaches may be most effective in controlling the invasion. Perhaps the most important is whether natural controls will emerge with time as the invasion progresses, reducing the need for, or

working in concert with human intervention. For example, an undisturbed, highly diverse ecosystem, such as a marine protected area, may be more resistant than a system that is already stressed and lacks protections from stressors, such as fishing pressure. Predation, parasitism, and diseases would appear to be the most likely mechanisms for natural population control. Observations suggesting natural biotic resistance via predation by large groupers and other species (Mumby et al. 2011) raise the idea of closures to, or reductions in fishing, in order to restore large predators. Recent work has not supported this concept (Hackerott et al. 2013; Valdivia et al. 2014), but it could be further tested in national marine sanctuaries, national parks, and other marine protected areas, where marine reserve research and monitoring efforts provide a foundation for this research. There is also a need to continue studies to better understand the level of effort required to control local populations and to explore new, untested control measures.

1.6 Connections and Relevance

The consequences of the lionfish invasion are not just a concern for national marine sanctuaries. The unprecedented scale of this invasion has the attention of higher levels of governments across the United States Southeast and Caribbean region (Morris 2012). It is a problem of international dimension with economic effects that are likely to be felt by recreational and commercial anglers, dive operators, resorts, hotels, restaurants, and countless other coastal stakeholders. Internationally, several island nations have developed plans for action. In the United States, the National Ocean Policy Implementation Plan calls for federal agencies to take actions “...to improve our ability to detect and reduce invasive species in coastal and ocean habitats to protect commercial and recreational fish stocks, help sustain the jobs and industries that depend upon healthy coastal aquatic ecosystems, and save millions of dollars in lost revenue and avoided infrastructure damage” (National Ocean Council 2013).

A similar call for action also appeared in the Commerce, Justice, Science, and Related Agencies Appropriations Bill in 2013 (H.R.5326) and two House Resolutions raising awareness and capacity building needs specifically for invasive lionfish (H.R. 132 of the 112th Congress and H.R. 67 of the 113th Congress). The National Park Service developed and implemented a Lionfish Response Plan that identified the threat of lionfish to national parks and instructions for developing control plans tailored to specific park needs (McCreedy et al. 2012). Recently, the National Invasive Lionfish Prevention and Management Plan (2015) was prepared by an ad-hoc group with representatives from state, regional, and federal government entities, academia, non-profit organizations, and industry. Its purpose is to serve as a guide to the Aquatic Nuisance Species Task Force (ANSTF) and other interested parties involved in managing lionfish and natural resources in U.S. waters.

The need for the NOAA National Marine Sanctuaries Lionfish Response Plan is to respond to these calls for action, and to outline specific actions to be taken within sanctuaries based on guidance provided by these and other planning efforts. In proposing these actions, however, the plan also supports calls for interagency coordination and all

eight goals of the interagency Aquatic Nuisance Species Task Force Strategic Plan (2013-2017) (Aquatic Nuisance Species Task Force 2012), and all seven goals of the National Fish, Wildlife, and Plants Climate Adaptation Strategy (2012). This plan most directly supports Goal 7: “*Reduce non-climate stressors to help fish, wildlife, plants, and ecosystems adapt to a changing climate.*” This plan’s actions draw heavily on the draft NOAA Invasive Lionfish Action Plan (Morris and Harmon, *in prep*) and address its five goals:

- Develop and implement localized lionfish control plans,
- Enhance research on lionfish ecology to improve and develop methods for lionfish population control,
- Develop and implement the use of standard monitoring methods,
- Implement lionfish sociocultural and economic assessments across impacted sectors, and
- Improve lionfish ecological impact assessments.

A number of the research priorities listed in the National Invasive Lionfish Prevention and Management Plan (2015) are also identified as priorities for the national marine sanctuaries. In addition, this plan contributes to the National Ocean Services priorities to enhance place-based conservation and resilience, and addresses research priorities of both the National Centers for Coastal Ocean Science and the Office of National Marine Sanctuaries.

Chapter 2. A Plan for Action

The actions proposed in this plan will provide guidance and enable each affected national marine sanctuary to continue to respond, control, and adapt to the lionfish invasion. They take advantage of the assets available at marine sanctuary facilities to focus removal, monitoring, and research efforts, and strengths in education and outreach to engage the public and support the need to spread information about this problem. Because of its high profile and the likely impacts of the lionfish invasion, this issue has the potential to invigorate public attention and action on behalf of marine conservation in general - a potentially significant positive outcome from the crisis. It also provides an opportunity to highlight NOAA’s science, service and stewardship roles on behalf of the American public.

The actions proposed (Table 1) are separated into groups coordinated primarily by the national and regional offices, and those facilitated by the individual national marine sanctuary sites. It is recognized, however, that many of the same people will be working at multiple levels, and considerable integration of activities will occur. The actions are further divided into four categories: monitoring, control, research, and education and outreach.

Table 1. Priority actions by staff working nationally, regionally, or at one of the three national marine sanctuaries responding to the lionfish invasion (see following sections for descriptions). Symbols are characterized as: √ completed, > ongoing, + needed or planned.

Category	Focus Area/Project	National & Regional	Florida Keys	Flower Garden Banks	Gray’s Reef
Monitoring	Tracking Protocols	>	>	>	>
	Impact Protocols	+	>	>	+
	Condition Reports	>	>	>	>
	NCRMP*	>	>	>	
	Tortugas Reserve		>		
	Reef Environmental Education Foundation (REEF) Volunteer Fish Survey Project	>	>	√	
	FGB Long-Term Monitoring			>	
	Stetson Bank Long-Term Monitoring			>	
	Research Area				>
	Invertebrate Disturbance				>
	Acoustic				+
Control	Identify Priority Areas	+	√	√	
	Permitting Mechanisms	>	√	√	+
	Regulatory Impediments	+	√		
	Capture/Trap Technologies	>	+		
	Market Development	+			
	Incentivizing Control	+			
	Targeted Removals		>	>	+
	Derbies		>	+	
“Eat Lionfish” Campaign		>		>	
Research	Diets	+	>	>	+
	Resistance & Resilience	+		+	
	Biological Controls	+		+	
	Ciguatera	>		>	
	KAPs**	+	+		

Category	Focus Area/Project	National & Regional	Florida Keys	Flower Garden Banks	Gray's Reef		
Research	Biology & Ecology	Removal Effectiveness	>	>			
		Recolonization	>	+	>		
		Impacts to Native Species	>	>			
		Habitat Utilization	>	>			
		Age & Growth	>	>			
		Attraction Devices		+			
		Impacts of Hunting		+			
		Movement		+	+		
		Seasonal Variation				>	
		Tissue Collection		>	>	>	
		Socioeconomics	Spiny Lobster Fishery		>		
			Economic Sector Impacts		>		
	Impact on Perceptions			√			
Education & Outreach	Training	+	>	>	>		
	Lionfish Messaging	>	>	>	>		
	Curriculum	+					
	Conservation Messaging	>	>	>	>		
	New web content				+		
	NOAA Working Group	+					
	Partnerships	>	>	>	+		
	Handling Workshops		>	>	√		
Events & Materials		>	>	>			

* NCRMP – National Coral Reef Monitoring Program administered by the NOAA Coral Reef Conservation Program

** Studies on knowledge, attitudes, and perceptions about lionfish and their impacts

2.1 National and Regional Response Actions

To date, the primary responses to the lionfish invasion in national marine sanctuaries have occurred at the local level, and involve removal, research, monitoring, and education and outreach. However, there are several activities that would benefit from regional, national, or international coordination, planning, or support. The lionfish problem is widespread, yet the drivers of change are fairly consistent across the affected range, so there may be economies of scale realized by regional and national actions. There are also agency and interagency initiatives that can both support and benefit from these actions.

A responsibility of the National Marine Sanctuary (NMS) system is to protect ecosystem integrity in marine sanctuaries, as resource protection is mandated by the National Marine Sanctuaries Act (NMSA). One of the specified purposes of the NMSA is to “...protect, and where appropriate, restore and enhance natural habitats, populations, and ecological processes” of the marine sanctuaries. The Act also calls for “...models of, and incentives for, ways to conserve and manage these areas, including the application of innovative management techniques.” These purposes, including provisions of the NMSA and regulations of the individual marine sanctuaries must be considered in dealing with the lionfish issue. NMSA also authorizes the issuance of permits for otherwise prohibited activities. For example, where a banned activity such as spearfishing at Gray’s Reef, Flower Garden Banks, or some areas of the Florida Keys

National Marine Sanctuary, is deemed the most efficient lionfish removal technique, permits may be issued for targeted removals. The same is true for removals related to research.

At both Flower Garden Banks and Gray's Reef National Marine Sanctuaries, regulations that may influence lionfish response include prohibitions on anchoring, injuring biota or bottom formations (this could occur during removals), and the use or possession of spearfishing equipment, traps, or fish caught using them. Pertinent prohibitions in Florida Keys National Marine Sanctuary include injury to coral or live rock, alteration of the seabed, and harvesting of marine life, and in certain areas, prohibitions on anchoring, spearfishing, trapping, and collecting any organisms. The national and regional offices of ONMS will work with all three sanctuaries to develop clear messaging and approaches for facilitating lionfish response, recognizing site-specific regulations.

Monitoring, control, research, and education and outreach activities that could be coordinated at the regional or national level to respond to the lionfish invasion include:

I. Monitoring

Monitoring is a critical part of adaptive management for lionfish control, as trends provide an indicator of how lionfish populations and the fish community are responding to management actions or biotic controls. Because lionfish are a new stress in marine sanctuaries, monitoring their populations and effects may require new techniques, or adapting protocols in current monitoring programs.

- Work with individual marine sanctuaries to identify or establish appropriate protocols for tracking progress of the invasion and evaluating status and change in impacts associated with lionfish.
- Work with sanctuaries to incorporate lionfish information and discussions into invasive species sections of condition reports.
- Develop or adopt monitoring protocols that will allow comparison of lionfish populations and impacts at various sites.
- Provide access to and sharing of regional data and protocols to enhance adaptive management.

II. Control

Based on current research and available technology, it is generally accepted that eradication of lionfish throughout the region is not feasible. However, recent research is showing that local control of lionfish populations to levels that will minimize ecological and economic impacts in priority areas may be possible (Frazer et al. 2012; Green et al. 2014). Control measures are likely to vary depending on the level of invasion, measurable impacts to the native coral reef community and human health, and available control resources. Furthermore, regulatory impediments to public involvement in removals must be reduced and the development of new technologies for lionfish control must be considered.

- Work with sanctuary sites to develop and apply criteria to identify priority areas for removal, removal frequency, monitoring, and outreach.
- Consider ways to facilitate permitting while ensuring safe and effective removals (e.g., evaluate use of a call-in permitting system based on experiences of the Florida Keys National Marine Sanctuary).
- Consider whether other currently restricted activities should be allowed, such as granting exceptions to no-take reserves or permitting spearfishing in restricted areas.
- Develop responsible capture technologies that enable control of populations in both shallow and deep water habitats without causing harm to the natural resources (e.g., bycatch, marine debris, entanglement).
- Incentivize technology and other control measures through innovative means, such as awards, market development, and social networking.

III. Research

Despite a decade or more of valuable research on lionfish in invaded areas, there is still much to be learned about lionfish biology and ecology that will inform the methods and approaches to population control. Research is also needed to understand the invasion's impacts on both natural and human systems, and the response of these systems to control actions.

- Track temporal changes and selectivity within lionfish diets in relation to prey availability and impacts to native species.
- Identify factors influencing resistance and resilience of different sanctuary ecosystems, and marine protect areas as a tool for natural control.
- Facilitate and encourage research in lionfish population ecology to better understand the variation in lionfish control efficacy.
- Assess relative impact of control approaches, including the development of adaptive control plans.
- Facilitate investigations of biological controls such as predation, disease, and parasites, as well as intervention options (e.g., genetic modification).
- Facilitate and encourage research in marine sanctuaries related to comparative toxicology, ciguatera testing, and social sciences related to ciguatera fish poisoning.
- Track changes in knowledge, attitudes, and perceptions of sanctuaries and conservation issues resulting from awareness generated by the lionfish invasion (e.g., Scyphers et al. 2014).

IV. Education and Outreach

Dealing with the lionfish invasion will require broad support from the public, necessitating a significant investment in outreach and education. But the lionfish issue is also an excellent tool for educating the public about invasive species, as well as a starting point for other topics such as coral reef biology and marine conservation more generally.

- Encourage and promote best practices for training conducted in the region.
- Identify and convey important messages related to lionfish impacts, controls, and consumption (e.g., the risk of ciguatera from eating lionfish).
- Support the development of curriculum relating lionfish to ecological principles about invasive species for both national and site levels. This could be part of a larger curriculum on invasive species that applies more broadly (e.g., “Respond, Control, and Adapt”).
- Promote conservation behavior through outreach focused on the human role in causing and exacerbating the lionfish invasion, as well as highlighting the successes of ongoing control efforts and partnerships.
- Work with NOAA invasive species initiatives, and create a lionfish working group at NOAA to coordinate agency response activities.
- Conduct evaluations of education and outreach efficacy for individual programs.



Figure 5. The Celebrity Chef Lionfish Challenge, hosted by the National Marine Sanctuary Foundation, the Office of National Marine Sanctuaries, and Seaweb as part of the 2015 SeaWeb Seafood Summit 2015, allowed for a unique outreach opportunity for guests to sample lionfish dishes, and learn about the invasion as well as national marine sanctuaries. Photos: Michelle Johnston and Brian Barber.

Chapter 3. Florida Keys National Marine Sanctuary

3.1 Status of the Invasion

Florida Keys National Marine Sanctuary (FKNMS) is one of the largest marine protected areas in the United States, encompassing 9,933 square kilometers. Marine zones for multiple uses, including highly protected "no-take" areas (currently 6% of the sanctuary), have been in place since 1997. Approximately 60% of the sanctuary is State of Florida waters, and 40% is federal waters. FKNMS shares boundaries with three national parks and overlaps with four national wildlife refuges, six state parks, and three state aquatic preserves. FKNMS surrounds the Florida Keys community of more than 72,000 year-round residents and 3-million annual visitors (Office of National Marine Sanctuaries 2011).



Figure 6. Bathymetric map of the Florida Keys National Marine Sanctuary.
Map: NOAA/ONMS.

Lionfish were introduced off the Atlantic coast of Florida in the 1980s, but did not reach the FKNMS until 2009 (Schofield 2009, 2010; Ruttenberg et al. 2012). Between January and September 2009, thirteen lionfish sightings were reported in FKNMS, of which ten were confirmed; eight of those were successfully captured and removed. Shortly thereafter, lionfish populations exploded in the Florida Keys, as elsewhere. They are now present in nearly all habitats where natural or manmade relief provides structure. Lionfish abundance has increased in FKNMS since 2009, and is predicted to affect the native fish population. In some shallow reefs of the nearby Bahamas for example, lionfish represent up to 40% of reef fish biomass, and have reduced native biomass by 65% (Green et al. 2012).

3.2 Resources at Risk

FKNMS helps protect more than 6,000 species of marine life, including the world's third largest barrier reef, and one of the largest seagrass communities in this hemisphere. The sanctuary surrounds approximately 1,700 islands and includes mangrove, seagrass, hardbottom, and coral reef habitats in coastal and oceanic waters. This ecosystem support fisheries and recreational activities that provide income for local economies and recreational opportunity to millions of people, annually. NOAA



Figure 7. Fish swim above the reef at the Florida Keys National Marine Sanctuary. Photo: NOAA/FKNMS.

estimates that coral reefs in southeast Florida have an asset value of \$8.5 billion, generating \$4.4 billion in local sales, \$2 billion in local income, and 70,400 full and part-time jobs (Office of National Marine Sanctuaries 2011).

How much economic impact the lionfish invasion may have on the Florida Keys is unknown, but there is ample evidence to suggest that the threat to ecosystems is large, and the economic impact could be as well. Lionfish compete for space and food with commercially and recreationally important reef-fish species, such as snapper, grouper, hogfish, and others. They also consume juveniles of these and many other species, which poses significant risk for reef-fish populations and threatens to prevent stock rebuilding efforts. Herbivorous fishes are also lionfish prey, which could lead to uncontrolled growth of algae on reefs, exacerbating an already stressed coral reef ecosystem. And because the lionfish prey base includes fish and invertebrates, their impact on reef food webs could be pervasive and severe.

3.3 Sanctuary Response Actions

Lionfish were first observed in FKNMS in 2009, and numerous response actions have taken place in an attempt to control this invasion. Table 2 lists past and some current responses, projects, and areas of focus on the lionfish invasion involving density control, research, monitoring, and education and outreach through 2014.

Table 2. Activities conducted by staff and partners at Florida Keys National Marine Sanctuary.

Category	Focus Area/Project	Brief Description
Monitoring	Permitting	FKNMS provides research permits for monitoring and tagging lionfish.
	CRCP NCRMP	National Coral Reef Monitoring Program. Lionfish abundance and size conducted along reef-wide random belt transects.
	Various projects of opportunity	Other projects that record lionfish presence while sampling/monitoring stations.
	Citizen science	Citizens are encouraged to report sightings of lionfish to either REEF or the Marine Ecosystem Event Response and Assessment (MEERA) program.
	Lionfish derbies	Data are regularly gathered on populations, size structure, and removal effort.
Control	FKNMS Invasive Lionfish Control and Management Action Plan	NOAA, REEF, and Mote Marine Lab developed action plan over a two-year period (2011).
	Permitting	FKNMS permits people who have been through a sanctioned workshop to remove lionfish from 18 Sanctuary Preservation Areas. Over 800 permits issued to date. FKNMS permits on-water professionals to remove lionfish from no-take areas using pole spears.
	Derbies	FKNMS and REEF have partnered to promote lionfish removal and control using 'derbies.'
	State of Florida laws changed	Florida law has been updated to address the lionfish invasion: 1) there is no fishing license required to harvest lionfish, 2) there is no bag or size limit within State waters, 3) participants are permitted in approved tournaments and other organized events to spear lionfish or other invasive species in areas where spearfishing is not allowed, with exceptions, 4) harvest of lionfish is allowed when diving with a rebreather, 5) import of live lionfish and breeding for the aquarium trade is banned
Research	U.S. Geological Survey (USGS) – Hg Concentrations	Testing and reporting of mercury concentrations of lionfish with researchers from USGS and University of Florida.
	USGS – non-native species database	Sightings reported and entered into USGS non-native species database.
	Tag recapture	Nova Southeastern University (NSU) worked in Tennessee Reef Special Use Area on tag and capture research to determine habitat utilization characteristics.
	Lionfish target density	Stephanie Green at Oregon State University researching effectiveness of lionfish removals in priority areas and recolonization rates to set removal frequency targets.
	Lionfish derbies	Data are gathered on populations, size structure, fecundity, age/growth, and removal effectiveness.
Education & Outreach	Non-native species guide	REEF, USGS, NOAA – Published 2012
	Regular lionfish outreach and training workshops	REEF and FKNMS – FKNMS permit requirement for removing lionfish within Sanctuary Preservation Areas.
	Social media (e.g., Facebook and twitter)	Regular updates to the public about training workshops, derbies, and special events.

In addition to the primary responses above, there are numerous activities and research needs that would benefit the sanctuary. Monitoring, control, research, and education and outreach activities that are in place, or could be coordinated to help respond to the lionfish invasion, are further described in detail below.

I. Monitoring

Purpose: Collect information to monitor trends in lionfish populations in FKNMS and the effectiveness of control programs in order to assess and adjust actions through adaptive management.

Several key questions marine resource managers will need to address through lionfish monitoring include:

- How is the lionfish population, including distribution, demographics, and condition, changing over time in FKNMS?
- What locations (depths, habitat types, etc.) are colonized or recolonized most quickly?
- How effective is removal in controlling lionfish abundance and how are native fish and invertebrate populations responding over time frames from months to years?
- How much effort is required to control lionfish in FKNMS, and what capacity needs to be in place to make this effort sustainable?

Currently, a range of monitoring projects occurs in FKNMS. Those that can be or have been adapted to include monitoring for lionfish are:

1. NOAA National Coral Reef Monitoring Plan. NOAA's Coral Reef Conservation Program (CRCP) implemented the National Coral Reef Monitoring Plan (NCRMP) in 2013. It is designed to support conservation of the Nation's coral reef ecosystems through documenting and understanding the status and trends of the Nation's reefs. Through NCRMP, NOAA will clearly and concisely communicate results of national-scale status and trends monitoring to national, state, and territorial policy makers, as well as resource managers and the general public every four years. The NCRMP focuses on the following four priority themes: benthic communities (especially corals), reef-associated fish communities, climate change and ocean acidification, and socioeconomic human dimensions related to perceptions of and interactions with coral reef ecosystems. Benthic and fish monitoring will be conducted on a biennial basis in the U.S. Atlantic/Caribbean, and every three years in the U.S. Pacific.

Status: Beginning 2014

Implementation: Benthic and fish monitoring using a stratified random sampling design throughout shallow water coral reefs (0-30m) in Florida (Martin to Monroe Counties) is scheduled to begin in 2014 and continue on a biennial basis. NCRMP will monitor coral cover, coral community structure, rugosity, incidence of bleaching and disease, and associated measures of fish community structure (abundance, diversity, size structure, key species) as quantified using the reef visual census method (RVC). Lionfish abundance and size will be documented in the FKNMS fish surveys, along with associated habitat type and depth in benthic surveys.

2. Tortugas Ecological Reserve Monitoring. The FKNMS Tortugas Ecological Reserve (TER) is located at the westernmost extent of the sanctuary. In partnership with NCCOS, NOAA Fisheries, and Florida Fish and Wildlife Conservation Commission (FWC), FKNMS has continued to monitor the performance of the TER, including the response of fishes to this the current level of protection provided by the reserve. Monitoring is also underway in the adjacent Dry Tortugas National Park, where lionfish abundances and distribution have been documented for the last two years.

Status: Initiated 2000 / Ongoing annually

Implementation: Benthic and fish monitoring using a stratified random sampling design throughout shallow water coral reefs (0-30m) in TER is conducted every two years. Lionfish abundance and size are now documented in the TER fish surveys, along with associated habitat type and depth in benthic surveys. Lionfish are also removed during this survey, to the extent practicable. Information gained from fish surveys may provide insight on whether biotic resistance will limit lionfish populations in the TER.



Figure 8. Fish survey conducted within the TER. Photo: FGBNMS/Nuttall.

3. REEF Marine Zone Monitoring. Starting in 1997, REEF has conducted fish counts using its Advanced Assessment Team (AAT) as part of the FKNMS Zone Monitoring Program. The main purpose of this project is to evaluate the effect of harvest restrictions on the fish assemblages at no-take zones within FKNMS.

Status: Initiated 1997 / Ongoing, but opportunistic and no longer annual

Implementation: Reef fish populations were regularly surveyed for comparisons between fully protected marine zones and reference sites

from 1997 to 2002, and opportunistically since 2003. The AAT conducted a minimum of 6 roving diver surveys at each no-take site, and at reference areas that are similar to the protected sites but where harvest has not been restricted. Lionfish are included in roving diver surveys to determine if there are differences in lionfish abundance in no take-sites and reference sites.

4. Florida Keys Reef Fish Monitoring. NOAA's Southeast Fisheries Science Center, in cooperation with the University of Miami, Florida Fish and Wildlife Conservation Commission, and the National Park Service, conduct annual scuba surveys of the coral reef fish communities along the Florida Keys coral reef tract.

Status: 1980-2013

Implementation: Using a habitat stratified sampling design, the program included approximately 350 sites annually. Project information has been used in stock assessments for reef-associated species, evaluating efficacy of marine zones in FKNMS, and assessment of changes in fish communities over the past 30 years. Community-level effects of the lionfish invasion are of particular concern to sanctuary management, and those effects are now monitored as part of NCRMP.

II. Control

Purpose: Develop measures to assess effectiveness and maximize efficiency of lionfish control strategies leading to more effective resource protection in FKNMS. The activities below depend on and address the needs of an actively involved public responding cooperatively to the lionfish invasion. Because eradication is unlikely, our response will require a continual commitment to control, and for area the size of the FKNMS, this will require a large number of participants.

1. Identify and prioritize FKNMS marine zones requiring active lionfish control.

The lionfish invasion requires assessment of critical and priority habitat towards which mitigation resources should be focused. It is prudent to prioritize FKNMS habitats (or marine zones) that should become focused removal areas.

Status: Initiated 2009 / Currently under review

Implementation: Combining community sentiment with best available science, develop a map of the FKNMS highlighting priority lionfish removals areas, consistent with NOAA policy and FKNMS management plan.

2. Establish permitting requirements and opportunity for removing lionfish from fully-protected (no-take) marine zones. FKNMS uses 24 "no-take" zones (Sanctuary Preservation Areas, Ecological Reserves, and Research Only Areas) to facilitate multiple-use and to protect coastal and ocean resources including coral reefs, seagrass meadows, mangroves, and shipwrecks. There are four zones types, one of which is called a Sanctuary Preservation Area or SPA, allowing regular visitation by the public, who primarily engage in snorkeling and diving activities. Reporting and removing invasive

lionfish from these zones is a management priority. A special permit was developed to allow the general public to remove invasive lionfish from the 18 SPAs with hand nets and slurp guns. Over 800 divers have been permitted as of 2014.

Status: Initiated 2009/ Ongoing annually

Implementation: After completing an FKNMS approved lionfish workshop, members of the public are authorized via a sanctuary permit to remove lionfish from the 18 SPAs (gear restrictions apply). FKNMS permit is not required to remove lionfish from areas outside the no-take zones (94% of FKNMS), but gear restrictions are applicable. As the invasion progresses, permitting requirements may need to be re-evaluated and additional resources for improving efficiency of collection strategies and reducing impacts of collections to the FKNMS may be considered. This may include adjusting gear restrictions.



Figure 9. Lionfish safe handling and collection workshops are free trainings. They are a requirement for a Sanctuary permit to remove lionfish from SPAs with handnets). Photo: NOAA/FKNMS.

3. Conduct targeted removals to control lionfish densities. By educating and training the public, partners, and resource managers in best collection and handling practices, community involvement in opportunistic removal of lionfish from sanctuary waters is facilitated.

Staff and Permitted Volunteer Removals

Status: Initiated 2009/ Ongoing annually

Implementation: Individuals including staff, volunteers, and researchers are trained to respond and safely remove lionfish, as well as gather important ecological and biological data through dissections, tissue sampling, and archival of specimens. Permits are required to remove lionfish from the FKNMS zones. Data is available to be shared with MEERA, REEF, and National Centers for Coastal Ocean Science (NCCOS), etc., for further distribution.

Lionfish Derbies

Status: Initiated 2010/ Ongoing annually

Implementation: FKNMS partners with REEF to train key users and derby participants to safely and effectively remove lionfish from sanctuary waters. Geographic and morphometric/meristic data are recorded for each lionfish removed and entered into the REEF lionfish database. Focused, intensive removals are repeated on a regular basis in an attempt to keep lionfish densities low in local areas.

In 2013, REEF in partnership with Dr. Stephanie Green (OSU), with funding from FL Sea Grant, began assessing effects of single-day lionfish removal events on lionfish population and size structure. Lionfish density and size are being assessed before and after derby events at a total of 64 sites in the upper Florida Keys and Biscayne National Park to determine percentage of the population removed and effects on size structure of the population. Quarterly surveys are documenting recruitment following derby removals.



Figure 10. REEF receives permits from the FKNMS and the state of Florida to host derbies in the sanctuary. Photo: REEF.

Bycatch in the Trap Fishery

Status: Ongoing

Implementation: Significant numbers of lionfish are removed through bycatch in the Florida Keys lobster trap fishery. One fisherman reported over 6,000 lbs of lionfish captured in a single year. Data are reported to FWC as part of the Saltwater Product Licensing requirements.

Aquarium Trade

Status: Ongoing

Implementation: Lionfish are being collected and sold through the marine life trade in the Florida Keys, no longer from overseas. Data are reported to the FWC.

III. Research

Purpose: Increase research activities to better understand lionfish biology and ecology, and further advance methods for lionfish population control in FKNMS. Research is also needed to understand the associated impacts on natural and human systems in the Florida Keys.

1. Lionfish ecology and impacts. Lingering questions about the ecology of lionfish still hinder the development of long-term control measures. Additional research is needed to better understand the following:

- Research on aging and genetics of lionfish
Status: Initiated 2009/ Ongoing
Implementation: Research is underway at NCCOS Center for Coastal Fisheries and Habitat Research to develop aging methods for invasive lionfish. Otoliths and tissue samples are sent to the NOAA NCCOS Lionfish Tissue Repository in Beaufort, NC and archived for studies on age, growth, diet, genetics, and stable isotope analysis.

- Study ecological impacts on native fish and benthic communities in shallow and deep reefs
Status: Initiated 2010/ Ongoing
Implementation: Dr. Stephanie Green (Oregon State University), Lad Akins (REEF), and NSU are examining the response of native reef fish community structure to lionfish population density at 12 nearshore patch reefs (~5m) and 14 offshore continuous reefs (~20m) between Tennessee ROA and Carysfort SPA. The relationship between lionfish densities and native fish populations will be used to calibrate an ecological model of predicted density thresholds at which lionfish deplete their fish prey base, which can be used to identify targets for population control. An extension of this study is also taking place in Biscayne National Park and Buck Island Reef National Monument.

- Determine habitat utilization characteristics of lionfish on both shallow and deep reefs
Status: Initiated 2010/ Ongoing
Implementation: Dr. Stephanie Green (Oregon State University), Lad Akins (REEF), and NSU are also examining drivers of recolonization in the sanctuary, which vary with habitat structure and connectivity, fish community assemblage, and oceanographic processes. An extension of

this study is also taking place in Biscayne National Park and Buck Island Reef National Monument. REEF, in partnership with Dr. Green, is assessing microhabitat occupancy and recruitment fidelity at eight sites in the upper Florida Keys. Data will be used to determine microhabitat preference, recruitment and use patterns with varying lionfish density at removal and control sites.



Figure 11. Lionfish spotted during a transect survey. Photo: REEF.

- Determine effectiveness of lionfish removals in priority areas and recolonization rates to set removal frequency targets to effectively mitigate ecosystem impacts

Status: Initiated 2012/ Ongoing

Implementation: Dr. Stephanie Green (Oregon State University) and Lad Akins (REEF), in partnership with NSU and funded through Mote, NOAA CRCP, Florida Sea Grant and the David. H. Smith Conservation Program are assessing 1) factors affecting catch per unit effort of lionfish by divers over time and across sites,



Figure 12. Lionfish removal can be an effective control method in priority areas. Photo: Alex Mustard.

including gear type, fish behavior and the effect of habitat on catch, in order to determine the level of effort required to keep lionfish densities below target impact thresholds, and 2) habitat and biotic community characteristics driving recolonization rates. An extension of this study is taking place at Biscayne National Park and Buck Island Reef National Monument. Tagging and re-sighting lionfish at sites in the Florida Keys Research Only Areas (ROA) is providing information on lionfish movement in response to removals at adjacent sites. These data will feed into a model to provide resource managers guidance on frequency of visitation and level of removal needed to minimize lionfish predation impacts.

- Investigate the effectiveness of different methods of attracting lionfish in support of trap development

Status: Initiated 2013/ Ongoing

Implementation: Preliminary research has been initiated at NCCOS Center for Coastal Fisheries and Habitat Research, REEF, and the Office of National Marine Sanctuaries to develop lionfish attraction devices. Researchers at Biscayne National Park (Kristian Rogers) and University of Miami (Dr. Evan D'Alessandro) are assessing the efficacy of a lionfish-specific trap device as compared to traditional diver removal in waters of the Park and FKNMS.

- Assess deepwater lionfish populations in relation to lobster fishery bycatch of lionfish

Status: Initiated 2014/ 12 months

Implementation:

Through a Sea Grant funded project, Lad Akins (REEF) working with Dr. Stephanie Green (OSU) and Dr. James Morris (NOAA) are using a ROV to assess deepwater (40-60 m) lionfish populations in comparison to catch of lionfish in the same areas in the lobster trap fishery.



Figure 13. REEF staff deploy a ROV to conduct surveys assessing lionfish populations near deep water lobster traps off Key Largo, Florida. Photo: REEF.

- Assess impact to reefs caused by divers and others hunting lionfish
Status: Research needed

2. Socioeconomic impacts. The lionfish invasion represents a socioeconomic threat, contributing to the decline of ecologically and commercially important species of fish in the Southeast U.S. Socioeconomic impacts remain largely unquantified, and analyses are needed across all potentially impacted economic sectors, including commercial fishing, recreational fishing, tourism, and food services. High priority research questions investigating lionfish socioeconomic impacts in the FKNMS include:

- Assess lionfish impacts on the spiny lobster fishery
Status: Initiated 2012
Implementation: Research underway by graduate student at the University of Miami in partnership with REEF is documenting the presence of lionfish in the commercial lobster trap fishery in relation to trap location and by-catch, and effects on the target lobster catch to determine impacts on the fishery. Data on trap catch is being recorded and assessed monthly in the Middle Keys during the lobster fishing season (August – March). Cameras are being deployed on a subset of traps to assess lobster-lionfish interactions.
- Assess economic impacts of the lionfish invasion on affected sectors of the community (fishing, tourism, recreation, ornamental fish collection, biotechnology)
Status: Research needed
- Determine how perceptions of stakeholders (e.g., recognition and appreciation) have changed over time, particularly regarding conservation requirements related to lionfish.
Status: Initiated 2013
Implementation: An ongoing collaboration between REEF and NSU is using lionfish derbies to gauge economic expenditures and impacts of participants. The same survey will also assess participant attitudes and experiences regarding lionfish, including how these experiences have changed since the invasion started.

IV. Education and Outreach

Purpose: Conduct outreach and education to FKNMS stakeholders and the general public about invasive species (e.g., lionfish).

1. Continue and strengthen key partnerships. Existing and new partnerships are needed to educate the public about lionfish, enact rapid response protocols and removals, and to assist with scientific investigations related to invasive marine species.

Status: Implemented 2008/ Ongoing annually

Implementation: Since 2009, REEF has been working in close partnership with FKNMS and partners throughout the region to help develop lionfish response plans, train resource managers and dive operators in effective collecting and handling techniques, and conduct cutting edge research to help address the invasion. REEF enlists divers and snorkelers to join organized lionfish research and removal projects and encourages public participation in helping address the invasion.

2. Conduct lionfish handling workshops. Training workshops educate the public on safe handling practices and promote detection and removal of lionfish from FKNMS waters.

Status: Implemented 2010/ Ongoing annually

Implementation: FKNMS partners with REEF to organize and execute training workshops that promote safe detection and removal of lionfish. Workshops target the general public, dive operators, lionfish derby participants, NGOs, and state and federal agency field staff. Outreach materials about lionfish threats to human health are distributed to the public through print, web, and social media outlets. Online awareness modules for the general public including awareness and reporting, safe handling, dissection, and processing of lionfish for human consumption are currently in development by REEF. Successful completion of these workshops is a requirement of the permit that allows stakeholders to remove lionfish from the FKNMS SPAs.



Figure 14. FKNMS and REEF partner to hold training workshops, a requirement for derby participation. Photo: REEF.

3. Increase public awareness and distribute outreach information. Key messaging is needed to explain the damaging ecological impacts of lionfish and to promote awareness, detectability and central reporting of lionfish in the FKNMS (Appendix A and B). This includes distribution of stickers, flyers, fact sheets, and other outreach materials to dive shops, NGOs, state and federal agencies, and schools.

Status: Implemented 2008/ ongoing annually

Implementation: Outreach material is distributed by REEF, Mote Marine Lab, FKNMS, and NCCOS. Social media networks, including Facebook and Twitter, are also utilized to distribute information. A June 2008 workshop in Marathon, FL, hosted by NCCOS, REEF, and USGS provided direct outreach on lionfish to representatives from over 30 institutions in South Florida. Various media outlets have covered the lionfish invasion along the Southeast U.S. and the Caribbean including newspapers, magazines, and major networks news coverage.

4. **Consume Lionfish** and promote “Eat Lionfish” campaigns

Status: Implemented 2009/ Ongoing annually

Implementation: It is unlikely that lionfish will be eradicated from FKNMS, but their densities can be controlled locally through removal, and consumption is a side benefit. Lionfish are a delicious and environmentally conscientious seafood choice considering many native reef-fish species are heavily exploited. REEF recently released *The Lionfish Cookbook*, co-authored by Trish Ferguson and Lad Akins, providing recipes and information on the invasion and proper handling and preparation techniques. Recipes from the cookbook, such as lionfish ceviche, are prepared after REEF derby events held in the FKNMS. In addition, lionfish by-catch in lobster traps has created a small market to sell lionfish to local restaurants. Several lobster fisherman and fish houses have created a commercial market for lionfish caught in lobster traps by selling fresh fish to restaurants from Florida to New York. Tracking of the changing market for lionfish could serve as a way to evaluate the effectiveness of these efforts.



Figure 15. Tasty lionfish ceviche and fried lionfish served at the Upper Florida Keys Lionfish Derby. Photo: NOAA/FKNMS.

Chapter 4. Flower Garden Banks National Marine Sanctuary

4.1 Status of the Invasion

Located in the northwestern Gulf of Mexico, Flower Garden Banks National Marine Sanctuary (FGBNMS) includes three separate areas, known as East Flower Garden Bank, West Flower Garden Bank, and Stetson Bank. The banks range in depth from 16 to 150 meters, perched atop underwater hills formed by rising domes of ancient salt, and support several distinct habitats, including the northernmost coral reefs in the continental United States (Office of National Marine Sanctuaries 2008a).

Stetson Bank is located 113 km south of Galveston, Texas, and 48 km northwest of West Flower Garden Bank. Depths at Stetson range from 17 meters to 52 meters. Though reef corals occur on Stetson Bank, environmental conditions, which include more extreme fluctuations in temperature and turbidity than at the Flower Gardens, do not support the growth of reefs like those found at East and West Flower Garden Banks (FGB) (Office of National Marine Sanctuaries 2008a).



Figure 16. Bathymetric map of the Flower Garden Banks National Marine Sanctuary. Map: NOAA/ONMS.

After their introduction off the Florida coast in the 1980s, lionfish reached the Gulf of Mexico in 2009 (Schofield 2010; Aguilar-Perera and Tuz-Sulub 2010). In the fall of 2010, lionfish were observed at Sonnier Bank (one of numerous shallow banks in the northwestern Gulf of Mexico) and nearby oil and gas platforms. In July of 2011, lionfish were observed on all three banks of the FGBNMS. The Flower Garden Banks long-term monitoring program has helped document the appearance and rapid spread of lionfishes in the sanctuary, as well as surrounding banks in the Northwest Gulf of Mexico. Between 2011 and 2012, lionfish sightings have increased 10-fold. In addition to distribution and abundance changes, researchers are studying lionfish diet through stomach content analysis and providing data and samples for age/growth and genetic studies. While fish biomass at the FGBNMS remains high, the invasion is still in the early stages, and negative impacts on the reef community may not be seen for several years. The FGBNMS currently works to remove lionfish when possible. However, a more focused effort is needed to control the population and to understand control targets and other effective control mechanisms that would minimize ecosystem-level impacts.

4.2 Resources at Risk

Brain and star corals dominate the coral caps of the East and West FGB. There are at least 23 species of coral on the coral cap between 30-40 m, and over 50% coral cover (Johnston et al. 2013). Somewhat less well known is the deepwater habitat of the FGB that makes up over 98% of the area within the sanctuary boundaries. Habitats below recreational scuba limits include algal nodule fields, coralline algae reefs, deep coral habitat, mud flats, mounds, mud volcanoes and at least one brine seep system (Nuttall et al. 2013). Different assemblages of sea life reside in these deeper habitats, including extensive beds of coralline algae pavements and algal nodules, colorful sea fans, sea whips, black corals, and basket and feather stars.

The benthic habitat of FGBNMS provides critical protection, food, and shelter for the associated fish community. At least 297 species of fish have been documented within the sanctuary, including colorful reef inhabitants such as parrotfish, wrasse, angelfish, damselfish, chromis, and squirrelfish. The conspicuous deeper water fish in the sanctuary include predators like grouper and snapper, scamp and marbled grouper, and large schools of smaller prey fish like roughtongue and threadnose bass. Commercially targeted species include the snapper, grouper, jacks, and mackerel (Office of National Marine Sanctuaries 2008a).

Stetson Bank has distinct sandstone pinnacles that push out of the seafloor for 457 meters along the northwest face of the bank. An area referred to as the "flats" stretches out behind the pinnacles region, and it is dotted with low relief outcroppings. The pinnacles of Stetson Bank were previously dominated by fire coral and sponges, though recent bleaching and other events have caused dramatic declines in certain species. There are at least ten coral species at Stetson Bank, but with the exception of fire coral and a large area of *Madracis decactis*, algae, sponges and rubble dominate benthic cover, and the

bank does not harbor a true coral reef. Sponges, gorgonians and black corals dominate outcroppings at deeper depths (50 to 60 m) (DeBose et al. 2012).



Figure 17. A yellowmouth grouper and creolefish swim above the reef at the FGBNMS. Photo: FGBNMS/Schmahl.

4.3 Sanctuary Response Actions

Since the first lionfish was observed at the FGBNMS in 2011, numerous actions have taken place, and many projects adapted or created, to manage this invasive species. To date, the primary responses, projects, and areas of focus on the lionfish invasion involving control, research, monitoring, and education and outreach at the FGBNMS are listed below (Table 3).

Table 3. Priority activities currently conducted by staff and partners at Flower Garden Banks National Marine Sanctuary.

Category	Focus Area/Project	Brief Description
Monitoring	CRCP NCRMP	National Coral Reef Monitoring Program. Lionfish abundance and size conducted along reef-wide random belt transects.
	FGB Long-Term Monitoring	Lionfish abundance and size documented on Bohnsack fish surveys within study sites.
	Stetson Monitoring	Lionfish abundance and size documented on Bohnsack fish surveys within study sites.
	Citizen science reporting	Lionfish sightings reported to the Sanctuary through an online report form.
Control	Identify Priority Areas	Priority areas for lionfish control include buoyed areas on the FGBNMS reef cap.

Category	Focus Area/Project	Brief Description
Control	Permitting Mechanisms	Select individuals are authorized via a permit and letter of authorization to remove lionfish from priority areas.
	Targeted Removals	Staff and permitted volunteers are trained and issued permits to safely remove lionfish.
Research	Diet	Stomach contents analyzed from all lionfish fish removed from the FGBNMS.
	Ciguatera	Partner with NOAA NCCOS and FDA to test lionfish for ciguatera fish poisoning.
	Mercury	Lionfish screened for mercury levels at the FGB.
	Habitat Utilization	Collect data on density, distribution, and habitats utilized on shallow and deep reefs through diver surveys and ROV surveys.
	Age and Growth	Partner with NOAA NCCOS and TAMU-CC for otolith analysis.
	Tissue collection	Partner with TAMU-CC and UTB for genetic analysis and gene mapping.
	Gulf Mapping	Partner with TNC for GIS analysis and map products documenting a time series of the Gulf of Mexico invasion.
Education & Outreach	Training and Handling Workshops	Partner with REEF, Houston Zoo, and Texas State Aquarium to host lionfish safe handling workshops.
	Lionfish messaging	Development of messages and facts incorporated in presentations given to dive clubs and community organizations. Work with local schools on "Host a Lionfish" in your classroom week.
	Partnerships	Key partners to date have included Fling Charters, REEF, NOAA NCCOS, TX State Aquarium, TAMUCC, TAMUG, UTB, The Nature Conservancy, the FDA, Haven, and The Houston Zoo.
	Special Events	Host Ocean Discovery Day and partner with Houston restaurants to hold special lionfish dinner events.
	Outreach Materials	Develop facts sheets and sighting forms. Partner with Moody Gardens and Gladys Porter Zoo on aquarium exhibits and provide lionfish for aquaria.

In addition to the primary responses in place, there are additional activities and research needs that would benefit the sanctuary. Monitoring, control, research, and education and outreach activities that are in place, or could be coordinated to help respond to the lionfish invasion, are further described in detail below.

I. Monitoring

Purpose: Collect information to monitor trends of the lionfish population in the FGBNMS and the impacts of control programs in order to assess and adjust actions using adaptive management principles.

Several key questions face sanctuary management in the struggle to deal with the lionfish invasion:

- How is the lionfish population, including density, distribution, and size structure changing over time in the FGBNMS?
- What locations (depths, habitat types, banks) are colonized or recolonized most quickly?
- What is the most effective methods of lionfish control considering the unique nature of the FGBNMS (e.g., fairly deep reefs and large areas beyond recreational diving limits).

- How effective is removal in controlling lionfish and how are native populations responding?
- How much effort is required to control lionfish in the FGBNMS, and is this effort sustainable?

Currently, there are two primary annual monitoring programs conducted by FGBNMS staff, one occurring at East and West FGB and one specific to Stetson Bank. The national coral reef monitoring program occurs biannually. All programs include fish surveys and monitoring for lionfish:

1. East and West Flower Garden Banks Long-Term Monitoring. The long-term monitoring program was initiated in 1988 by the Minerals Management Service (now the Bureau of Ocean Energy Management [BOEM]) to insure protective measures regulating potential impacts of offshore oil and gas development. Since 2009, the FGBNMS has conducted the long-term monitoring and BOEM continues to support the cost of half of the monitoring effort through an interagency agreement with the FGBNMS. In more than 20 years of continuous monitoring, the coral reefs of East and West FGB have maintained high levels of coral cover (above 50%), suffered minimally from hurricanes, coral bleaching, and disease outbreaks, and supported relatively diverse and abundant fish populations as well as other vertebrate and invertebrate species.

Status: Initiated 1988 / Ongoing annually

Implementation: Single 100 x 100 m study sites at the East and West FGB are used to monitor benthic community structure (coral cover, relative dominance, and species diversity), accretionary and encrusting growth rates, water quality parameters, and fish communities as indicators of reef health. Lionfish abundance and size are documented in the fish surveys, along with associated habitat type and depth.



Figure 18. Random transect taken within the East FGB long-term monitoring study site. Photo: FGBNMS/Schmahl.

2. Stetson Bank Monitoring. Stetson Bank was first studied in 1974, but annual monitoring, first by the Gulf Reef Environmental Action Team (GREAT), and later by FGBNMS, did not begin until 1993. Over the course of this monitoring, a major shift in community structure occurred, in which the coral-sponge community was replaced by an algal-dominated community. During the initial years of monitoring, the coral community at Stetson Bank was relatively stable, but in the late 1990s, sponge cover began to decline and in 2005, the benthic community underwent a significant change when living coral cover declined from 30% to less than 8% and sponges declined to less than 20% benthic cover. The combined effects of hurricane impact, elevated temperatures, coral bleaching, and perhaps the influence of coastal runoff, contributed to the shift.

Status: Initiated 1993 / Ongoing annually

Implementation: Repetitive photo stations at Stetson Bank are used to capture images from the same places every year. Currently, approximately 50 stations are marked by metal pins embedded in the reef, with number tags attached. Repetitive photo analysis is used to monitor benthic community structure. Water quality parameters are measured and fish community surveys are conducted. Lionfish abundance and size are documented in the Stetson Bank fish surveys, along with associated habitat type and depth.

3. NOAA National Coral Reef Monitoring Plan. The program was implemented at the East and West FGB in 2013 to track benthic communities (especially corals), reef-associated fish communities, climate change and ocean acidification, and socioeconomic human dimensions related to perceptions of and interactions with coral reef ecosystems. Benthic and fish monitoring will continue on a biennial basis, as with other reefs in the U.S. Atlantic/Caribbean.

Status: Initiated 2013/ Ongoing biennially

Implementation: Benthic and fish monitoring using a stratified random sampling design at the East and West FGB. NCRMP monitoring protocols include coral cover, coral community structure, rugosity, incidence of bleaching and disease, and associated measures of fish community structure (abundance, diversity, size structure, key species). Lionfish abundance and size are documented in reef-wide fish surveys at the East and West FGB, along with associated habitat type and depth in benthic surveys.

II. Control

Purpose: Ensure that populations in priority locations remain below levels that could alter ecosystem integrity. This requires development of measures to assess effectiveness and maximize efficiency of lionfish control.

Implementing control targets (managing populations at levels that will minimize ecological and economic impacts within FGBNMS priority areas) and allocating resources according to removal priorities will provide FGBNMS managers with

measurable goals for removal activities. Collaborative efforts among community stakeholders and partners will promote buy-in and enhance removal activities.

1. Identify and prioritize FGBNMS priority areas requiring active lionfish control.

The lionfish invasion requires assessment of critical and priority habitat towards which mitigation resources should be focused. As demonstrated in the Bahamas and some parts of the Caribbean, lionfish are capable of reaching high densities within a couple of years. It is prudent to assess which areas of the FGBNMS should be focused removal areas, especially as the invasion progresses.

Status: Initiated 2012/ Ongoing

Implementation: Through monitoring and previous habitat characterization efforts, as well as stakeholder use of sanctuary areas, priority areas for lionfish control in the FGBNMS include all buoyed areas on the reef cap of the East FGB (seven buoys), West FGB (5 buoys), and Stetson Bank (five buoys). Because the majority of the FGBNMS is below diveable depths using SCUBA, lionfish removal/control areas include diveable areas of a 100-m radius around all mooring buoys. Lionfish removal within a 100 m radius of all mooring areas was initiated in 2013. Morphometric/meristic data are recorded for each lionfish removed, tissues and fins clips are sampled, and gut contents are analyzed in partnership with TAMUCC.



Figure 19. Stomach contents are analyzed from lionfish removed from the FGBNMS to determine what native fish fishes are eaten by lionfish. Photo: FGBNMS/Drinnen.

2. Establish permitting requirements for lionfish removal. Proper permitting will encourage the reporting of lionfish and allow the collection of lionfish within buoyed zones.

Status: Initiated 2012 / Ongoing

Implementation: Select individuals are authorized via permit and a letter of authorization (LOA) to remove lionfish from the FGBNMS buoy zones.

All researchers with permits are requested to report all lionfish sightings, along with geographic and morphometric/meristic data, to FGBNMS management. Gear is restricted to nets and pole spears. As the invasion progresses, permitting requirements may need to be re-evaluated and additional resources for improving efficiency of collection strategies and reducing impacts of collections to the FGBNMS may be considered.

Additional collection gear may also have to be allowed for controlling populations in new target areas, such as deep water.

3. Facilitate community involvement in targeted removals. Through education and training, members of the public, partners, and resource managers will be knowledgeable of best collection and handling practices.

Staff and Permitted Volunteer Removals

Status: Initiated 2012/ Ongoing

Implementation: Select individuals (staff, volunteers, researchers) are trained and issued permits to respond and safely remove lionfish, as well as gather important ecological and biological data through dissections, tissue sampling, and archival of specimens.



Figure 20. Permitted lionfish removal at FGBNMS. Photo: FGBNMS/Schmahl.

Lionfish Derbies

Status: To be implemented in 2015

Implementation: The FGBNMS will partner with REEF, Oregon State University, the Texas State Aquarium, Fling Charters, and the National Marine Sanctuary Foundation to train researchers and divers from the community to effectively remove lionfish from sanctuary waters for the first ever Texas removal event in 2015. The focus will be a four-day permitted research and removal event within the FGBNMS, using both net and pole spear collecting methods. Important ecological and biological data will be gathered through dissections, tissue sampling, and archival of specimens. This pilot project will determine the extent to which focused, intensive removals repeated on a regular basis can keep lionfish densities low in the FGBNMS priority areas.

III. Research

Purpose: Increase research activities to better understand factors influencing lionfish population control in the FGBNMS. Research is needed on the biology, ecology, and potential impacts of the species, namely the response of other marine sanctuary resources to the invasion. This will help managers design appropriate tools and targets for control, based on best available science.

High priority research in support of adaptive management includes:

1. How relatively undisturbed ecosystems like the FGBNMS respond to the lionfish invasion

Status: To be implemented in 2015

Implementation: FGBNMS staff will investigate whether relatively undisturbed communities with healthy fish communities, including large predators, respond differently to the lionfish invasion than those of other reefs. Fish surveys will be conducted outside removal zones (buoy areas) at the FGBNMS in 2015 to determine if the FGBNMS exhibits signs of biotic control, specifically whether consumption by large predators impedes lionfish population growth.

2. Determine the level of risk from ciguatera associated with lionfish at the FGBNMS

Status: Initiated 2013

Implementation: FGBNMS staff are partnering with the FDA and NOAA NCCOS to test lionfish from the FGBNMS for ciguatera fish poisoning (CFP). Based on several FDA-confirmed reports of CFP following consumption of other fish caught in the sanctuary, the FDA advises that seafood processors avoid purchasing certain fish species, including lionfish, from the area. Once tests are complete, the information will be provided to the FDA for possible re-evaluation of the advisory.

3. Determine effectiveness of lionfish removals in priority areas, as well as recolonization rates, to set removal frequency targets that effectively mitigate ecosystem impacts

Status: To be implemented in 2015

Implementation: FGBNMS staff is partnering with REEF, Dr. Stephanie Green from Oregon State University, the Texas State Aquarium, the National Marine Sanctuary Foundation, and Fling Charters to hold a lionfish derby and research cruise in 2015. The effort will help determine the effectiveness of removals by divers at the Flower Garden Banks, and the rate of recolonization following removal. Combined with temporal information on other fish species, including those that serve as prey for lionfish, control levels will be determined. This information will help FGBNMS managers determine frequency of removal required to protect key resources.

4. Assess the ecological impacts of lionfish on native fish and benthic communities in shallow and deep reefs

Status: Initiated 2012/ Ongoing

Implementation: Annual monitoring on the shallow reef cap will provide information on impacts to native fish and benthic communities through fish surveys, benthic surveys, and lionfish gut content analysis. Deep surveys using ROV footage will provide information on fish and benthic communities in depths below recreational dive limits. Future captures of lionfish in deep water would enable gut content analysis and comparative studies of impacts in shallow vs. deep water.



Figure 21. Fish survey conducted at the FGBNMS. Photo: FGBNMS/Eckert.

5. Determine habitat utilization characteristics of lionfish on both shallow and deep reefs

Status: Initiated 2012/ Ongoing

Implementation: Annual monitoring and NCRMP studies currently provide information on lionfish density, distribution, and habitats utilized on the coral cap. ROV surveys provide information on lionfish density and habitats used in depths below recreational dive limits. This data can be used to target removal efforts and inform the design of traps or other devices to capture or kill lionfish.

6. Research on lionfish movement through tagging and photo identification to determine if lionfish move across the reef cap or exhibit site fidelity, as understanding site fidelity will help managers target removal efforts and assess the spatial extent of the threats to potential prey.

Status: Research needed

IV. Education and Outreach

Purpose: Conduct outreach and education about lionfish and the FGBNMS to stakeholders and the general public. Lionfish is an excellent subject for educating the public about invasive species, as well as a starting point for other topics such as coral reef biology and marine conservation in the FGBNMS.

1. Continue and strengthen partnership with the Reef Environmental Education Foundation (REEF) to educate the public about lionfish, hold lionfish derbies, and assist with scientific investigations related to invasive marine species.

Status: Implemented 2012/ Ongoing

Implementation: The Reef Environmental Education Foundation is a grassroots organization that seeks to conserve marine ecosystems by educating, enlisting and enabling divers and other marine enthusiasts to become active ocean stewards (Scyphers et al. 2014) and citizen scientists. Since 2012, REEF has been working in close partnership with the FGBNMS and partners throughout the region to help develop lionfish response plans, train resource managers and dive operators in effective collecting and handling techniques, and conducting cutting edge research to help address the invasion.

2. Conduct lionfish handling workshops to educate and train the public in safe handling practices to promote detection and removal of lionfish from FGBNMS waters.

Status: Implemented 2013/ Ongoing

Implementation: The FGBNMS partners with REEF to organize and execute training workshops to promote safe detection and removal of lionfish. Workshops target dive operators, lionfish derby participants, NGOs, and state and federal agency field staff. Outreach materials on threats to human health are distributed to the public through print, web, and social media outlets. In 2013, the first three REEF lionfish handling

workshops were held in Texas to educate and train the public. Handling workshops will also be held before each lionfish derby event. Other partners that could be engaged for similar workshops include Sea Grant, NOAA Fisheries, and regional aquaria.



Figure 22. Lionfish handling workshop hosted by REEF at the FGBNMS Office in Galveston , TX. Photo: FGBNMS/Drinnen.

3. Increase public awareness through outreach and information on the damaging ecological impacts of lionfish. This will promote awareness, detection, and central reporting of lionfish in the FGBNMS. It includes participation in events and evaluation of participants as well as distribution of stickers, flyers, fact sheets, and other outreach materials to dive shops, aquariums, state and federal agencies, and schools (Appendix A and B).

Status: Implemented 2012/ ongoing

Implementation: FGBNMS staff has given lionfish presentations to local schools, dive clubs, NGOs, and restaurants in Galveston and Houston. Staff have also partnered with the Moody Gardens Aquarium, Texas State Aquarium, and Brownsville Aquarium to create lionfish displays. Social media networks, including Facebook and Twitter, are also utilized to distribute information. Live lionfish are used for education and outreach purposes at the FGBNMS office and when visiting school groups and at public outreach events. FGBNMS sighting forms are made available to the dive community for reporting purposes.

Chapter 5. Gray's Reef National Marine Sanctuary

5.1 Status of the Invasion

Located 17.5 nautical miles offshore of Sapelo Island, Georgia, and 40 miles south of Savannah, Georgia (the second busiest port on the eastern seaboard), Gray's Reef National Marine Sanctuary (GRNMS) encompasses 22 square nautical miles. Gray's Reef offers some of the best recreational fishing and diving to be found in the Southeast Atlantic region.

Lionfish were first observed within GRNMS in 2007, but were not sighted again until 2012 when 28 lionfish were observed by staff, scientific, and volunteer divers. In 2013, only 15 were observed, however, time offshore to conduct research was limited. As of mid-2014, two 3-cm lionfish were seen during June. To date, small numbers of lionfish have been observed within sanctuary boundaries, and the fish are not thought to overwinter due to low temperatures. It may be significant, however, that higher densities of lionfish are seen on deeper reefs offshore of GRNMS.

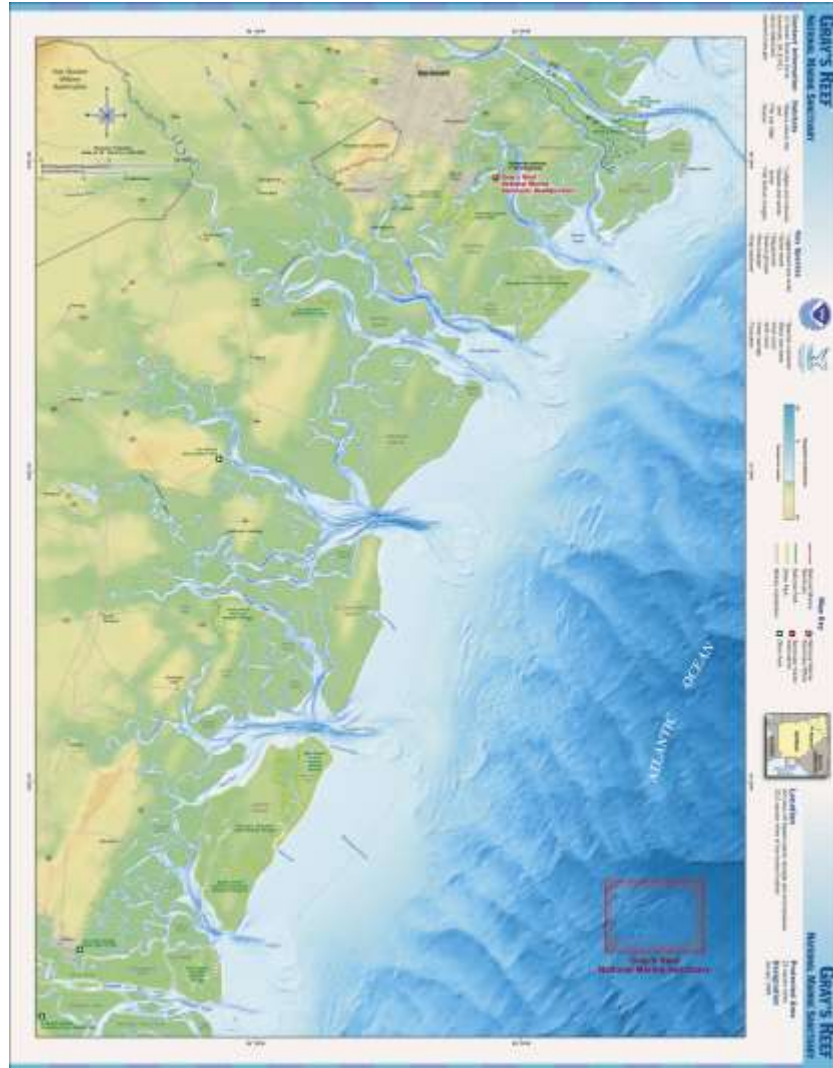


Figure 23. Bathymetric map of the Gray's Reef National Marine Sanctuary. Map: NOAA/ONMS.

5.2 Resources at Risk

Gray's Reef National Marine Sanctuary protects particularly dense patches of productive hard bottom habitat. Comparable habitats are sparsely distributed from Cape Hatteras,

NC, to Cape Canaveral, FL, on the inner- and mid-shelf of the South Atlantic Bight. Influenced by complex ocean currents, this area serves as a crossroads for both temperate and sub-tropical species.

Algae and invertebrates grow on the exposed rock surfaces and ledges of Gray's Reef. The dominant invertebrates include sponges, bivalves, barnacles, fan corals and other soft corals, hard coral, sea stars, crabs, lobsters, snails, and shrimps. The reef hosts numerous species of fish including black sea bass, snappers, groupers, and mackerels. Since Gray's Reef lies in a transition area between temperate and tropical waters, fish population composition changes seasonally. Loggerhead sea turtles use Gray's Reef year-round for foraging and the reef is part of the only known winter calving ground for the highly endangered North Atlantic right whale (Office of National Marine Sanctuaries 2008 b).



Figure 24. Black sea bass at Gray's Reef National Marine Sanctuary. Photo: NOAA/GRNMS.

5.3 Sanctuary Response Actions

Since lionfish were first observed in the Gray's Reef National Marine Sanctuary in 2007, several actions have taken place, and projects adapted, to manage this invasive species. To date, the primary responses, projects, and areas of focus on the lionfish invasion involving control, research, monitoring, and education and outreach at the GRNMS are listed below (Table 4).

Table 4. Priority activities currently conducted by staff and partners at the Gray’s Reef National Marine Sanctuary.

Category	Focus Area/Project	Brief Description
Monitoring	Research Area Monitoring	Lionfish abundance and size collected on ledge habitat along 50 meter transects.
	Opportunistic Lionfish Surveys	Abundance and size of lionfish observed during dive operations conducted for various purposes.
	Invertebrate Disturbance Monitoring	Lionfish observed during this project are noted and removed when possible
	Acoustic Monitoring	Lionfish observed during this project are noted and removed when possible.
Control	Targeted removals	Staff and trained volunteers remove lionfish when encountered.
Research	Habitat utilization	Collect data on size, distribution and habitats where lionfish are observed.
	Lionfish genetics	Collect tissue samples from lionfish for USGS genetics research.
	Lionfish tissue repository	Contribute lionfish from GRNMS to the NOAA NCCOS Lionfish Tissue Repository.
Education & Outreach	Outreach Materials	Siting report form on web site.
	Lionfish messaging	Provide information on lionfish in presentations and at special events.

In addition to the primary responses in place, there are additional activities and research needs that would benefit the sanctuary. Monitoring, control, research, and education and outreach activities that are in place, or could be coordinated to help respond to the lionfish invasion, are further described in detail below.

I. Monitoring

Purpose: Collect information to monitor lionfish population trends in GRNMS and the impacts of control programs in order to assess and adjust actions using adaptive management principles.

Several key questions facing resource managers at Gray’s Reef can be addressed through monitoring:

- How is the lionfish population changing over time in the sanctuary?
- To what extent do seasonal changes in oceanographic conditions control lionfish populations at Gray’s Reef?
- What source populations supply recruits to Gray’s Reef?
- At what point is removal of lionfish needed at Gray’s Reef to limit impacts to native populations?
- How much effort is required to control lionfish in the GRNMS, and is this effort sustainable?

Currently, there are three primary monitoring efforts at GRNMS that are being adapted to include monitoring for lionfish:

1. Research Area Monitoring. Under a new regulation that went into effect December 4th, 2011, the southern third of GRNMS is now a research area where scientists are able to study the impact of human activities on the sanctuary's marine resources. Fishing and diving are prohibited in the research area. Vessels are allowed to pass through the research area, but only without stopping. Monitoring is currently being conducted to investigate differences in the benthic and fish communities inside and outside the research area.

Status: Initiated 2011/ Ongoing annually

Implementation: Benthic and fish monitoring using a stratified random sampling design began in 2011. Forty repetitive sites are visited annually. Lionfish abundance and size are documented in the surveys, along with associated habitat type and depth.

2. Invertebrate Disturbance Monitoring. GRNMS staff partners with Georgia Southern University to monitor cleared plots of substrate for recruitment and colonization and succession of invertebrates to determine how long it will take recruits to re-establish on damaged areas of substrate.

Status: Initiated 2013/ Ongoing bi-monthly

Implementation: Plot photographs taken by scientific divers document change over time. Lionfish observed are documented in the surveys, along with associated habitat type and depth in benthic surveys. The data help track temporal/seasonal changes in lionfish abundance and distribution.

3. Acoustic Monitoring. Several commercially and recreationally important snapper and grouper species are found in GRNMS. Scientists have some information on the habitat preferences of these fish; however they have little information on their movement patterns. Therefore, fish are acoustically monitored to determine how long managed fish species (red snapper, gag grouper, scamp grouper, and black sea bass) reside in the sanctuary.

Status: Initiated 2008 / Ongoing annually (data downloaded quarterly)

Implementation: Fish are surgically implanted with acoustic tags that emit a unique signal. Acoustic receivers placed around the sanctuary to listen for these tags. When a fish is detected, the receiver records the date and time that the fish was in the vicinity of



Figure 25. Acoustic tag insertion in the underbelly of a Scamp at GRNMS. Photo: NOAA/Park.

the receiver. The tags last for several years. Acoustic receivers are recovered by divers and data is downloaded and analyzed. Lionfish observed during divers field visits are documented, along with associated habitat type and depth, to help determine seasonal variation at GRNMS.

II. Control

Purpose: Ensure that populations in priority locations remain below levels that could alter ecosystem integrity (based on prior studies and surveys of potentially affected species). Control measures at Gray's Reef may vary through time, as recruitment and abundance are likely to be highly variable. Measurable impacts to native species would also be expected to vary. And because cold temperatures may limit lionfish densities in the winter, lionfish may only be a seasonal concern. Nevertheless, levels of impact could be high in some years, so controls measures may at times be appropriate.

1. Conduct opportunistic removals using GRNMS staff and permitted volunteer divers. Proper collection and handling practices will facilitate removal of lionfish from sanctuary waters.

Status: Initiated 2012/ Ongoing

Implementation: Select individuals (staff, volunteers, researchers) are trained to respond and safely remove lionfish, as well as gather important ecological and biological data through dissections, tissue sampling, and archival of specimens. Because lionfish densities are currently low at Gray's Reef, only opportunistic removals are conducted both inside and on structures in waters adjacent to the sanctuary (e.g. Navy towers). GRNMS will monitor the situation closely as the invasion progresses, and adapt management as needed. Furthermore, GRNMS staff is working alongside FKNMS and FGBNMS, and with partners such as REEF, in formulating plans for detection, reporting, and monitoring.



**Figure 26. Juvenile lionfish removed from GRNMS in 2015.
Photo: GRNMS/Fangman.**

III. Research

Purpose: Use research activities to better understand factors influencing lionfish population control in GRNMS. Though some research has begun in the GRNMS, there are topics that still need to be investigated. High priority research areas include:

1. Determine the seasonal variability of lionfish occurrences in GRNMS

Status: Initiated 2013

Implementation: GRNMS staff is currently investigating factors affecting lionfish seasonality in the sanctuary, as temperature tolerance appears to control population densities. GRNMS is currently monitoring water temperatures, and correlating these with lionfish observations made in the monitoring studies.

2. Contribute to the NOAA NCCOS Lionfish Tissue Repository

Status: Initiated 2012 / Ongoing

Implementation: Lionfish removed from GRNMS are sent to the NOAA NCCOS Lionfish Tissue Repository in Beaufort, NC for studies on age, growth, and stable isotope analysis. Morphometric/meristic data are recorded for each lionfish, tissues and fins clips are sampled, and gut contents are analyzed to determine diet habits and assess consumption impacts at Gray's Reef.

3. Contribute to USGS Genetics Investigation

Status: Initiated 2014 / Ongoing

Implementation: Tissue samples from lionfish removed from GRNMS are collected and sent to researchers at the USGS in Gainesville, FL for genetics investigations into population connectivity.

IV. Education and Outreach

Purpose: Conduct outreach and education about lionfish and GRNMS to stakeholders and the general public. Gray's Reef staff use lionfish as a tool to teach constituents about invasive species. They also use them to address other topics such as hard bottom ecology and marine conservation generally.

1. Renew partnership with the REEF to educate the public about lionfish and assist with scientific investigations related to invasive marine species.

Status: Implemented 2013/ Not currently active

Implementation: REEF worked with GRNMS and partners throughout the region to help develop lionfish response plans, train resource managers and dive operators in effective collecting and handling techniques, and conduct cutting edge research to help address the invasion.

2. Increase public awareness and distribute outreach information on the damaging ecological impacts of lionfish. This includes creating web content, distribution of

stickers, flyers, fact sheets, and other outreach materials to dive shops, aquariums, state and federal agencies, and schools (Appendix A and B).

Status: Implemented 2012/ Ongoing

Implementation: GRNMS staff has given lionfish presentations to local schools, dive clubs, and NGOs. GRNMS staff have also partnered with the Georgia Aquarium and University of Georgia’s Marine Extension Service Aquarium to create GRNMS displays and raise lionfish awareness. Social media networks, including Facebook and Twitter, are also utilized to distribute information. Lionfish information is distributed at public outreach events, such as the Savannah Ocean Film Festival.



Figure 27. The Ocean Film Festival is held annually in Savannah, GA.
Photo: NOAA/GRNMS.

3. Promote “Eat Lionfish” campaigns.

Status: Implemented 2002/ Ongoing

Implementation: While many native fish species are under immense fishing pressure and in need of protection, lionfish are a delicious and environmentally conscious seafood choice. REEF recently released *The Lionfish Cookbook*, co-authored by Trish Ferguson and Lad Akins, providing not only recipes, but information on the invasion and proper handling and preparation techniques. “Eat Lionfish” information is distributed to local Savannah restaurants and at public outreach events.

Chapter 6. Recommendations

6.1 The Path Forward

While NOAA's national marine sanctuaries in the Southeast Region have already implemented some activities described in this plan, the remaining response actions still need to be implemented to promote long-term protection. Recommended actions in this plan serve as a guide to address key national marine sanctuary priorities for management including monitoring, control, research, and education and outreach (see Table 1). Each national marine sanctuary will address increases in lionfish populations by assessing their distribution through monitoring and safely removing them in targeted priority areas through control programs. This requires both immediate action and resources at national marine sanctuary sites, but also regional and national coordination and support. Each sanctuary will identify specific needs, resources, partnerships, and management strategies that best prepare it for action. The plan should be evaluated and updated on a regular basis to include further actions as the lionfish invasion progresses and needs change at individual national marine sanctuary sites.

6.2 Resources

With limited budgets and competing priorities facing national marine sanctuaries, a response plan clearly identifying needs will help site managers identify staff members with the skills needed to carry out new and different roles. Below are leadership roles we believe are needed to help execute lionfish actions within NOAA's Office of National Marine Sanctuaries. It should be recognized, however, that people may assume multiple roles depending on available staff and resources.

- Site Coordinator - Responsible for leading all activities arising in the course of monitoring, control, research, and outreach and education at a sanctuary site. This person must keep pace with current research and outreach within the area, apply for funding, and build partnerships with the local community to increase lionfish awareness and volunteer participation, if appropriate.
- Regional Coordinator - Responsible for staying informed of lionfish activities at the national and regional levels, and within all three affected national marine sanctuaries (Florida Keys, Gray's Reef, and Flower Garden Banks). When appropriate, this person will need to coordinate efforts with staff and partners at the sites, including, for example, attending meetings and facilitating partner collaboration. This person is also responsible for updating the response plan as new needs arise.
- National Coordinator - Responsible for working closely with the regional coordinator to stay abreast of lionfish activities within national marine sanctuaries. The National Coordinator is also responsible for raising awareness about lionfish impacts on national marine sanctuary resources at the national level, and helping establish partnerships with other federal agencies, non-

governmental organizations, foundations, and universities to support monitoring, control, research, and education and outreach activities at individual sites.

Together, the coordinators will regularly inform program leadership on progress of the lionfish invasion, the latest understanding of impacts, and the status of response activities described in this plan, and recommend resource allocations (staff, funds, and time) required for future response.

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Appendix A. NOAA NCCOS Invasive Lionfish Factsheet

Biology

- Lionfish may live decades and reach sizes up to 47cm (19 inches).
- Lionfish inhabit all marine habitat types and depths (shoreline to over 1000’).
- Lionfish possess venomous spines capable of deterring predators and inflicting serious stings and reactions in humans.
- Lionfish temperature tolerance is approximately ~10 – 35C.
- Lionfish become sexually mature in less than one year and spawn in pairs.
- A single female lionfish spawns over ~2 million eggs/year.
- Lionfish eggs are held together in a gelatinous mass and are dispersed by currents.
- Lionfish larval duration is ~25 days.

Ecology

- Lionfish can reach densities higher than 200 adults per acre.
- Lionfish are generalist carnivores that consume >70 species of fish and many invertebrate species, with prey exceeding half the lionfish’s body size.
- Many lionfish prey are commercially, recreationally, and ecologically important.
- Native predators have been observed to exhibit avoidance for lionfish.
- Lionfish have very few parasites compared to native species.
- Lionfish exhibit site fidelity.
- Lionfish have high affinity for structure and feed primarily during dawn and dusk time periods.

Invasion history

- Lionfish was first documented as established off the coast of North Carolina in 2000.
- Two visually identical species (*Pterois miles* and *P. volitans*) of lionfish were introduced into the Atlantic via the U.S. aquarium trade beginning in the 1980’s.
- Lionfish are widespread throughout the Southeast U.S., Caribbean, and are presently invading the Gulf of Mexico.
- Lionfish are expected to invade South America as far south as the northern coast of Argentina.
- Lionfish have established throughout most of the Caribbean in less than five years.

Ecological impacts

- Impacts to biodiversity and resilience of coral, hardbottom, and artificial reefs.
- Potential reduction of ecologically important species such as cleaners, herbivores, and forage fishes.
- Interactions with other reef stressors could exacerbate lionfish impacts (e.g., ocean acidification, fishing impacts, etc.)
- Cascading impacts across food webs is possible (e.g., predation on herbivores, increased macroalgae, decreased coral biomass).
- Potential impacts to species of concern (Nassau grouper, Warsaw grouper, speckled hind, striped croaker, key silverside).

- Scale of ecological impacts is high in magnitude and geographically broad (North Carolina to the Caribbean and the Gulf of Mexico).

Socioeconomic impacts

- Potential impacts to stock rebuilding efforts for commercially important species.
- Economic losses for commercial fishermen include loss of fishing days when envenomation occurs and reduction of native species catch rates.
- Potential economic loss in the trade of native marine ornamental species.

Human health impacts

- Lionfish sting symptoms include tachycardia, hypertension, hypotension, seizures, chest pain, abdominal pain, swelling, pain, and subdermal necrosis at the sting site, and temporary paralysis to all extremities.
- Long term health impacts of repeated envenomations are unknown.
- Divers, fishermen, and swimmers are at increased risk of envenomation at locations where lionfish have reached high densities.
- Envenomation risk to bathers/swimmers increases at locations with structure such as piers, breakwaters, and confined tidal swimming pools.
- Lionfish, similar to native reef fish, may cause ciguatera fish poisoning in some locations.

Control

- Control plans that support sustained removals can significantly reduce local lionfish densities.
- Tools for local lionfish control include commercial harvesting as a food fish, harvesting juveniles for the aquarium trade, sport tournaments, and adopt-a-reef and other citizen-based removal efforts.
- Based on current technology, lionfish eradication at the regional scale is likely not feasible given the expansive depths and geography of lionfish habitat.

Appendix B. National Invasive Lionfish Prevention and Management Plan Key Messages

In order to capture and retain public attention, it is important for resource managers to distill and refine the considerable knowledge about lionfish into a subset of key messages. Concise messages should be designed to elicit the changes in perception and behavior necessary to support program goals, and it is important that messaging by all sites and partners is consistent within education and outreach activities.

Further, key messages necessarily vary by audience and may change over time in response to various control strategies and new understanding. Effective programs should periodically re-evaluate and update these messages. The following are key components from the National Invasive Lionfish Prevention and Management Plan (2015) for communication pertaining to the lionfish invasion:

Impacts from Invasion

- Lionfish are an invasive species and are detrimental to native systems. They are not native to western Atlantic waters and are capable of causing negative impacts to native marine life, ecosystems, economies, and human health.
- Invasion progresses rapidly. Even though initial sightings of lionfish in a new area can be sporadic over time and space, the invasion progresses rapidly. Most countries have experienced invasion progression from the first sighting to multiple lionfish occurring on most sites in less than two to three years.
- Impacts from lionfish may be severe. Recent research indicates that lionfish impacts can be severe and affect broad spectrums of the environment, including economically important species like juvenile grouper and snapper and ecologically important species like grazers and cleaners (e.g., parrotfish, cleaner shrimp and fish).

Pathways

- Aquarium releases are a source of the invasion. Genetic research and monitoring of lionfish distribution suggest that the source of introduction is likely to have been multiple releases of aquarium specimens off the coast of southeast Florida.
- Eggs and larvae are transported via ocean currents. Lionfish are distributed to new areas in this way.

Control Measures

- Natural predation is not controlling the invasion. While some incidental predation or conditioned feeding on captured lionfish occurs, it appears that these are not controlling predators of lionfish in this region.
- Community involvement is necessary. To effectively address the lionfish invasion, we must develop wide-scale support and the involvement of the local communities.

- We can make a difference: Local control can be effective. Local control efforts, including adopt-a-reef type programs and the development of food-fish markets are showing success. Areas that promote and conduct regular removals are showing fewer lionfish than non-removal areas, though removals will need to be long-term in nature due to recruitment of lionfish from upstream populations (see eggs and larvae message above).
- Eradication is not likely. Under current technologies and considering the spatial extent and severity of the invasion, eradication is not a likely outcome. Honest dialogue regarding this issue is important in developing accurate and achievable outcomes and subsequent strategies. Additionally, statements regarding the possible eradication or prevention of lionfish establishment will set up a situation of distrust and damage credibility as these goals are unmet.

Human Safety Concerns

- Lionfish are edible. In their native range, lionfish are considered a delicacy and are consumed regularly. Human health concerns associated with eating reef fish include ciguatera poisoning and mercury intake. Some lionfish have been found to carry the ciguatera toxin in known hotspot locations, though the spatial extent of the toxin is not well understood. Managers should implement the same caution for lionfish as they do for other reef fish.
- Venom (typically injected to cause harm) does NOT equal poison (typically ingested to cause harm). Lionfish possess venomous dorsal, anal, and pelvic spines for defense. The meat of lionfish does not contain poison.