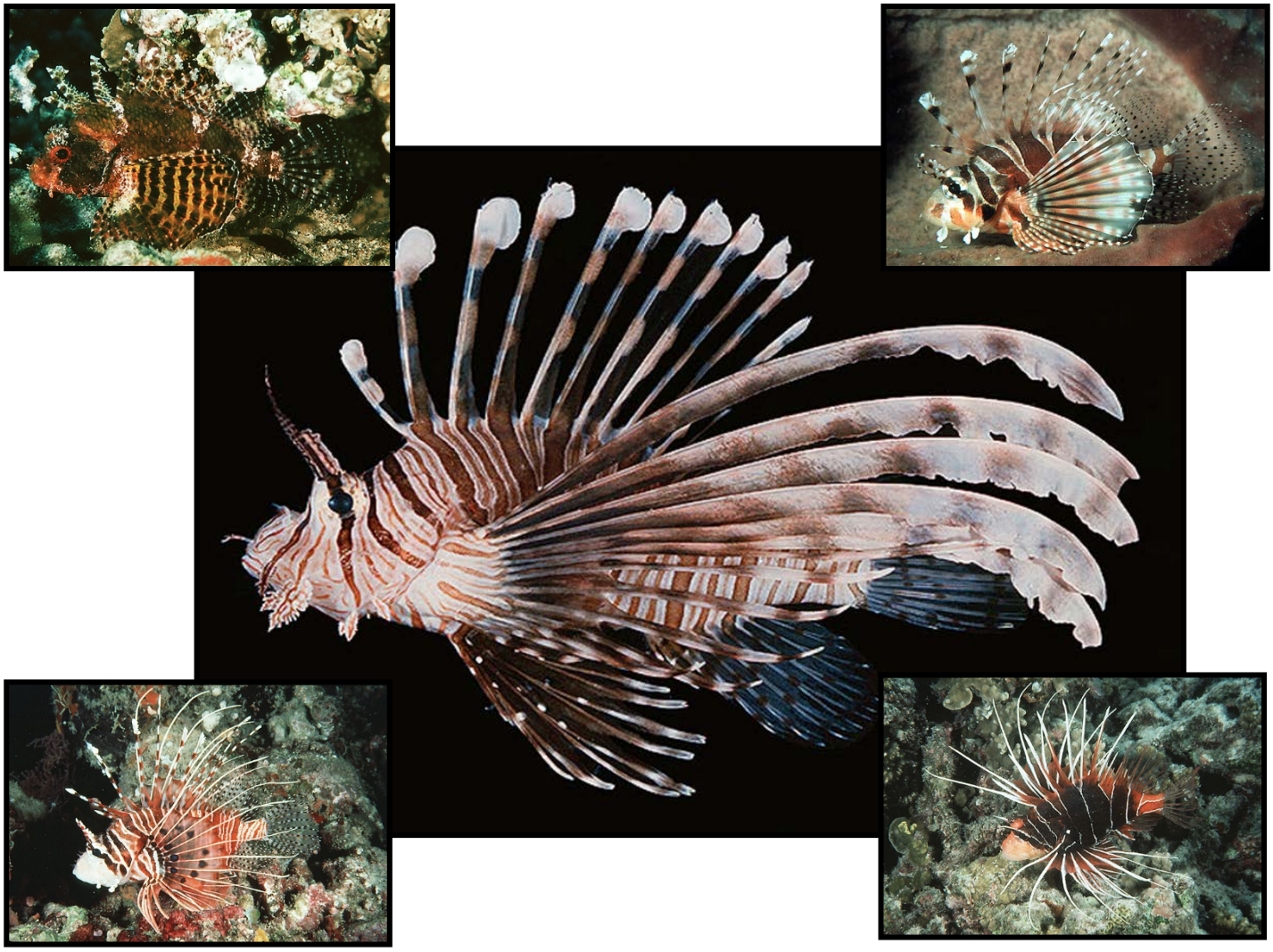
4/1/2015

National Invasive Lionfish Prevention and Management Plan



PREPARED BY:

INVASIVE LIONFISH CONTROL AD-HOC COMMITTEE OF THE AQUATIC NUISANCE SPECIES TASK FORCE

ABBREVIATIONS LIST

ANS – Aquatic Nuisance Species

ANSTF – Aquatic Nuisance Species Task Force

DOC – Department of Commerce

DOI – Department of the Interior

EDRR – Early Detection and Rapid Response

E&O – Education and Outreach

FGBNMS – Flower Garden Banks National Marine Sanctuary

FKNMS – Florida Keys National Marine Sanctuary

FWC – Florida Fish and Wildlife Conservation Commission

GSARP – Gulf and South Atlantic Regional Panel

GSMFC – Gulf States Marine Fisheries Commission

HACCP – Hazard Analysis and Critical Control Point

ICRI – International Coral Reef Initiative

ICS – Incident Command System

IPM – Integrated Pest Management

NANPCA – Nonindigenous Aquatic Nuisance Prevention and Control Act

NAS – Non-Native Aquatic Species

NGOs – Non-Governmental Organization

NISA – National Invasive Species Act

NISC – National Invasive Species Council

NMFS – National Marine Fisheries Service

NOAA – National Oceanic and Atmospheric Administration

NPS – National Park Service

Plan – National Invasive Lionfish Prevention and Management Plan

REEF – Reef Environmental Education Foundation

TNC – The Nature Conservancy

USFWS – U.S. Fish and Wildlife Service

USGS – U.S. Geological Survey

Cover images clockwise from upper left: *Dendrochirus brachypterus*, *Pterois volitans (center)*, *Dendrochirus zebra, Pterois radiate*, *Pterois antennata* photos by J.E. Randall (Fishbase 2014).

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EXECUTIVE SUMMARY

Two lionfish species (*Pterois volitans* and *Pterois miles*) represent the first non-native marine finfish to become established in Atlantic waters of the United States, including the Gulf of Mexico and Caribbean. During the course of their nearly three decade invasion, lionfish have demonstrated how challenging a marine invasive can be to control once it becomes established. Since the first sighting off the Atlantic coast of the United States in 1985, lionfish have shown great ability to adapt to a wide variety of habitats across a vast spatial range. Lionfish are currently established along the Atlantic coast, throughout the Caribbean, and most recently in the Gulf of Mexico from near-shore out to depths of 300+ meters. Because they are the first known marine finfish to successfully invade these waters, there is a large amount of uncertainty as to the impacts lionfish will have on invaded environments. Compounding this problem is the lack of information on lionfish from their native range, including what factors keep populations from reaching nuisance levels within their native range. Preliminary findings from the invaded range show that lionfish can reach high densities, and have become one of the most abundant species on some Caribbean reefs (Green and Côté 2009; Morris and Whitfield 2009; Whitfield et al. 2007). Lionfish are proficient opportunistic predators, consuming a wide variety of prey which has led to drastic declines in the abundance and richness of native species in some areas. Both species have biological advantages over native species that protect lionfish from predation throughout their life cycle.

The specific vector that led to this invasion may never be identified; however, one possibility is intentional releases by aquaria owners. Lionfish (numerous species within the genera *Pterois*, *Parapterois,* and *Dendrochirus*) are popular aquarium fish and are imported into the U.S. on a daily basis through the pet trade. Other possible vectors include unintentional releases from large public aquaria and larval releases from the ballast water of ships. No matter what the exact vector of introduction was, it is certain that the lionfish invasion is the product of human activities, not natural processes.

Given the widespread range of the lionfish invasion, eradication of either species will likely be extremely difficult and costly, if not pragmatically impossible. However, it is critical to learn as much as possible from this invasion to determine the best ways to control and manage lionfish numbers to reduce ecological and socioeconomic impacts, as well as harm to human health. By researching the invasion ecology of lionfish, we can gain a better understanding of the highest risk vectors for marine finfish introductions, the potential impacts, and possible ways to control and manage a marine invasive finfish. In addition to the benefits of managing existing lionfish populations, this information will serve as preparation to prevent future introductions, and rapidly respond to new sightings of non-native marine species before they have a chance to become established and reach the scale of the lionfish invasion. This plan was developed by the Invasive Lionfish Control Ad-Hoc Committee of the Aquatic Nuisance Species Task Force to address the above issues.

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1.0 VISION, GOALS, AND OBJECTIVES

The vision of the National Invasive Lionfish Prevention and Management Plan (Plan) 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. For the purposes of this plan, all species in the genera *Pterois*, *Parapterois*, and *Dendrochirus* are collectively referred to as lionfish. Specifically, the Plan implementation would provide federal agencies and other stakeholders an opportunity to contribute through relevant programs and authorities to:

1) Prevent the further introduction of additional invasive lionfish.
2) Conduct risk assessments and research on high priority pathways and high risk marine invasive species.
3) Promote public education and awareness on invasive lionfish.
4) Participate in the development of early detection and rapid response frameworks and plans for marine environments.
5) Monitor invasive lionfish populations accurately and reliably.
6) Coordinate and control populations of invasive lionfish in a cost-effective and environmentally sound manner.
7) Provide the mechanisms and venues for coordinated and collaborative research and management.
8) Expand research efforts that focus on the biology, ecology, impact, and control of the species.
9) Provide the guidance to restore native species and habitat conditions in ecosystems that have been invaded.

To achieve this vision, the Plan is structured by integrated management approaches that set forth the following Goals and Objectives (detailed strategies to achieve these Goals and Objectives are outlined in Chapter 4.0 of this plan):

<u>Goal 1: Prevent the Spread of Invasive Lionfish</u>

Objective 1.A) 100% prevention of new populations in high-priority sites. A high-priority site may be defined as an area with elevated ecological value, economic value, and/or human health aspects (e.g. nursery grounds, marine protected areas, sanctuaries, etc.). The designation of high-priority sites may vary by state and/or region, and will be determined by the lead agency/organization conducting the management activities.

Objective 1.B) Determine the risk of invasiveness for lionfish species in trade.

Objective 1.C) Examine importation and pet trade practices and regulations.

Objective 1.D) Increase awareness through education and outreach activities.

Objective 1.E) Identify management areas that should remain free from lionfish that include careful consideration of the site selection, purpose, and management operations.

Objective 1.F) Develop monitoring strategies to evaluate and improve prevention objectives.

Goal 2: Coordinated Early Detection and Rapid Response

Objective 2.A) Develop and implement EDRR programs.
Objective 2.B) Develop tools to improve EDRR for lionfish.
Objective 2.C) Develop monitoring strategies to evaluate and improve each EDRR objective.

Goal 3: Control and Management of Invasive Lionfish

Objective 3.A) Develop tools for localized control and management.
Objective 3.B) Reduce lionfish population densities at high-priority sites.
Objective 3.C) Research and improve fisheries management tools for the control of invasive lionfish.
Objective 3.D) Develop and implement ecologically-relevant indices to determine reef health.
Objective 3.E) Develop species-specific tools for large-scale invasive lionfish eradication.
Objective 3.F) Identify and address current regulatory hurdles and tools.
Objective 3.G) Incorporate climate change scenarios into lionfish predictive models.
Objective 3.H) Build new, and expand existing partnerships between federal and state agencies, tribes, private sector, and other stakeholders.
Objective 3.I) Develop monitoring strategies to evaluate and improve each control and management objective.

Goal 4: Assess Impacts of the Lionfish Invasion

Objective 4.A) Develop a better understanding of the impacts of the lionfish invasion on native species and habitats.
Objective 4.B) Assess impacts to human health, safety, quality of life, and communities.
Objective 4.C) Protect commercially and recreationally-important fishery stocks from harm related to the lionfish invasion.
Objective 4.D) Protect species of concern from both direct and indirect effects of invasive lionfish.

The implementation of this Plan will fall to the ANSTF and the agencies that make up its membership. To oversee the implementation, the ANSTF should establish an Invasive Lionfish Work Group made up of representatives from federal/state agencies, NGOs, universities and other stakeholder groups with expertise in the management of invasive lionfish. This Work Group should monitor and evaluate the activities carried out through the implementation of the Plan, and report back to the Task Force on ways to modify or improve the objectives and strategies outlined in the Plan. It would also be the responsibility of the Work Group to update the Prevention and Management Plan with the most recent information about invasive lionfish as it becomes available. This will insure that the activities carried out under this Plan are always using the best available science, and are resulting in the best use of resources.

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2.0 BACKGROUND AND OVERVIEW

2.1 INTRODUCTION

Two lionfish species (*Pterois volitans* and *Pterois miles*) have been introduced and are now invasive along the Atlantic coast, throughout the Caribbean and most recently in the Gulf of Mexico. Native to the waters of the Indo-Pacific region, the lionfish was first documented in the waters of the United States in 1985. In response to the increasing range and density of these invasive species, the Gulf and South Atlantic Regional Panel (GSARP) of the Aquatic Nuisance Species Task Force (ANSTF) provided a recommendation to the ANSTF in May 2011. GSARP proposed that invasive lionfish are a nuisance and have the potential to impact ecology, economy, and human health, and recommended that the ANSTF convene a group to review lionfish information and determine if there is need for a National Control Plan. The ANSTF accepted this recommendation and requested that GSARP convene the Invasive Lionfish Control Ad-hoc Committee (Committee). The purpose of the Committee was to scope the issues related to prevention, control, and management of invasive lionfish for the ANSTF.

The ANSTF is an intergovernmental entity established under the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (Act, 16 U.S.C. 4701-4741), as amended by the National Invasive Species Act of 1996 (NISA) and is co-chaired by the United States Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration (NOAA). The ANSTF is responsible for coordination of national efforts to prevent the introduction and spread of aquatic invasive species. These responsibilities include the development of management plans for specific high-risk invasive species.

The Committee has representatives from the USFWS, Gulf States Marine Fisheries Commission (GSMFC), NOAA, National Park Service (NPS), Reef Environmental Education Foundation (REEF), and United States Geological Survey (USGS) and was responsible for reporting recommendations for consideration by the ANSTF. The Committee compiled and synthesized relevant literature, and provided an assessment on the current state of knowledge of invasive lionfish. The culmination of these efforts was a recommendation to the ANSTF for a National Invasive Lionfish Prevention and Management Plan (Plan) which would serve as a guide to the ANSTF and other interested parties involved in management of lionfish and natural resources in U.S. waters.

The Committee's recommendation for a Plan was accepted at the November 2011 ANSTF meeting. The ANSTF recommended that the Committee 1) expand its current roster and 2) provide a Plan for ANSTF approval.

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2.2 LIONFISH BIOLOGY

Two species of lionfish, *Pterois miles* (Bennett, 1828) and *P. volitans* (Linnaeus, 1758), have been documented in the Western Atlantic Ocean (Schofield 2009). Lionfish are part of the scorpionfish family (Scorpaenidae) with aposematic coloration consisting of dark and white alternating vertical bands. They have a venom defense made up of 13 dorsal, 2 pelvic, and 3 anal fin spines (Schofield et al. 2014). While lionfish appear to prefer coral and hard bottom reef habitats, they are commonly found around artificial structures, mangroves, sea grass, and most other marine habitat types (Morris and Akins 2009). They release buoyant eggs that are encased in gelatinous material (Morris et al. 2011). The larvae of lionfish are dispersed by ocean currents for approximately 26 days after which the larvae settle to the benthos (Ahrenholz and Morris 2010). Recent research has demonstrated that the diet of lionfish consists of a wide variety of fish and crustaceans, including several ecologically and economically-important species (Morris and Akins 2009). Lionfish are capable of reaching sizes up to 476 mm total length, and can live for decades (Morris unpublished data; Potts et al. 2011).

2.3 LIFE HISTORY

The seasonality of lionfish reproduction throughout their native range is unknown. Collections off North Carolina and in the Bahamas suggest that lionfish reproduce in all seasons of the year, approximately every 3–4 days (Morris 2009). Lionfish are gonochoristic (separate genders from birth), though males and females exhibit minor sexual dimorphism. Lionfish females become sexually mature at approximately 180 mm total length, while males have been found to be mature around 100 mm total length, corresponding to approximately one full year of growth (Morris 2009). The age at senescence is unknown for lionfish, although one individual was held in a public aquarium for over 30 years (Potts et al. 2011).

Courtship has been described for the pygmy lionfish, *Dendrochirus brachypterus* (Fishelson 1975) and zebra turkeyfish, *D. zebra*, (Moyer and Zaiser 1981). Acknowledging the *Dendrochirus* is a closely related genus to *Pterois*, Fishelson (1975) suggested that courtship behaviors for *Pterois* species may be similar to *D. brachypterus*, in that the male and female circle each other, side-wind, follow, and lead one another. This behavior begins shortly before dark and extends well into nighttime hours. Following courtship, the female releases two

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buoyant egg masses that are fertilized by the male. The egg masses exhibit a hollow center that may enhance fertilization success by entrapping sperm (Morris et al. 2011). Following fertilization, the egg masses ascend to the surface. Each egg mass contains approximately 10,000–20,000 eggs, depending on female size (Morris 2009). The eggs and later embryos are bound in adhesive mucus that breaks down within a few days, after which the embryos and larvae become free floating (Morris et al. 2011).

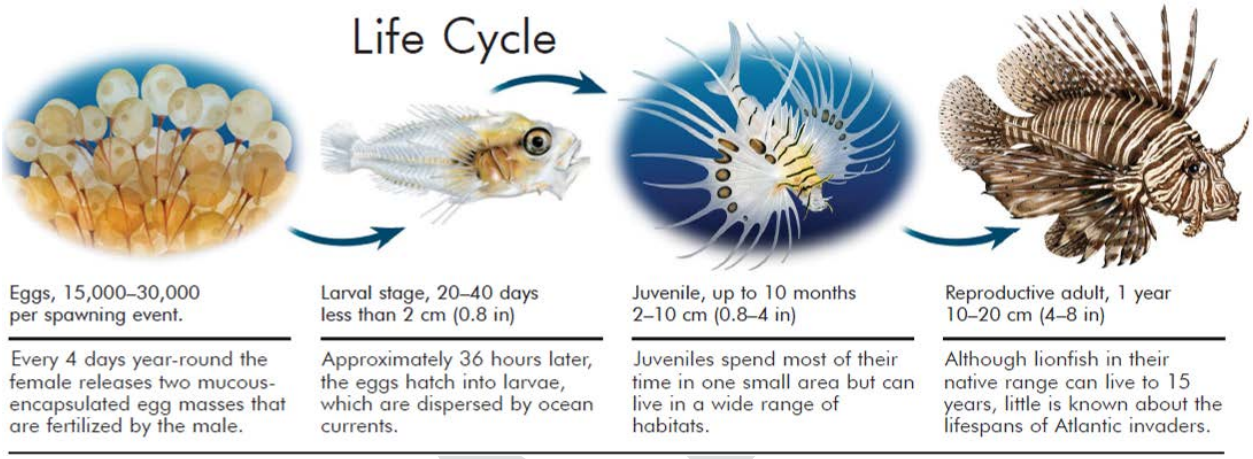

Figure 2.1: Life cycle of the lionfish. Adapted from Poster series No. 7, Loxahatchee River District and The Nature Conservancy.

Moyer and Zaiser (1981) reported that lionfish egg masses may be chemically defended based on observations of avoidance by some egg predators in aquaria. In contrast, a single sergeant major (*Abudefduf saxatilis)*, a common egg predator of the Atlantic, was observed feeding on a lionfish egg mass in the laboratory (Morris, unpublished data).

Lionfish embryos hatch at the surface from a buoyant egg mass. The size of *P. miles* or *P. volitans* larvae at hatching is not documented, but is likely to be approximately 1.5 mm as seen for *P. lunulata* (Mito and Uchida 1958, Mito 1963). Long distance dispersal of lionfish occurs primarily during the pelagic larval phase, during which geostrophic and wind-driven currents transport the larvae. The settlement age of lionfish in the Atlantic is estimated to be between 20–35 days, with a mean of 26.2 days (Ahrenholz and Morris 2010). Lionfish juveniles are found in nearly all marine reef habitats, suggesting that no one habitat serves as a nursery. Lionfish adults exhibit some site fidelity, however, some movement of lionfish among and within habitats has been observed (Akins, Green, Morris, unpublished data).

2.4 SPECIES DESCRIPTION AND HISTORIC RANGE

Pterois volitans and *P. miles* are closely-related species that are very similar in appearance. In fact, the two species were historically treated as the same species (i.e., as synonyms), but are now considered separate species (Schultz 1986). Meristics (e.g., dorsal and anal-fin ray counts) comprise overlapping ranges and are not generally useful to distinguish the two species,

Pterois volitans

Pterois miles

Photographs by John Randall, Bishop Museum (used with permission).

except at the extreme ranges of their native habitat (Hamner et al. 2007). Therefore, the only way to definitively distinguish the two species is through genetic analysis. Genetic techniques have revealed that lionfish in the Atlantic Ocean are primarily *P. volitans* with a small number of *P. miles*, primarily on the Atlantic coast of the U.S.A. and in the Bahamas (Hamner et al. 2007). However, lionfish sampled from the Caribbean Sea are comprised solely of *P. volitans* (Betancur-R. et al. 2011). Both *P. volitans* and *P. miles* have greatly elongated dorsal and pectoral fins and strong vertical banding. The membranes of all fins are often spotted. The body is white or cream colored with red to reddish-brown vertical stripes. The vertical stripes alternate from wide to very thin (with the thin stripes being more numerous), and sometimes merge along the flank to form a V-shape. Overall coloration can be variable, ranging from dark black to deep red.

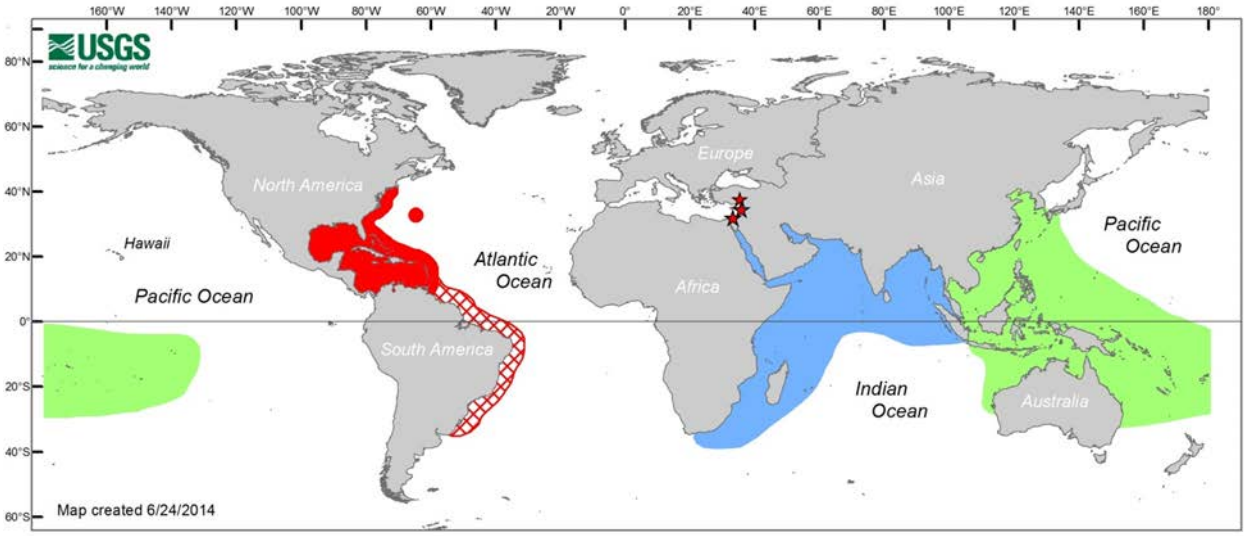

Figure 2.2: Map of native range of *Pterois volitans* (green) and *P. miles* (blue) adapted from Schultz (1986) and Randall (2005). Stars in Mediterranean Sea denote Lessepsian migration of *P. miles* via the Suez Canal (Golani and Sonin 1992; Bariche et al. 2013; Turan et al. 2014). Non-native range of *P. volitans* and *P. miles* in the Americas is shown in red (from Schofield et al. 2014). Predicted future distribution of lionfish along coastal South America is shown in red hatching (Morris and Whitfield 2009).

Native range: *Pterois volitans* is native to most of Oceania (including the Marshall Islands, New Caledonia and Fiji) east to French Polynesia (Randall 2005). *Pterois miles* is from the Indian Ocean and Red Sea, although its range extends to Sumatra (Schultz 1986). Additionally, *P. miles* has been collected in the Eastern Mediterranean Sea (Golani and Sonin 1992; Bariche et al. 2013; Turan et al. 2014) where it is not native, but has gained access via the Suez Canal.

2.5 CURRENT NON-NATIVE RANGE AND EXTRALIMITAL SIGHTINGS

Lionfish are a popular ornamental aquarium fish that have been imported into the U.S.A. in large numbers (Morris and Whitfield 2009). The first confirmed sighting in coastal waters occurred in 1985 off Dania Beach, Florida (Morris and Akins 2009). Although lionfish are the first invasive marine fish to become established in this region, Florida is a known hotspot for marine fish introductions, as nearly 40 species of non-native fishes have been seen in Florida waters in the last two decades (Ruiz-Carus et al. 2006; Schofield et al. 2009; Semmens et al. 2004; Whitfield et al. 2002). The exact cause of the lionfish introduction has not been determined; however, the work of Betancur-R et al. (2011) shows that the invasive population of lionfish in the western Atlantic has a significantly lower genetic diversity than populations from their native range, which is associated with a strong founder effect. These findings suggest that all invasive lionfish share a common geographical origin of introduction, and the invasive population could have been caused by a relatively small number of individuals being released.

Figure 2.3: Lionfish sightings as of 12/4/2014
http://nas.er.usgs.gov/taxgroup/fish/Lionfishanimation.gif

The first record of a *Pterois volitans* larva in the Atlantic was collected in 2010 (Vásquez-Yeomans et al. 2011). Since this first collection, at least 229 additional larval specimens have been collected. Larval fish densities during one survey ranged between 1.3 to 31.8 fish per 1000 m^3, which is comparable to some native reef fishes that inhabit the region; however, a more comprehensive comparison is needed. Dispersal patterns for larval lionfish are unknown, but are urgently needed to improve our understanding of the biophysical dynamics of the early life stages of *P. volitans*, and to identify potential hot spots for recruitment in the Atlantic Ocean.

Lionfish are established along the Atlantic coast of the U.S.A., throughout the Caribbean, and in the Gulf of Mexico (Schofield 2009, 2010; Schofield et al. 2014). Lionfish inhabit marine environments from the shallow estuaries to depths of 300+m within a temperature range of ~10-35°C (Kimball et al. 2004; Cerino 2010; Yeomans et al. 2011). A variety of habitats are used by lionfish, including seagrass beds, coral reefs, artificial (man-made) reefs, and mangrove zones. It is expected that lionfish will continue their southward expansion along the coast of South America until they reach areas where water temperatures fall below their thermal tolerance (Morris and Whitfield 2009). One mechanism helping to fuel the spread of lionfish throughout the region is larval dispersal by ocean currents. Lionfish typically spend about one month drifting in the currents as a larvae (Ahrenholz and Morris 2010). In that time period, they can move great distances. Lionfish are also achieving high population densities, reaching well over 400 lionfish per hectare, and becoming one of the most abundant species on some reefs (Green and Côté 2009; Morris and Whitfield 2009; Whitfield et al. 2007).

Figure 2.4: Potential invaded range of lionfish based on temperature tolerances (Kimball et al. 2004).

3.0 IMPACTS AND REGULATIONS

3.1 ECOLOGICAL IMPACTS

The ecological impacts of lionfish vary greatly in space and time, and are dependent on a number of variables including the population density, habitat type, native species assemblage, composition and abundance of top level predator species, forage fish and invertebrate community structure, and the effects of oceanographic conditions on colonization rates and recruitment dynamics.

Lionfish are generalist carnivores that feed on a wide variety of fishes and crustaceans up to half their own body size (Morris and Akins 2009). Lionfish are crepuscular predators (primarily feed during dawn and dusk) with prey capture success rates of 85%, while consuming between 7-10% of their own body weight/day (Green et al. 2011). The first evidence for the impacts of predation by invasive lionfish was provided by Albins and Hixon (2008), who reported a 79% reduction in forage fish recruitment on experimental patch reefs in the Bahamas. Data were collected over a five-week period when a single small lionfish was present. In addition to reductions in forage fish, there is evidence that broader habitat changes may occur as a result of lionfish predation. For example, Lesser and Slattery (2011) state that phase shifts to an algal-dominated coral community at mesophotic depths in the Bahamas may be the result of consumption of herbivores by lionfish. This cascading effect has produced severe ecological effects to fish communities within this habitat.

The lionfish invasion challenges the resilience of native ecosystems, as it can profoundly impact biodiversity, as well as community composition and function. The level of resiliency of invaded ecosystems is not known; however, resilience is expected to vary by location in relation to the composition of the biotic community and physical oceanographic features. When considering the resiliency of various habitats, it is necessary to also consider external impacts that may exacerbate the potential negative effects. For example, it is expected that the degraded condition of marine ecosystems from overfishing, pollution, and climate change will intensify the effects of this invasive species, and provide additional opportunities for their long-term success. Lionfish may be filling a vacant niche in the reef community that was vacated by overfishing of top level predators such as snapper and grouper (Morris and Whitfield 2009). If so, this not only provides increased opportunity for population growth of this invasive species, but reduces opportunities to recover native species.

Reducing lionfish numbers and restoring populations of native fish may be difficult, given the lionfish's ability to inhabit expansive and diverse habitats. Also, the lionfish's high recruitment pressure may create permanent alterations to the structure of the native reef fish community. Albins and Hixon (2011) provided a summary of "worst-case" scenarios for the lionfish invasion that highlighted the many life-history and ecological traits that make lionfish highly invasive. These traits may combine with other ecosystem stressors (e.g. overfishing) and

produce detrimental changes to coral reef habitats. The authors also suggest management actions that may reduce the potential impact from the species; many of those recommendations are considered by this Plan.

3.2 SOCIOECONOMIC AND HUMAN HEALTH IMPACTS

The socioeconomic impacts of lionfish remain largely unquantified, but have the potential to be severe. Vulnerable sectors include fishing and tourism economies that are often critically important to coastal communities. For example, it has been confirmed that lionfish prey on economically-important species such as juvenile grouper and snapper (Morris and Akins 2009). These species are an important component of a multi-billion dollar per year fishery that supports thousands of jobs in the invaded range (NMFS 2014). Predation on these juveniles may lead to reductions in landings, hamper stock rebuilding efforts, and/or slow conservation-based initiatives which will subsequently have devastative effects on local economies (Morris and Whitfield 2009).

In regard to human health impacts, increased lionfish densities correspond to an increased risk of lionfish encounters and the risk of envenomation. The lionfishes' venomous spines can cause significant human harm from pain and swelling to, in severe cases, tachycardia, seizures, and temporary paralysis (Kizer et. al. 1985). Direct impacts to recreational activities and tourism from the lionfish invasion have been observed. For example, some dive charter operators have changed their dive plans to avoid envenomation of their clients by lionfish (Akins personal observations). Presently, the long-term economic impacts to tourism resulting from lionfish have yet to be quantified. Further, it is unknown whether increasing lionfish densities will reduce recreational activities and cause economic hardship for associated businesses. The commercial diving industry has also encountered impacts due to lionfish, with divers getting stung while working in the Gulf of Mexico. These envenomations have resulted in workers requiring days off of work and new training requirements for all divers to deal with this new on-the-job hazard.

Risk assessments for lionfish envenomation are expected to aid in the development of educational programs and management actions. Obtaining data appropriate to make these assessments will be an important component of lionfish monitoring. Factors that may impact the economic effects of lionfish on tourism and businesses associated with recreational activities include, but are not necessarily limited to, the local density of lionfish, the rate of human encounters with lionfish, and the effectiveness of education and outreach programs.

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3.3 REGULATORY ACTIONS/HURDLES

While numerous freshwater systems in the U.S. have experienced invasive fishes, never before has there been a large-scale finfish invasion recorded in the waters of the Southeast Atlantic, Caribbean, or Gulf of Mexico. As a result, few coastal governing bodies have rules or regulations that address recreational or commercial harvest of non-native marine fishes. In fact, many existing regulations governing all marine fishes may provide obstacles to the removal of invasive species. In the U.S., lionfish are found in federal, state, and county marine waters, as well as in estuary systems. Management of these waters varies by location, and may include multiple jurisdictions and regulatory frameworks, especially in relation to gear types, bag limits, marine protected areas, county parks, and other refugia. Additional restrictions on removals may also be applied relative to endangered, threatened, or otherwise protected species.

States and U.S. territories in the invaded range cite a lack of dedicated funding and personnel as the primary hurdle in their management of lionfish invasion. At the time of this Plan's drafting, most states, with the exception of Florida, indicated that lionfish have not become a large problem in the state's jurisdictional waters, and therefore, have not forced a shift in the allocation of state resources. Currently, states are focusing their limited resources on educating the public about the problem, and monitoring their state waters for increasing lionfish numbers. Florida and Puerto Rico, on the other hand, have seen impacts from the lionfish invasion in their jurisdictional waters, and have shifted their position to actively controlling and managing existing lionfish populations.

Florida Fish and Wildlife Conservation Commission (FWC) encourages people to remove lionfish from state waters to reduce potential impacts to native fish and wildlife. The state has also created an agency-wide internal lionfish control team to evaluate management options for addressing the control of lionfish within state waters. Florida state parks and the Florida Keys National Marine Sanctuary (FKNMS) have created permitting workshops that are intended for professionals and avid divers interested in obtaining a permit to collect lionfish in the sanctuary preservation areas. These workshops are sponsored by REEF and the FKNMS. Workshop topics include background of the invasion, lionfish biology, ecological impacts, current research findings, and collecting and handling tools and techniques. Following each workshop, each participant has the opportunity to obtain a FKNMS lionfish collecting permit that allows the harvest of lionfish within the sanctuary with hand nets. The State of Florida has also instituted regulations with the goal to reduce regulatory barriers to enhance removal efforts. Regulatory changes include: waiving the fishing license requirement for harvest by specific gear types, removing the bag limit for recreational and commercial fisherman, removal of the Collier County spearfishing ban, allowance of rebreathers when harvesting lionfish, creating a permit for tournaments/events allowing spearing in areas otherwise prohibited to spearfishing,

prohibiting the importation of all species of Pterois into Florida, and prohibiting the breeding or aquaculture of larvae of Pterois species.

3.4. USE OF INCENTIVE PROGRAMS AND ESTABLISHMENT OF FISHERIES

Various incentive and alternative-use programs utilizing lionfish have risen in popularity and serve as a means to raise awareness and encourage the harvest, use and consumption of invasive lionfish on local and regional scales. Development of markets for lionfish jewelry, aquarium specimens, and as a food fish, among others, provide incentives encouraging removals. Such programs have demonstrated success in reducing numbers, suggesting that incentives have the potential to control lionfish populations. For example, over 5,000 invasive lionfish have been removed from the Florida Keys since 2010 through annual derbies hosted by REEF (Boganoff et. al. 2013). Several campaigns have also been developed to encourage chefs, wholesalers, and fishing communities to promote the lionfish as a food choice. The development of commercial fisheries for lionfish has been supported by research demonstrating that lionfish are edible and have higher levels of healthy omega-3 fatty acids than some frequently consumed native marine fish species (Morris et. al. 2011).

Studies have indicated that the reduction of numbers from commercial harvesting and incentive programs may be an effective way to suppress lionfish. They may also be a means to recover native fish populations at high priority locations, such as Marine Protected Areas and juvenile fish habitat (Green et al 2013). However, these efforts are not always sustainable or practical. Removal efforts will only be successful if the number harvested exceeds the number that would normally not survive during a single breeding cycle. This number is often very high; models have predicted that annual removal rates between 15 and 65% are required to reduce lionfish populations (Barbour et al. 2011). Even if this level of reduction is achieved, reinvasion from surrounding areas remains possible, emphasizing the need for sustained prevention and containment measures.

Incentive programs often involve members of the general public who may be untrained in proper techniques for capturing and handling of lionfish, which have venomous spines that may cause significant human harm (Morris and Whitfield 2009). Additional risks may be associated with promoting invasive species as a viable food source. The toxin that causes ciguatera poisoning has been found in lionfish, and represents a health hazard when fish containing high levels of ciguatoxin are ingested (Cearnal 2012). As of February 2015, no known cases of ciguatera fish poisoning from eating lionfish have been confirmed. Further, recent research suggests that proteins in the lionfish venom may mimic ciguatoxin, possibly creating false positives in testing procedures. This evidence does not eliminate the possibility that lionfish may carry the toxin, only that the risk to public health is no greater than that for grouper and similar fish species (Wilcox and Hixon 2014).

Perhaps the biggest challenge to promoting harvest of lionfish is its potential to be self-defeating and generate perverse incentives that could unintentionally cause further spread. Some individuals may come to rely on the income that commercial markets or other incentives generate. Even without a direct economic incentive, people may develop a "taste" or preference for the species, and value its long-term presence. This may encourage breeding programs or intentional release of lionfish back into management areas or into previously non-invaded habitats. To avoid such conflicts, outreach is essential to communicate the long-term benefits of lionfish population reductions, and the need to eventually phase out commercial markets and other benefits that the species may generate.

Overall, programs that encourage harvest of lionfish may be an effective management tool in targeting small, distinct populations, or play a supplementary role within larger control efforts. Their use, however, will require careful review, planning, and monitoring of the biological, ecological, human health, and socioeconomic factors involved, to ensure success and that they do not unintentionally lead to the further spread of lionfish or cause additional harm to native species (Pasko and Goldberg 2014).

3.5 PATHWAYS OF INTRODUCTION

The specific vector that led to this invasion may never be identified; however, intentional releases by aquaria owners seems the most likely, as this invasive species is a popular aquarium fish. Lionfish (multiple species within the genera *Pterois*, *Parapterois*, and *Dendrochirus*) are imported into the U.S. daily through the pet trade. Other possible vectors include unintentional releases from large public aquaria and larval releases in the ballast water of ships. Regardless of the exact vector of introduction, lionfish were introduced into U.S. waters through human activities, rather than natural processes.

3.6 OTHER LIONFISH SPECIES IN TRADE

Although there is uncertainty as to how lionfish were first introduced into U.S. waters, the most likely vector is the international aquarium trade. The aquarium trade represents a $1 billion-a-year global industry and a popular hobby, second only to photography (Wabnitz et al. 2003, SCBD 2010). Although aquariums have introduced relatively fewer species compared to other pathways, this pathway has contributed to a third of the world's worst aquatic and invasive species (Williams et. al. 2012). Aquarium species are often very hardy, and if they are released, it normally occurs when they have reached a large size (Duggan et al. 2006), which increases their probability of survival, establishment, and potential to reproduce and spread if released (Keller and Lodge 2007).

The U.S. accounts for over 50% of the marine aquarium fishes and invertebrates being sold globally (Wabnitz et al. 2003, Tissot et al. 2010). As a result of its high value, the marine ornamental trade is promoted as a means of sustainable development in many countries from which specimens are collected. Accordingly, the environmental effects of the trade resulting from collection and shipping practices have received a great deal of attention, and strategies have been developed to manage and mitigate the undesirable effects (e.g., Bruckner 2005). Unfortunately, far less attention has been devoted to the potential release of non-native species into waters where they might establish and become invasive (Williams et. al. 2012).

Lionfish are members of the scorpionfish family (Scorpaenidae) and the subfamily Pteroinae. There are five genera in this subfamily, and approximately 20 species (Fishbase, 2014). The species most often seen in the aquarium trade belong to two genera: *Dendrochirus* and *Pterois. P. volitans* is one of the 10 most valuable marine fish imported into the U.S., accounting for approximately 28% of the total value of marine fish, or about $3.05 million per month (Balboa, 2003).

Even though the lionfish invasion of the Western Atlantic Ocean consists of only two species (*P. miles* and *P. volitans*), numerous other species of lionfish are moved around the U.S. on a regular basis in the aquarium trade. These species include:

- Broadbarred firefish (*P. antennata*),
- Frillfin turkeyfish (*P. mombasae*),
- Radial firefish (*P. radiata*),
- Plaintail turkeyfish (*P. russelli*),
- Hawaiian turkeyfish (*P. sphex*),
- Hawaiian lionfish (*Dendrochirus barberi*),
- Twospot turkeyfish (*D. biocellatus*),
- Shortfin turkeyfish (*D. brachypterus*),
- Zebra turkeyfish (*D. zebra*), and
- Blackfoot firefish (*Parapterois heterura*).

Descriptions of each of these species are available in Appendix 1. This list of lionfish species is by no means exhaustive, but rather demonstrative of lionfishes in trade within the United States. Given the invasiveness that *P. miles* and *P. volitans* have demonstrated, there is a need to gather more information on these species. One action item in this management plan is to perform a risk analysis for all lionfish species in trade, including the economic value and number of individuals imported into the United States. This information may be used to determine if there is a risk for establishment in U.S. waters, and if these species present a risk of harm to the economy, ecology, or human health.

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4.0 INVASIVE LIONFISH PREVENTION AND MANAGEMENT

In this section of the Plan, the Committee has outlined the goals and objectives determined to be most important to the lionfish invasion at the time of this Plan's drafting. This plan is intended to be a living document; as such, the goals and objectives may evolve as more is learned about the invasion and new ways to manage it.

4.1 GOALS

Goal 1: Prevent the Spread of Invasive Lionfish

Objective 1.A) 100% prevention of new populations in high-priority sites. A high-priority site may be defined as an area with elevated ecological value, economic value, and/or human health aspects (e.g. nursery grounds, marine protected areas, sanctuaries, etc.). The designation of high-priority sites may vary by state and/or region, and will be determined by the lead agency/organization conducting the management activities.

1.A.1 Identify high priority sites in the U.S., and the vector(s) of introduction most likely to impact these sites.

1.A.2 Identify the most likely vectors of introduction of individuals to new areas, including intentional and accidental releases from the aquarium trade, natural disasters such as hurricanes, and spread from existing populations. Investigate additional or newly identified modes of introduction.

1.A.3 Encourage prevention through the use of Hazard Analysis and Critical Control Point (HACCP) planning to facilitate development of pathway/vector risk assessments and prevention measures.

1.A.4 Encourage the use of the ANSTF's Federal Aquatic Nuisance Species Research Risk Analysis Protocol to prevent unintentional species introductions during research activities.

Objective 1.B) Determine the risk of invasiveness for lionfish species in trade.

1.B.1 Conduct ecological risk screening for all species of lionfish in trade within the U.S.

1.B.2 Determine which U.S. states and territories may be vulnerable to invasion.

Objective 1.C) Examine importation and pet trade practices and regulations.

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1.C.1 Develop solutions with the pet trade industry for lionfish species that indicate risk of invasiveness.

1.C.2 Promote commercial markets and incentive programs that encourage the harvest, use, and consumption of invasive lionfish on local and regional scales. Ensure that these activities are conducted in a manner that does not lead to further spread of lionfish or cause additional harm to native species.

Objective 1.D) Increase awareness through education and outreach activities.

1.D.1 Ensure the people of the U.S. understand the problems and impacts associated with lionfish, particularly in areas outside of the invaded range.

1.D.2 Develop a messaging campaign specific for lionfish in collaboration with Habitattitude™ and other partners.

1.D.3 Explore media options to raise awareness and good stewardship practices.

1.D.4 Encourage education and outreach to targeted groups, including the aquarium trade. Possible activities include best management practices for getting rid of unwanted fish, and recommended practices to prevent accidental release during natural disasters.

1.D.5 Encourage coordination of lionfish research findings, education materials, and outreach activities among federal and state agencies, as well as stakeholders, to reduce duplicative efforts and waste of limited funds.

1.D.6 Establish an online clearinghouse of existing and new outreach materials to increase availability to agencies and other stakeholders.

1.D.7 Translate new and existing outreach materials into multiple languages.

Objective 1.E) Identify management areas that should remain free from lionfish that include careful consideration of the site selection, purpose, and management operations.

1.E.1 Develop and implement management plans that provide technical guidance to achieve invasive lionfish-free areas. These plans should use an Integrated Pest Management (IPM) approach to develop strategies for routine surveillance, rapid response, prioritization of managed areas, and tracking costs to understand the effort associated with management actions.

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1.E.2 Develop strategies to reduce propagule pressure in areas around invasive lionfish-free management areas.

Objective 1.F) Develop monitoring strategies to evaluate and improve prevention objectives.

Goal 2: Coordinated Early Detection and Rapid Response

Early Detection/Rapid Response (EDRR) plans are second only to prevention in controlling the spread of invasive species. Early Detection can come from a variety of sources including public reports, citizen science groups, incidental collections during scientific surveys, and targeted Rapid Assessment Teams (RATs). Rapid Response actions are only available for a narrow window of time after a new introduction is detected. If a species introduction is not responded to soon after detection, the invasion may become widespread, and eradication may no longer be feasible.

Objective 2.A) Develop and implement EDRR programs.

2.A.1 Encourage a cohesive standardized monitoring strategy for all high-priority sites.

2.A.2 Develop a training program and standardized practices for monitoring invasive lionfish, and promote them through publications or manuals.

2.A.3 Develop tools that will aid in the early detection of lionfish across a wide range of water depths and habitat types.

2.A.4 Geospatially track lionfish sightings and captures to inform natural resource managers about catch-per-unit-of-effort and trends in this metric over time.

2.A.5 Adopt consistent messaging to encourage reporting of lionfish sightings, particularly in areas where lionfish are not established.

2.A.6 Incorporate the USGS NAS Sighting Report Form, or other nationally/regionally approved reporting systems, into outreach material and national AIS campaigns.

2.A.7 Establish confidentiality clauses that permit academicians to immediately report sightings of invasive species while protecting credibility of future publications.

2.A.8 Identify the challenges in handling early detection reports for each state where invasion is possible.

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2.A.9 Perform annual evaluations of the national monitoring strategies and reporting systems to identify and address any problems, and to make sure all of the contact information is accurate.

2.A.10 Encourage development of a Rapid Response plan for lionfish that incorporates the Incident Command System (ICS) in states where invasion is possible. The plan should include direction of who should receive the reports, how that information will be disseminated, who will respond, and flow plans to ensure timely transfer of invasive information to the appropriate personnel.

2.A.10.a Develop or expand upon a current system to ensure reports are forwarded to appropriate authorities.

2.A.10.b Identify funding sources to support Rapid Response activities to ensure all eradication needs can be immediately purchased.

2.A.10.c Identify agencies, NGOs, and academic facilities that have personnel and assets that can be used to respond.

2.A.11 Encourage all federal agencies that have jurisdiction over U.S. waters, to develop agency protocols for carrying out a Rapid Response to a lionfish (or other ANS) sighting and to set aside designated funding in their annual budget to support a response.

Objective 2.B) Develop tools to improve EDRR for lionfish.

2.B.1 Create and disseminate information and materials related to EDRR.

2.B.1.a Target local dive organizations, webpages, and shops with reporting plans.

2.B.1.b Create regional PowerPoint presentations that provide uniform information for public outreach specific to Early Detection.

2.B.1.c Create a prioritized list of outreach groups and solicit presentation time to discuss EDRR.

2.B.1.d Establish general media outreach campaigns including safe handling methods.

2.B.2. Create distinct tools for Rapid Response.

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2.B.2.a Develop a regional map of personnel and assets that could be used to aid in an Rapid Response for lionfish. This should include federal and state agencies, NGO's, and academia.

2.B.2.b Preemptively establish Memorandums of Understanding (MOU) between neighboring states, entities, and agencies to share assets and personnel.

2.B.2.c Ensure field response staff and direct managers are trained in ICS.

Objective 2.C) Develop monitoring strategies to evaluate and improve each EDRR objective.

Goal 3: Control and Management of Invasive Lionfish

For circumstances when prevention have failed and species populations have become so widespread that eradication through EDRR is no longer possible, control and management efforts may be used. Control efforts should establish species density thresholds that trigger management action. For example, increased lionfish densities (e.g., 1 standard deviation in Catch-Per-Unit-Effort) should trigger increased management and control efforts. When determining which control and management tools are most appropriate, all aspects of the environment should be considered to achieve the best outcome possible while minimizing impacts on the habitat. For instance, control gear options may be limited in sensitive coral habitats.

Objective 3.A) Develop tools for localized control and management.

3.A.1 Develop and set control levels and density-dependent thresholds that trigger management actions.

3.A.1.a Determine thresholds of selected non-target species and lionfish metrics that would inform natural resource managers when to change existing control efforts.

3.A.1.b Utilize existing models (e.g., Green et al. 2014) to determine densities for lionfish that may only minimally impact native species populations.

3.A.2 Determine the cost effectiveness of control at different geographic scales.

3.A.3 Synthesize the applied management activities in existing management plans to produce a document that agencies can immediately implement to support volunteer and agency efforts.

Objective 3.B) Reduce lionfish population densities at high priority sites.

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3.B.1 Establish priority sites for lionfish removal based on reef type and community resilience.

3.B.2 Develop and implement site-based eradication or control plans. These plans should include descriptions of the lionfish (target) population, potentially impacted resources, potential partners, and costs. The plan should also consider future costs associated with the impacts if no control action is taken.

3.B.3 Promote use of existing protocols for handling and capture of lionfish, reporting, and best management practices.

Objective 3.C) Research and improve fisheries management tools for the control of invasive lionfish.

3.C.1 Develop metrics and technical information to support fish-based assessment tools including proportional stock density and relative stock density.

3.C.2 Develop spatially explicit models to predict lionfish distribution. Models should integrate oceanographic variables, habitat, anthropogenic structures and characteristics, and associated species information.

3.C.3 Develop stock recruitment models for lionfish to better assess potential impacts from invasive lionfish and improve control efforts.

3.C.4 Develop lionfish stock assessments using mathematical and statistical approaches to understand natural mortality versus harvest and the influence these factors have on the lionfish populations.

3.C.5 Estimate natural, fishing, and total mortality as well as survival and exploitation rates for site-specific populations for incorporation into stock assessments.

3.C.6 Determine the contribution of local reproduction and population augmentation from outside areas to inform stock models.

Objective 3.D) Develop and implement ecologically relevant indices to determine reef health.

3.D.1 Develop metrics for lionfish monitoring that utilize standardized approaches that are easily collected, repeatable, and applicable over large areas.

Objective 3.E) Develop species specific tools for large-scale invasive lionfish eradication.

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3.E.1 Explore characteristics in the life history of invasive lionfish to exploit possible vulnerabilities.

3.E.2 Develop novel control tools such as mechanical removal, traps, genetic techniques, etc. that can be utilized to control lionfish populations across the entire invaded range.

Objective 3.F) Identify and address current regulatory hurdles and tools.

Objective 3.G) Incorporate climate change scenarios into lionfish predictive models.

Objective 3.H) Build new and expand existing partnerships between federal and state agencies, tribes, private sector, and other stakeholders.

Objective 3.I) Develop monitoring strategies to evaluate and improve each control and management objective.

Goal 4: Assess Impacts of the Lionfish Invasion

There is a broad knowledge gap when it comes to the impacts lionfish are having on the invaded environment. Several localized studies have been conducted to investigate these impacts; however, these studies vary greatly in both the type and level of impacts found. Consequently, additional research is needed to develop a clearer understanding of the impact that lionfish will have on native habitats, economic interests, and human well-being.

Objective 4.A) Develop a better understanding of the impacts of the lionfish invasion on native species and habitats.

4.A.1 Determine the impacts of lionfish predation and density on native fish species.

4.A.2 Determine habitat preferences of lionfish (e.g., bank, patchy, hard bottom).

4.A.3 Develop a better understanding of the interactions between invasive lionfish establishment and the placement and material type of artificial reefs.

Objective 4.B) Assess impacts to human health, safety, quality of life, and communities.

4.B.1 Develop an economic assessment of the impact of lionfish on communities.

Objective 4.C) Protect commercially and recreationally important fishery stocks from harm related to the lionfish invasion.

4.C.1 Develop a better understanding of the diet of lionfish.

4.C.2 Provide results on predation patterns to regulatory authorities to inform decisions and relate lionfish predation as a significant stressor to fishery stocks.

Objective 4.D) Protect species of concern from both direct and indirect effects of invasive lionfish.

4.D.1 Develop a better understanding of the impacts lionfish are having on commercially, recreationally, and ecologically important as well as, threatened and endangered species at all trophic levels, and the long term consequences to these species.

4.D.2 Improve management techniques to minimize the harm to non-target species.

4.2 MANAGEMENT AND CONTROL ACTIONS TO DATE

Management and control actions of lionfish in U.S. coastal and U.S. Caribbean territorial waters has been challenging at best. Efforts have been localized and not well coordinated across agencies or with other stakeholders. However, within these entities there have been some successes. For example, NOAA has researched lionfish biology, ecology, and ecological impacts since the invasive species were first detected and continues to apply research findings to develop control and management options for coastal managers. NOAA's "Eat Lionfish" campaign, launched in 2010, advocates marketing and consumption of lionfish to provide removal incentives for both commercial and recreational fishers and divers. In addition, NOAA and REEF have trained more than 250 divers and snorkelers on how to identify and safely capture lionfish. These organizations coordinate lionfish derbies that have brought public attention to the lionfish invasion, removed lionfish from localized areas, and have highlighted the procedures for safe preparation and consumption of lionfish. The lionfish derbies also provide NOAA and USGS scientists with information on stomach contents, age classifications, and genetics of lionfish populations. The FKNMS developed a pro-active lionfish response program that was implemented in 2009, prior to the lionfish invasion of the sanctuary. Outreach campaigns associated with this program have led to significant reporting and capture efforts. The Flower Garden Banks National Marine Sanctuary (FGBNMS) has had an active lionfish removal and research program since 2011 when lionfish were first reported within the sanctuary. They have a lionfish response plan and targeted priority removal areas, conduct site removals and research, partner with NOAA's National Centers for Coastal Ocean Science and the FDA on ciguatera testing in lionfish, and have an active monitoring program. The NPS developed a lionfish response plan that has been used as a foundation for individual parks to develop local management plans. In the Caribbean, the Puerto Rico Department of Natural and Environmental Resources has worked with NGOs and key business partners to conduct outreach programs and collection workshops. Furthermore, the U.S. Virgin Islands have

developed a lionfish management plan with significant stakeholder involvement. At a broader scale, reporting efforts across the entire invaded range have been facilitated by the USGS, USFWS, and NGOs that manage lionfish reporting hotlines and websites. Finally, Florida is implementing efforts to encourage public involvement in long-term control initiatives. Specifically, the Florida Fish and Wildlife Conservation Commission (FWC) supports and sponsors local removal efforts and derbies. In the spring of 2015, the FWC launched a Reef Rangers program, where groups or individuals pledge to conduct lionfish removals at local reefs of their choice. Removal efforts are logged into a reporting application and participants are recognized for their efforts.

In addition to efforts within the U.S., there have been concerted international efforts since 2010 to recognize the impacts of lionfish and develop regional approaches and knowledge sharing relative to best practices for control. These efforts have included workshops, training programs, and development of a best-practices manual funded by the International Coral Reef Initiative (ICRI), the Government of France through SPAW-RAC, NOAA, REEF, the Government of Mexico, NGOs and private foundations. Lionfish control or response plans have also been developed for numerous countries and "Eat Lionfish" campaigns are widespread throughout the invaded range.

4.3 RESEARCH: CURRENT/FUTURE ACTIONS

Current Research: Instead of developing a full summery of all the available literature at the time of this Plans drafting, the Committee decided to provide a literature list. This list of published, peer-review scientific journal articles focusing on *Pterois* species from their native and invaded range can be found in Appendix 2.

Future Research Needs: The following list was composed and agreed upon by the members of the Committee as the highest priority future research needs for invasive lionfish at the time of this plan's drafting (not listed in priority order).

1. What are the controlling factors of lionfish densities within their native range?
2. What is the response from native species to the lionfish invasion?
3. What life history stage of lionfish is most vulnerable to control measures?
4. What control measures are most effective at reducing lionfish densities in sensitive areas?
5. At what lionfish density does the impact of control measures outweigh the benefit of removal?
6. What is an acceptable density of lionfish?
7. What habitats are being utilized by the different life history stages of lionfish in both invaded and native ranges?
8. Are lionfish utilizing a specific habitat or area within the invaded range for spawning?
9. What environmental factors, if any, influence spawning?

10. What are the main factors affecting the spread and population abundance of lionfish in the invaded range?
11. What is the likelihood that lionfish may invade the U.S. western coast?
12. What are the ecological impacts of the lionfish invasion on native marine communities?
13. What is the economic impact of the lionfish invasion, including but not limited to, tourism, commercial fisheries, recreational fisheries, and scuba diving?
14. What impacts do lionfish have on commercially and recreationally important species (e.g. snapper and grouper)?
15. What impacts do lionfish have on protected species?
16. How will climate change affect the current invaded range of lionfish?

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5.0 EDUCATION AND OUTREACH: CURRENT/FUTURE ACTIONS

Successful Education and Outreach (E&O) can help shape public perception, enhance constituent involvement, and provide support and funding for control programs.

This section provides recommendations on E&O strategies aimed at increasing support for programs addressing the lionfish invasion, including developing E&O priorities, key messages, program considerations, communication strategies, and examples of messaging and outlets. In addition, education programs targeting stakeholders and agency control personnel are outlined.

5.1 THE EARLIER, THE BETTER

By forming and implementing E&O programs before a lionfish invasion, managers can greatly aid their efforts to manage the problem. In two successful examples, Stichting Nationale Parken Bonaire (STINAPA) and FKNMS initiated education and outreach activities in priority areas prior to lionfish colonizing their waters. These management organizations targeted their proactive outreach activities to the general public, dive industries, health and medical industries, educational institutions, and the media. They developed outreach materials, including posters and stickers, and control plans; and they held workshops in advance of the invasion (Figure 5.1).

The STINAPA and FKNMS activities ensured that all user groups in each respective location were equipped with accurate information and were aware of protocols for responding to lionfish sightings. Because of these advance efforts, community awareness in both locations was relatively high and misconceptions were addressed prior to invasion. As lionfish began to colonize local areas, the respective communities supported removal activities. They continue to be among the most supportive communities in the region.

Figure 5.1 Sticker used by the Florida Keys National Marine Sanctuary to encourage reporting of sightings.

5.2 E&O TO SUPPORT CONTROL PLANS

The primary mission of most lionfish control plans is to minimize the economic, ecological, and human health impacts of the invasion. Impacts can take many forms, including disruptions

to marine communities, fishing and tourism activities, and the safety of those encountering or collecting lionfish.

The level of E&O efforts depend on the specific goals and objectives of the program. Resource managers who dedicate time to developing solid mission statements, goals, objectives, and strategies will strengthen their E&O efforts and help facilitate a stronger overall program. Moreover, programs that involve stakeholders from broad sectors (e.g., media, education, research, management, political office) will be strengthened by identifying and developing strategic methods for key audiences.

Examples of outreach goals for minimizing lionfish impacts include:

- Increase removals of lionfish to reduce local populations,
- Increase public awareness of lionfish impacts to generate support for effective management,
- Maximize efficiency in utilizing human and fiscal resources,
- Increase political support for lionfish management and control,
- Minimize health risks to the general public and those handling or collecting lionfish,
- Link lionfish research to management strategies, and
- Prevent future introductions of additional lionfish as well as other non-native species.

5.3 DEVELOPING COMMUNICATION STRATEGIES

In developing communication strategies, managers should first identify what they expect the E&O activity to accomplish. The question: "What would successful communication look like or result in?" should be asked. Possible answers may include "Increasing the number of people who realize lionfish are a threat", "Increased reports to the ANS Hotline", or "More people eating lionfish." The answer(s) will assist resource managers in determining the target audience(s). Once these audiences have been identified (e.g., anglers, divers, politicians, school groups, the general public, and/or businesses), messages can be developed that are specific to that target group. It is important to select broad overarching messages aimed at the groups.

Importance of clear and credible messaging

When developing messaging for outreach efforts, managers should remember that not all outlets are equal. Messaging should be tailored to suit both the media outlet and target audience. Print, radio, television, documentaries, and public and political forums are all key messaging venues or "tools," but each one has its differences and limitations in format, content, style, and length. Different versions of the same general message can be used for different groups; however, it remains important to remember that the audience and the desired behavioral change will dictate which of the many messages are relevant.

It is also important that managers and programs stay consistent with the desired message, especially when working with the media or in public forums. It is easy to get sidetracked by a question or comment, but it is important to come back to the main message.

Key messages

Managers may feel compelled to convey every known piece of information about lionfish and the invasion; however, it is important to distill and refine the material into a subset of key messages to retain public attention. Concise key messages should be designed to elicit the changes in perception and behavior necessary to support program goals. It is important that all partners are consistent with messages delivered in their E&O activities.

Further, key messages will vary by audience and may change over time in response to various control strategies. Effective programs should periodically re-evaluate and update these messages.

Vetting information

The information to be disseminated through E&O activities must be accurate. In this age of mass communication and public media, messages are sometimes disseminated before their accuracy is verified. Misinformation or exaggeration can damage the credibility of E&O programs and hinder the success of management. It often takes only one small piece of incorrect information for an entire message or outreach campaign to lose credibility. Managers should take the utmost care to properly verify all information used or distributed in outreach efforts.

Sources of credible information

Accurate information on lionfish and the lionfish invasion is widely available. Examples of credible information sources include peer-reviewed scientific publications, direct quotes, and the websites of peer-reviewed researchers. If the source or credibility of information is uncertain, managers should verify the messages with a second opinion or outside source prior to distribution.

Outreach Outlets

Traditional media venues, including print, radio, television, film documentaries, and public and political forums, are all key messaging outlets or tools (See table 5.1 for examples). However, social media and emerging new informational tools and technologies are becoming increasingly relevant to public informational needs. Managers should think beyond traditional formats to come up with ideas that will work specifically for their management program, their community, and their target audience(s).

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Table 5.1 Examples of outreach outlets with samples of targeted audiences, message type, advantages/disadvantages, and estimated development times.

Outlet/tool	Audience	Message types	Advantages	Disadvantages	Development Time
TV, radio	General public	New information events	• Free • Large audience • Can be visual	• Live interviews offer little chance for review • Low control over message	Short
Documentaries	Select audience according to interest	Detailed information	• Managers can often help direct message or story	• Significant delays between filming and broadcast	Very long
Magazines, newspapers	General public	New information events	• Free • Audience size varies • Opportunity for review • Multiple readership	• Text-based format requires focused attention of reader	Short
Printed outreach (flyers, stickers, pamphlets)	Targeted audience (depending on distribution)	Ongoing messages	• Long-lived • Select distribution can target specific audience or locations • Can contain detailed information	• Limited audience • Can be defaced • Difficult to modify with updated information	Long
Websites	Select audience according to interest	Ongoing	• Can provide wealth of information (links)	• High maintenance • May require specific expertise	Very long (to develop initially)
E-mail	Select subscribers	Updates events	• Short message length • Text based	• Can be easily discarded without reading	Short
Public forums	Select audience according to interest or venue	Detailed information	• Opportunity to engage public in Q&A	• Misinterpretation of information • Opens forum to special interests	Moderate
Community events, festivals	General public	Broad messaging, events	• Opportunity to reach public, Q&A, disseminate materials and brief info	• Non-targeted audience • Easily discarded info	Moderate
Clubs, organizational meetings	Special interest	Detailed information	• Targeted audiences • Opportunity to provide detailed info and Q&A	• Requires presenter expertise	Moderate
School groups	Next generation	Age-appropriate messaging/ activities	• Reaches next generation • Can reach parents, relatives, friends	• Requires appropriate messaging and media	Moderate
Social media	Select audience according to subscription	Very brief info bytes	• Rapid and frequent • Can provide links to detailed information • Easily circulated	• May get lost in high volume media • Low longevity	Very short
Listservs	Select audience according to subscription	Detailed professional briefings	• Can provide links to detailed information • Easily circulated • Often archived for later searches	• May get lost in high volume	Short

Several lionfish informational portals currently exist, most managed by interested members of the public or stakeholder groups. A large portion of the public receive their information from these various portals, yet these sources of information rarely undergo a formal vetting process and may represent various personal opinions on practices, regulations, and/or policies (See table 5.2 for examples of lionfish informational portals). Accordingly, there is a strong need for an official informational outlet for public information and consensus on policy and practice.

Table 5.2 Sample outreach portals matched with examples of media type, number of people reached, and relevance of the audience (based on information in Akins 2012). Readers may consider using this table to prioritize messaging by matching an outlet with importance of audience and number of persons reached.

	Portals	Media Type Commonly Used	Number of Persons Reached	Target Audience Reached
Private	Lionfish U	Website, Facebook	Medium	Public
	World Lionfish Hunters	Website, Facebook	Medium	Public
	Restaurants	Printed materials	Medium	Public
	Aquaria	Printed materials, forums, videos	High	Public
	Citizens	Word of mouth	Medium	Public
Government	USGS	Printed materials, website	Medium	Public
	NPS	Printed materials	Low	Government, public
	NOAA	Printed materials, website	Medium	Government, public
	GSARP	Printed materials, website	Low	Government, public
Social/Civil/NPO	REEF	Printed materials, forums, websites	High	Public, media
	Oregon State University	Forums, website, conferences	Low	Public, media
	GCFI	Forums, website, publications	High	Public, media
	CORE	Facebook, festivals, school groups	Medium	Public
	Dive clubs (GCLC)	Website, publications	Low	Public, media

5.4 KEY LIONFISH MESSAGES

The following are key components for communication pertaining to the lionfish invasion. These messages may assist in the development of effective communications strategies.

Impacts from Invasion

- *Lionfish are an invasive species and are detrimental to native systems*. Lionfish 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 cross 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 via dispersal of their eggs and larvae by ocean currents.

Control Measures

- *Natural predation is not controlling the invasion.* While some incidental predation or conditioned feeding on captured lionfish may occur, it appears that there are no 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

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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. However, recent research suggests that innate scorpaenitoxins in the flesh of lionfish may be generating false positive results in ciguatoxin tests (Wilcox and Hixon, 2014). Even though there have been no confirmed cases of ciguatoxin poisoning as a result of eating lionfish, 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.

5.5 TRAINING

A key element in addressing the lionfish invasion includes training of field operators and the public in safe and effective collecting and handling practices. Lionfish may be taken opportunistically as by-catch in both the hook and line and trap fisheries, but targeted removal is currently restricted to diver and snorkeler removal via hand spearing and netting. As lionfish possess venomous spines and are quick to learn diver avoidance, proper procedures are critical in both human safety and removal success.

Training programs focusing on removal tools and techniques as well as diver safety have been developed and are in place for regional entities. For example, the FKNMS has worked with REEF to develop and conduct training programs for divers wishing to remove lionfish from FKNMS protected areas. The USFWS has funded regional training workshops led by REEF throughout the Southeast U.S. coastal states. The Professional Association of Dive Instructors (PADI) has a lionfish awareness specialty course available for dive instructors to teach students safe collecting techniques. Further, lionfish derbies typically include brief training sessions to ensure participant safety.

Lionfish removal can be achieved using many different tools and techniques; however, dissemination of accurate information is critical during the training process. Currently, no standardization or certification program exists for validating effective training programs.

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5.6 CHALLENGES

Accurate information and a thorough plan are the foundations of a solid E&O program, but even a good outreach plan can be de-railed by a few minor issues. Some easily avoidable pitfalls are described below.

- *Lack of coordination among points of contact.* Designate one or two people for each media release to be the primary contacts. If possible, utilize the same contacts for all messaging. These contacts typically field general questions and direct media to the appropriate person for more information.

- *Unsustainable (static) messaging.* Avoid sending the same (or similar) media releases repeatedly to the same outlets. Be creative and come up with new angles or elements.

- *Unbalanced messaging.* Avoid unbalanced messaging between human health and ecological impacts. For example, human health risk may differ in priority compared to ecological impacts; therefore, it is important to note these differences. Similarly, unbalanced messaging regarding human consumption can quickly de-rail local control efforts. For example, while the risks of ciguatera from consuming lionfish may be worth noting, there is little information on the relative risk compared to that posed by consuming native species. Therefore, the message should be balanced, and provide similar caution for ciguatera in lionfish as is provided for ciguatera in native reef fish.

- *Inaccurate information.* Be sure to validate and verify information before passing it along. Common inaccuracies, such as the source of the lionfish introduction or location of venomous spines can confuse audiences and can place people at risk.

- *Inappropriate visual aids.* Use images that support the message. For example, when describing lionfish impacts managers should use images depicting the significance of the invasion, such as a picture showing high densities of lionfish or degraded fish communities. A beautiful image of lionfish in its native range could create an affinity for lionfish among some viewers. Also, as there are many different species of lionfish in the native range, the use of incorrect species when describing the invasion may cause confusion.

5.7 MEASURING SUCCESS

Measuring changes in public perception and the effectiveness of messaging is difficult. Feedback is important in determining the direction for increasing success. There are a few simple tools that managers can use to determine how well their outreach programs are working. They include:

- *Tracking.* Responses to e-mails, calls, or personal feedback can be tracked and summarized to determine where the respondent heard about the issue. A simple notepad next to the phone will often suffice.

- *Participation.* Keep track of how many people attend specific events or public forums, and relate that back to the outlet and messaging used.

- *Short questionnaires.* Questionnaires and/or surveys can be useful tools, though special training or skills may be required to provide valid results. Administering questionnaires through face-to-face contact or via e-mail can provide valuable information on how the perceptions and behaviors of target audiences are changing in response to E&O efforts. Be cautious about survey length and in the use of questions that may lead the respondent towards a specific answer.

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6.0 LEADERSHIP, COMMUNICATION, AND COORDINATION

This section provides an overview of the leadership, communication, and coordinating roles among partners involved in the Invasive Lionfish Control Ad-hoc Committee (Committee) and implementation of the National Invasive Lionfish Prevention and Management Plan (Plan). The following is a description of roles and responsibilities for supporting prevention, control and regulatory efforts through funding, operations, and research within the U.S. The Committee recognizes all of the great work that is taking place throughout the Caribbean to address the invasive lionfish problem; however for this chapter, has chosen to focus only on activities that U.S. agencies and organizations are directly involved with.

FEDERAL

6.1 U.S. DEPARTMENT OF THE INTERIOR

Several agencies in the Department of the Interior (DOI) are integral to the effort to control invasive lionfish. In general, the Office of Insular Affairs (OIA) is providing funding in the Caribbean for a complimentary effort. The U.S. Fish and Wildlife Service (USFWS) provides coordination of the multi-agency effort and some funding. The U.S Geological Survey (USGS) provides research, method development and rapid response capabilities. The National Park Service (NPS) prevents and mitigates impacts from invasive species within units of the National Park System.

6.1.1 OFFICE OF INSULAR AFFAIRS

The OIA carries out the Secretary of the Interior's responsibilities for the insular areas. OIA's major charge is to coordinate federal policy and to provide technical and financial assistance to the territories of the U.S. Virgin Islands, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands (CNMI). The office also provides technical and financial assistance to the freely associated states (FAS) of the Federated States of Micronesia, the Republic of the Marshall Islands, and the Republic of Palau. The OIA's primary role in assisting the implementation of the National Invasive Lionfish Prevention and Management Plan is to support efforts in Puerto Rico and the U.S. Virgin Islands that complement the International Coral Reef Initiative and other OIA programs in the region.

6.1.2 U.S. FISH AND WILDLIFE SERVICE

USFWS is the regulatory and management arm of the DOI for fish and wildlife resources. Its primary mission is to conserve, protect, and recover populations of fish, wildlife, and plants for the continuing benefit of the public. Regulatory authorities include the National Environmental Policy Act, Endangered Species Act, Sikes Act, the

Fish and Wildlife Coordination Act, and other legislation specifically related to the interdiction of invasive species, such as the Lacey Act, Executive Order 13112, Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA), and the National Invasive Species Act of 1996 (NISA). The USFWS also serves as a co-chair for the Aquatic Nuisance Species Task Force (ANSTF).

The USFWS's Southeast Regional Office, Fisheries, Aquatic Invasive Species Program will continue to provide technical assistance as a member of Committee, provide resources to support the implementation of the National Invasive Lionfish Prevention and Management Plan, continue to support efforts in implementing state Aquatic Nuisance Species Plans, and coordinate activities in Puerto Rico and the U.S. Virgin Islands that compliment other National and Regional programs and activities.

The Southeast Region's National Wildlife Refuge System, pursuant to the National Wildlife Refuge System Administration Act (16 U.S.C. 668dd-ee), the Coral Reef Protection Executive Order 13089, and other pertinent statutes, will provide support towards the management of lionfish and other non-native aquatic species to preserve and protect the biodiversity, health, heritage, and social and economic value of U.S. coral reef ecosystems and the marine environment through activities on refuges in the Gulf of Mexico, south Atlantic, and Caribbean waters of Puerto Rico and the U.S. Virgin Islands.

6.1.3 U.S. GEOLOGICAL SURVEY

The U.S. Geological Survey (USGS) is the scientific and research agency within the DOI. The USGS's primary role in assisting the implementation of the National Invasive Lionfish Prevention and Management Plan is to: 1) collect, maintain and provide information on lionfish geographic range and expansion via the USGS Nonindigenous Aquatic Species database, and 2) provide technical assistance regarding biological and ecological scientific data on lionfish.

6.1.4 NATIONAL PARK SERVICE

The National Park Service (NPS) manages the units of the National Park System to conserve natural and cultural resources for the enjoyment of current and future generations and is required by statute to ensure these resources remain unimpaired. NPS policy states that exotic species will not be allowed to displace native species if displacement can be prevented. Invasive species that are present and detrimental to park resources or visitor experience are to be managed up to and including eradication, to the degree prudent and feasible. The NPS manages 85 units with marine resources, including eight in Florida, the U.S. Virgin Islands, and the Gulf of Mexico that are currently invaded or threatened with invasion by lionfish. The NPS Lionfish Response Plan

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(http://www.nature.nps.gov/water/marineinvasives/lionfish.cfm) was completed in 2012 to guide the NPS and its partners in addressing the invasion of lionfish by preventing and mitigating impacts, protecting staff, visitors and others and by educating and engaging the public. Management actions described in the plan will be implemented by the affected parks with technical support from the NPS Ocean and Coastal Resources Branch, NPS Fisheries Program Office and NPS Southeast Region Office. It is anticipated that achieving Plan goals and objectives will require working with diverse partners, including other federal agencies, states, NGOS and universities.

6.2 U.S. DEPARTMENT OF COMMERCE

6.2.1 NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

The mission of the National Oceanic and Atmospheric Administration (NOAA), a bureau within the Department of Commerce (DOC), is to understand and predict changes in Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social, and environmental needs. Under NANPCA of 1990, reauthorized by NISA in 1996 (collectively, the Act), NOAA has responsibility to reduce environmental and economic impacts resulting from invasions from aquatic organisms. The Act also designates NOAA as a leader in the coordination of federal invasive species efforts; as it names the Undersecretary of Commerce for Oceans and Atmosphere and the Director of the Fish and Wildlife Service as the Aquatic Nuisance Species Task Force (ANSTF) Chairpersons. Further, Executive Order (EO) 13112 designates the Secretary of Commerce (represented by NOAA), the Secretary of the Interior, and the Secretary of Agriculture as co-chairs of the National Invasive Species Council (NISC), an interagency organization that provides national leadership and oversight on both terrestrial and aquatic invasive species to reduce environmental and economic impacts resulting from invasions from aquatic organisms

NOAA has researched lionfish biology, ecology, and ecological impacts since lionfish were first observed by a NOAA researcher on a shipwreck off the coast of North Carolina in 2000. The agency issued its first ecological forecast of their spread and predicted Atlantic range in 2003 and is now applying the research findings to develop control and management options for coastal managers. NOAA has also responded to the public demand for information on lionfish through media campaigns, workshops, social media campaigns, podcasts, annual symposia, and direct briefings to fishery managers. NOAA also chaired a subcommittee of lionfish experts to synthesize information for the development of a web portal (http://lionfish.gcfi.org/index.php). The portal provides training tools for managers and outreach information for the public and educators. It also includes current and reliable information on the lionfish invasion, including status, reporting, management techniques, sample control plans, and legislation.

In addition, NOAA's Office of National Marine Sanctuaries (ONMS) has prepared a Lionfish Response Plan (http://sanctuaries.noaa.gov/science/conservation/pdfs/lionfish15.pdf) in cooperation with the Agency's National Centers for Coastal Ocean Science. The plan documents a variety of ongoing monitoring, control, research, and education/outreach activities at the three marine sanctuaries affected by the invasion (Florida Keys, Flower Garden Banks, and Gray's Reef) and recommends several new or enhanced activities. Although the plan specifically applies to National Marine Sanctuaries, it recognizes that close coordination and cooperation with other organizations and agencies across both domestic and international boundaries and jurisdictions is essential for success. NOAA's Lionfish Response Plan complements this Plan as well as other existing response plans, including the Regional Strategy for the Control of Invasive Lionfish in the Wider Caribbean and the National Park Service Lionfish Response Plan (http://www.icriforum.org/sites/default/files/ICRI_lionfish_Strategy_En.pdf).

6.3 U.S. DEPARTMENT OF STATE

The Bureau of Oceans and International Environmental and Scientific Affairs (OES) is the main point of contact in the Department of State (DOS) for invasive species issues. OES is responsible for international and transboundary issues related to marine, coastal, and terrestrial invasive species in a variety of contexts, and advocates for policies and approaches consistent with those of the United States in a range of international fora. DOS works closely with other Federal agencies to develop U.S. policies on invasive species as they relate to international issues, e.g., involving international boundaries and trade pathways. DOS also engages in various activities intended to increase awareness, build regional and global capacity to address invasive species, share data and information, and provide a platform for international diplomacy. The United States (DOS and NOAA) participated in a regional, technical experts group along with Mexico, the UN Environment Programme, and several other regional organizations to develop the Regional Strategy for the Control of Invasive Lionfish in the Wider Caribbean. The technical experts group was established by the International Coral Reef Initiative in 2010.

6.4 AQUATIC NUISANCE SPECIES TASK FORCE

The ANSTF is an intergovernmental organization dedicated to preventing and controlling aquatic nuisance species, and implementing NANPCA of 1990. The various NANPCA mandates were expanded later with the passage of NISA in 1996. The ANSTF consists of 13 Federal agency representatives and 13 Ex-officio members, and is co-chaired by the USFWS and NOAA. The ANSTF coordinates governmental efforts dealing with ANS in the U.S. with those of the private sector and other North American interests via regional panels and issue-specific committees and work groups. ANSTF's primary role in assisting the implementation of the National Invasive Lionfish Prevention and Management Plan (Plan) is to support, review, and approve drafts of the Plan from the Committee.

6.4.1 GULF AND SOUTH ATLANTIC REGIONAL PANEL

The Gulf and South Atlantic Regional Panel (GSARP) of the ANSTF helps to coordinate AIS activities in the region through information sharing. It is made up of approximately 40 members from federal and state governments, NGOs, universities, industry and one international member representing Mexico. It was through a recommendation from the GSARP to the ANSTF that the drafting of this Plan was set in motion. Following the approval of the plan, the GSARP will coordinate lionfish prevention and management activities in the region to meet the objective outlined in the Plan.

6.5 NATIONAL INVASIVE SPECIES COUNCIL

The National Invasive Species Council (NISC) is an interagency council that helps to coordinate and ensure complementary, cost-efficient and effective federal activities regarding invasive species. NISC was established February 3, 1999 by Executive Order 13112. NISC members include three co-chairs: the secretaries of Agriculture, Commerce, and Interior, as well as the secretaries of State, Defense, Homeland Security, Treasury, Transportation, Health and Human Services, and the Administrators of the Environmental Protection Agency, the U.S. Agency for International Development, the U.S Trade Representative, and the National Aeronautics and Space Administration. NISC staff work with NISC members to implement Council goals. NISC's primary role in assisting the implementation of the National Invasive Lionfish Prevention and Management Plan is to support and provide technical assistance when needed.

STATE AND TERRITORY

6.6 STATE OF ALABAMA

In Alabama the Department of Conservation and Natural Resources' Marine Resources Division (AMRD) has regulatory authority and responsibility for the lionfish invasion. To date, AMRD's efforts have been primarily focused on documenting/validating reports and saving specimens for further processing. AMRD has relinquished 54 specimens to the NMFS for gut content analysis, aging, and potential DNA investigations. AMRD is also an active entity of the Mississippi Bight Lionfish Response Unit and will conduct dive surveys to monitor the extent of the invasion in northern Gulf waters and the impacts the invasion is having on native species. Although Alabama has legislation concerning invasive species, lionfish are not specifically mentioned.

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6.7 STATE OF FLORIDA

The Florida Fish and Wildlife Conservation Commission (FWC) has state constitutional authority over fish and wildlife. However, other agencies such as Florida State Parks (which is under the Florida Department of Environmental Protection) are also directed through Florida statute to address nonnative species on their lands and waters. The FWC has efforts underway to gather more information about the invasive lionfish, including a project looking at lionfish expansion in the Indian River Lagoon system and one exploring management strategies for lionfish in the Florida Keys. Based on information gathered in these efforts, effective management strategies can be identified and developed to prioritize selected habitats for the management of the lionfish population. FWC has made multiple regulatory changes in an effort to reduce regulatory barriers to enhance removal efforts. FWC has encouraged the harvest of lionfish by removing recreational or commercial bag limit. A recreational fishing license is also no longer required to target lionfish while using a hand held net, pole spear, Hawaiian sling, or other spearing device specifically designed and marketed exclusively for lionfish. The spearfishing ban in Collier County has been removed. Further, rebreathers are now allowed to be used when harvesting lionfish. Additional regulations were enacted in 2014 that prohibit the importation of all species of *Pterois* into Florida and prohibit breeding of lionfish or the aquaculture of larvae in an effort to reduce future additional releases of these species. FWC has also been active in engaging stakeholders to encourage statewide involvement and support in long-term management. In October 2013, FWC held a Lionfish Summit and gathered input on potential future actions Florida could take in addressing lionfish. The FWC has been encouraging public involvement in long-term controls by supporting and sponsoring localized removals and lionfish "derbies", are holding lionfish workshops and presentations for the public, and have developed a Reef Rangers program. The Reef Rangers program was modeled after "adopt-a-highway" programs where divers pledge to conduct lionfish removals at local reefs of their choice. To further support this initiative and to promote lionfish awareness, FWC has developed a reporting application, many online and print publications, and have proclaimed that the third Saturday of May each year is Lionfish Removal and Awareness day. Finally, FWC has been working to better understand public perception and knowledge concerning lionfish in Florida by conducting a human-dimension research project in an effort to determine the effectiveness of our public awareness campaigns.

6.8 STATE OF GEORGIA

At the time of drafting this plan, the State of Georgia had not established any regulations or policies regarding invasive lionfish. Instead, the State is deferring to regional and federal plans for this species. If Georgia decides to pursue establishment of regulations or policies in the future, the Georgia Department of Natural Resources, Coastal Resources Division (CRD) will be the responsible state agency. There are currently no State efforts to study, control, or monitor lionfish. If lionfish are encountered during periodic assessments of offshore artificial reefs, the number of animals observed and general location is documented. Staff with Grays

Reef National Marine Sanctuary (17 miles offshore of the Georgia coast) documents lionfish during their activities and the National Marine Fisheries Service Marine Resources Monitoring, Assessment, and Prediction (MARMAP) Program is also monitoring lionfish as part of its demersal fish trap survey conducted offshore of Georgia. To date, lionfish have not been captured in any CRD's fishery independent surveys conducted within near shore Atlantic Ocean and estuarine waters.

6.9 STATE OF LOUISIANA

In Louisiana, the Louisiana Department of Wildlife and Fisheries (LDWF) has regulatory authority and responsibility for the lionfish invasion. LDWF has an existing monitoring project that documents the presence of lionfish. LDWF is seeking more money to continue or expand the project, including looking at impacts from lionfish. Currently Louisiana does not have lionfish on any state prohibited list and does not have any regulations for the catch of lionfish. The state only requires the standard licensing that is required to fish in the waters where the lionfish are located for the appropriate gear used.

6.10 STATE OF MISSISSIPPI

The Mississippi Department of Marine Resources (MSDMR) is the lead state agency with regulatory authority and responsibility over the management of the state's marine environments. Their ongoing efforts dealing with the lionfish invasion include the development and distribution of outreach materials to inform the public about the problems associated with the invasion. MSDMR is also an active member of the Mississippi Bight Lionfish Response Unit in which they conduct diver surveys to monitor the extent of the invasion in northern Gulf waters and the impacts the invasion is having on native species. Currently there are no specific regulations in the state of Mississippi to combat the lionfish invasion.

6.11 STATE OF NORTH CAROLINA

The North Carolina Department of Environment and Natural Resources – Division of Marine Fisheries is the lead state agency with regulatory authority and responsibility over the management of the state's jurisdictional waters At the time of this Plan's drafting, the state had no formalized activities addressing lionfish control or monitoring.

6.12 STATE OF SOUTH CAROLINA

At the time of this plan's drafting, the lionfish invasion was an issue only within the federal waters off of South Carolina, an area that falls under the authority of NOAA's National Marine Fisheries Service (NMFS). If the invasion was to spread into state waters then South Carolina's Department of Natural Recourses would have regulatory authority and responsibility for the invasion. The only lionfish-related activities that are currently taking place at the state level is limited monitoring that might occur by the South Carolina Marine Artificial Reef Program and

monitoring through the MARMAP program. South Carolina has a list of species prohibited from import into the state that could be used to restrict importation of lionfish. In addition, the state could prohibit release of lionfish into state waters through existing laws.

6.13 STATE OF TEXAS

The Texas Parks and Wildlife Department (TPWD) is the state regulatory agency charged with management of coastal fisheries resources under the policy direction of the Texas Parks and Wildlife Commission and has an established method for prohibiting importation of certain species, including aquatic animals. Texas currently has no prohibition against lionfish, but the TPWD does understand the impact of these species and monitors and reports sightings. The Department will also continue to provide technical assistance as a member of the Committee, provide support for the implementation of the National Invasive Lionfish Prevention and Management Plan, and continue to support efforts through the state Aquatic Nuisance Species Plan. The artificial reef management group of TPWD also contributes to lionfish removal during their regular monitoring. These fish are measured and their stomachs are analyzed at the Flower Garden Banks National Marine Sanctuary facility in Galveston, Texas.

6.14 U.S. COMMONWEALTH OF PUERTO RICO

The Puerto Rico Department of Natural and Environmental Resources (DNER) has state constitutional authority over fish and wildlife, including responsibility to deal with terrestrial and aquatic invasive species. The DNER has worked with several NGOs, Sea Grant, some local schools, and others to inform the public through the press, word of mouth, television and radio about the lionfish invasion since its inception, and has encouraged research to inform management efforts. Local dive shops and local spear fishing enthusiasts have been key partners in control efforts and in training the diving public to capture lionfish. Several local restaurants have been offering lionfish on their menus for some time, but establishment of commercial fishing for lionfish has been difficult to achieve. Efforts are on-going to increase demand for lionfish, promoting it as a top-quality fishery product, and renowned local chefs are providing expert assistance. Ornamental fish collectors export small quantities of juvenile lionfish from Puerto Rico. Importation has been prohibited since 2004.

In 2010, DNER released new fishing regulations with specific measures to facilitate control of lionfish, within Marine Reserves (with a special permit) as well as outside of Reserves. DNER has provided Reserve management personnel and permitted divers with special gloves, pole spears, and lionfish dive flags to assist with their collaboration. The fishing regulations are due to be updated in 2014, and may include modifications to the lionfish management measures based on recent research and experience.

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6.15 U.S. VIRGIN ISLANDS

The U.S. Virgin Islands Department of Planning and Natural Resources (DPNR) is charged with protecting, preserving, and where feasible, enhancing and restoring the natural resources of the Virgin Islands. The first confirmed sighting of a lionfish in the waters off St. Croix in November 2008 impelled an ad-hoc working group made up of territorial resource managers and others from around the territory to develop a *Lionfish Response Plan for the U.S. Virgin Island.* Since the development of this response plan in 2009, the lionfish invasion in the territorial waters of the Virgin Islands went from occasional sightings of individual fish to numerous sightings of multiple fish from a variety of habitats and depth ranges. This rapid change in the abundance and distribution of the invasion prompted the DPNR and the Nature Conservancy to update and revise the response plan in February 2014 with specific strategies for education and outreach, removal, research and monitoring, marketing and communications. The Plan outlines approaches for decision-makers, marine managers, researchers, fishers, divers, and educators to implement in an effort to control the worst effects of the invasion. It also outlines some of the current research and management actions taking place in the Virgin Islands. A copy of the Plan can be found at:
http://virrp.reefconnect.org/wp-content/uploads/sites/3/2013/12/LionfishPlan_USVI_Update_Feb2014_sm.pdf.

NON-GOVERNMENTAL ORGANIZATIONS

6.16 REEF ENVIRONMENTAL EDUCATION FOUNDATION

The Reef Environmental Education Foundation (REEF) is a Key Largo, FL based marine conservation NGO with over 45,000 members and additional staff in San Diego, CA, Vancouver, WA, and Eleuthera, Bahamas. REEF focuses programs on solving marine conservation issues and has major initiatives dealing with grouper spawning aggregations, artificial reefs, effects of marine protected areas, and invasive species. REEF staff sit on the Florida advisory panels for the marine life trade and for artificial reefs and have been widely recognized for effective programs utilizing volunteers. REEF has worked in close partnerships and led efforts to address non-native marine fishes in Florida waters, including successful removals of Indo-Pacific batfishes and damselfish as part of an early detection rapid response program. REEF efforts in addressing the lionfish invasion through outreach, research, and response plan development have included work throughout the invaded region including primary research, consultations, and training workshops for resource managers. REEF also helped organize and conduct the first regional lionfish response planning workshop in Mexico in 2010 and has co-organized the annual lionfish session at the GCFI conference since 2009. REEF staff sit on the GSARP, have been invited experts in development of NPS and NMFS lionfish response plans and are the primary authors on the UNEP Best Practices for Lionfish Control and Research manual.

6.17 GULF STATES MARINE FISHERIES COMMISSION

The Gulf States Marine Fisheries Commission (GSMFC) was established by an Act of Congress (P.L. 81-66) in 1949 as a compact of the five states bordering the Gulf of Mexico. Its charge is to promote better utilization of the fisheries, marine, shell and anadromous, of the seaboard of the Gulf of Mexico. This is accomplished by the development of a joint program for the promotion and protection of such fisheries and the prevention of the physical waste of the fisheries from any cause. One of the roles the GSMFC fills is coordinating the activities of the GSARP and serving as an ex-officio member of the ANSTF. The GSMFC will help to implement the Plan through the activities of the GSARP.

6.18 THE NATURE CONSERVANCY

The Nature Conservancy (TNC) is working to build partnerships along the Gulf of Mexico that increase knowledge of the potential threats posed by invasive lionfish and identify control mechanisms to restore valuable habitats and reef communities. Its work in the Gulf ranges from building science-based products for managers such as the distribution database that TNC has developed in collaboration with the Gulf of Mexico Coastal Ocean Observing System and the Nonindigenous Aquatic Species Program of USGS (http://gcoos.org/products/maps/lionfish/) and facilitating TNC's international networks on lionfish to conducting trapping studies with Texas Parks and Wildlife Department. They also, co-organizing removals at sensitive areas in the Flower Garden Banks National Marine Sanctuary to educating stakeholders and citizens about the opportunities to control them to looking at policy opportunities for reducing future vectors of introduction that will expand their distribution and threats. TNC is facilitating across the Gulf of Mexico joining forces between scientists and resource managers and the conservation community to exchange data, practices and opportunities to identify future key actions in controlling the invasion of lionfish and restoring habitats. In the Caribbean, TNC has focused on invasive lionfish in the U.S. Virgin Islands, U.S. Commonwealth of Puerto Rico, and Bahamas working to build consumer awareness through a sustainable seafood campaign, encouraging commercial harvest and local marketing of lionfish, and convening forums for marine resource managers to discuss lionfish issues and strategies.

Although the work varies, our Gulf and Caribbean teams are working together and TNC is hosting a Wider-Caribbean Invasive Lionfish: Strategies, Actions and Tools web workspace on the Conservation Gateway.
(https://www.conservationgateway.org/ConservationPractices/Marine/HabitatProtectionandRestoration/Pages/lionfish.aspx).

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6.19 PET INDUSTRY JOINT ADVISORY COUNCIL

Pet Industry Joint Advisory Council (PIJAC) promotes responsible pet ownership and animal welfare, fosters environmental stewardship, and ensures the availability of pets. It is a nonprofit, service-oriented organization comprised of members who care about pets and the pet industry. PIJAC's primary role in assisting the implementation of the National Invasive Lionfish Prevention and Management Plan is to support outreach activities to the pet industry and pet owners on responsible pet husbandry practices.

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7.0 POINTS OF CONTACT FOR AIS ISSUES IN THE AFFECTED REGION

Agency	Website	Phone Number
Alabama Department of Conservation and Natural Resources	http://www.dcnr.state.al.us/	**(251) 861-2882**
Florida Fish and Wildlife Conservation Commission	http://myfwc.com/	**(850) 487-0554**
Georgia Department of Natural Resources	http://www.gadnr.org/	**(912) 264-7218**
Louisiana Department of Wildlife and Fisheries	http://www.wlf.louisiana.gov/	**(225) 765-2800**
Mississippi Department of Marine Resources	http://www.dmr.ms.gov/	**(228) 374-5000**
North Carolina Department of Environment and Natural Resources	http://portal.ncdenr.org/web/guest	**(252) 726-7021**
South Carolina Department of Natural Resources	http://www.dnr.sc.gov/	**(843) 953-9300**
Texas Parks and Wildlife Department	http://www.tpwd.texas.gov/	**(512) 389-4800**
Puerto Rico Department of Natural and Environmental Resources	http://www.drna.gobierno.pr/	**(787) 999-2200**
U.S. Virgin Islands Department of Planning and Natural Resources	http://www.digmeonline.com/?p=4296	**(340) 774-3320**

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8.0 PROPOSED INVASIVE LIONFISH PREVENTION AND MANAGEMENT FUNDING NEEDS

In this section of the Plan the Committee has outlined the estimated yearly funding needs to address some of the major knowledge and management gaps with the lionfish invasion, at the time of the plan's drafting. This is intended to be a living list, as funding needs may change as more is understood about invasive lionfish and new ways to manage the invasion are discovered.

Tasks	Objectives Addressed	Anticipated Outcomes of the Task	Estimated Yearly Cost
Lionfish Research	1.A, 1.B, 2.A, 2.B, 3.A, 3.B, 3.C, 3.D, 3.E, 3.F, 3.G, 4.A, 4.B, 4.C, 4.D	• Improved control procedures and tools. • Better understanding of impacts to native species and habitats. • Better ways to manage the invasion to minimize potential impacts. • Better description of the invasive lionfish population. • More complete understanding of the economic impacts of the lionfish invasion.	**$10,000,000**
Identify High Priority Sites and the Vectors of Introduction Threatening Them.	1.A, 1.C, 1.E, 3.B	• Provide a more focused approach to addressing the lionfish invasion. • Protect ecologically and economically important areas and native species from the impacts of invasive lionfish.	**$1,000,000**
Develop and Implement a Standardized Monitoring Program	1.A, 1.F, 2.A, 2.B, 2.C, 3.A, 3.D, 3.I, 4.A, 4.C, 4.D	• Help prevent new populations of invasive lionfish from becoming established. • Protect ecologically and economically important areas and native species from the impacts of invasive lionfish.	**$5,000,000**
Establish a Rapid Response Fund	1.A, 2.A	• Decrease response time to new sightings. • Provide timely funding to address new occurrences before a population can establish.	**$5,000,000**
Outreach	1.A, 1.C, 1.D, 2.A, 2.B, 3.A, 3.B, 3.F, 3.H, 4.B, 4.C, 4.D	• Increase awareness about the lionfish invasion. • Decrease response time to new sightings. • Help prevent new introductions. • Fully fund existing efforts (e.g. USGS NAS database)	**$1,000,000**

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APPENDIX 1: LIONFISH SPECIES IN TRADE

The sections below provide information on ten lionfish species (representing three genera) that are not known to be invasive in U.S. waters. For comparison, species descriptions are also given for the existing invasive lionfish within the Western Atlantic Ocean (*P. volitans* and *P. miles*). All of the species listed below are currently in trade. This list of lionfish species is by no means exhaustive, but rather demonstrative of lionfish in trade within the United States. Species descriptions were obtained from Fish Base (http://www.fishbase.org), a global database of fish species that provides comprehensive species data including information on taxonomy, geographical distribution, biometrics and morphology, behavior, habitats, ecology, and population dynamics (Fishbase, 2014). Species included in this Appendix are:

- Broadbarred firefish (*P. antennata*),
- Devil Lionfish (*P. miles*)
- Frillfin turkeyfish (*P. mombasae*),
- Radial firefish (*P. radiata*),
- Plaintail turkeyfish (*P. russelli*),
- Hawaiian Turkeyfish (*P. sphex*)
- Red lionfish (*P. volitans*)
- Hawaiian lionfish (*Dendrochirus barberi*),
- Twospot turkeyfish (*D. biocellatus*),
- Shortfin turkeyfish (*D. brachypterus*),
- Zebra turkeyfish (*D. zebra*), and
- Blackfoot firefish (*Parapterois heterura*).

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SPECIES ACCOUNT: broadbarred firefish (*Pterois antennata*) (Block, 1787)
Source for info and photos: http://www.fishbase.org/summary/4914

Figure A.1: This photograph of the broadbarred firefish (*Pterois antennata*) by J.E. Randall (26 February 1969) is of a specimen from Tahiti. It was 12.8 cm standard length and 16.8 cm total length (Fishbase, 2014).

Morphology

- Reddish to tan with many dark bars on its body.
- Median fins have scattered dark spots.
- Tentacle above the eye that is long with dark bands.
- Adults have bluish black blotches near the base of the pectoral fins.
- 13 dorsal spines; 11-12 dorsal soft rays; 3 anal spines; and 6 anal soft rays.

Distribution

- Indo-Pacific; East Africa to Marquesan and Mangaréva islands, north to southern Japan, south to Queensland, Australia and Kermadec and Austral islands.

Biology

- Occurs in lagoons and seaward reefs.
- Found in waters from 2-50 meters in depth.
- Cryptic and hides in crevices under rocks and coral formations during the day and hunts at night.
- Feeds on crustaceans including shrimps and crabs.
- Venom defense that is capable of inflicting a painful sting.

SPECIES ACCOUNT: devil lionfish (*Pterois miles*) (Bennett, 1828)
Source for info and photos: http://www.fishbase.org/summary/Pterois-miles.html

Figure A.2: This photograph of the devil lionfish (*Pterois miles*) by J.E. Randall (10 April 1975) is of a specimen from Sudan, Port Sudan. It was 10.6 cm standard length and 13.5 cm total length (Fishbase, 2014).

Morphology

- Reddish to tan or grey in color, with numerous thin dark bars on body and head.
- Tentacle above eye may be faintly banded.
- Adults have a band of small spines along the cheek and small spots on the median fins.
- 13 dorsal spine; 9-11 dorsal soft rays; 3 anal rays; and 6-7 anal soft rays.

Distribution

- Indian Ocean: Red Sea south to Port Alfred, South Africa and east to Sumatra, Indonesia.
- Invasive to the eastern Mediterranean and Western Atlantic Ocean.

Biology

- Lives in coastal waters in muddy habitats.
- Fin spines are highly venomous.

SPECIES ACCOUNT: frillfin turkeyfish (*Pterois mombasae*) (Smith, 1957)
Source for info and photos: http://www.fishbase.us/summary/10288

Figure A.3: This photograph of the frillfin turkeyfish (*Pterois mombasae*) by J.E. Randall (07 November 1993) is of a specimen from Kuria Muria Island, Oman. It was 14.1 cm standard length and 18.6 cm total length (Fishbase, 2014).

Morphology

- Reddish brown in color with alternating broad and thin dark bars, which are separated by white stripes and it has a dark spot on its cheek.
- Small tentacle above the eye which may have banding.
- Upper half of the pectoral fins have large dark spots located on the inner surface.
- 13 dorsal spine; 10 dorsal soft rays; 3 anal rays; and 6-7 anal soft rays.

Distribution

- Indo-West Pacific, first recorded in the northeastern Indian Ocean from Indonesia and Australia.
- Tropical reef-associated species, documented in Durban in South Africa, Sri Lanka, India, and New Guinea.

Biology

- Found at depths from 10-70 meters.
- Associated with soft-bottom or muddy substrates with rich rubble ridges amongst rich invertebrate growth, especially sponges and soft corals.
- Seldom found as an inhabitant of rocky bottoms of deep offshore reefs.
- Maybe found solitary or in small groups.

SPECIES ACCOUNT: radial firefish (*Pterois radiata*) (Cuvier, 1829)
Source for info and photos: http://www.fishbase.org/summary/Pterois-radiata.html

Figure A.4: This photograph of the radial firefish (*Pterois radiata*) by J.E. Randall (18 July 1978) is of a specimen from Mao Pi Tou, Taiwan. It was 10.0 cm standard length and 13.2 cm total length (Fishbase, 2014).

Morphology

- Reddish to brownish with 5-6 broad dark bars on the body, which are separated by pale lines.
- Horizontal dark area on the caudal peduncle.
- Only species of *Pterois* that lacks markings between its vertical fin rays and has a pair of horizontal white stripes at base of its tail.
- 12-13 dorsal spine; 10-12 dorsal soft rays; 3 anal rays; and 5-6 anal soft rays.

Distribution

- Indo-Pacific, documented in tropical waters ranging from 1-30 meters in depth in the Red Sea to Sodwana Bay, South Africa, to the Society Islands, north to the Ryukyu Islands, south to New Caledonia.

Biology

- Uncommon and inhabits lagoons and seaward reefs.
- Prefers rocky reefs and seems to avoid stony corals.

- Found in coastal areas in the surge zones inhabiting narrow crevices or in small caves along rock walls.
- Feeds exclusively on small crabs and shrimps.
- Venom defense and is capable of inflicting a painful sting.

SPECIES ACCOUNT: plaintail turkeyfish (*Pterois russelii*) (Bennett, 1831)
Source for info and photos: http://www.fishbase.org/summary/Pterois-russelli.html

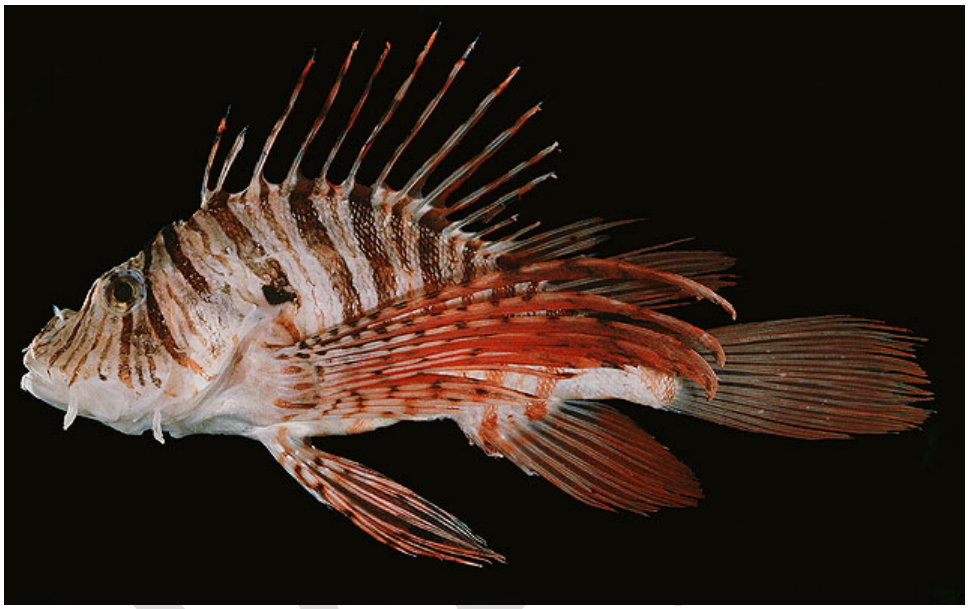

Figure A.5: This photograph of the plaintail turkeyfish (*Pterois russelii*) by J.E. Randall (10 March 1977) is of a specimen from Oman. It was 25.6 cm standard length and 34 cm total length (Fishbase, 2014).

Morphology

- Distinguished by having no spots on the median fins.
- Relatively shorter dorsal spines.
- 13 dorsal spine; 10-12 dorsal soft rays; 3 anal rays; and 7-8 anal soft rays.

Distribution

- Indo-Pacific, documented in tropical waters ranging in depth from 15-60 meters from the Persian Gulf and East Africa to New Guinea, south to Western Australia.

Biology

- Found on muddy substrates that are in well-protected shallow estuaries.
- Could be associated with deep offshore reefs.
- Solitary.

SPECIES ACCOUNT: red lionfish (*Pterois volitans*) (Linnaeus, 1758)
Source for info and photos: http://www.fishbase.org/summary/5195

Figure A.6: This photograph of the red lionfish (*Pterois volitans*) by J.E. Randall (17 April 1968) is of a specimen from Eniwetok, Marshall Islands. It was 10.5 cm standard length and 15 cm total length (Fishbase, 2014).

Morphology

- Cycloid scales and is variable in color which is usually in relation to habitat.
- In coastal individuals, the colors are generally darker, sometimes almost black in estuaries.
- Large tentacles above the eyes.
- 13 dorsal spine; 9-12 dorsal soft rays; 3 anal rays; and 6-8 anal soft rays.

Distribution

- Western Pacific Ocean, documented in tropical waters ranging in depth from 2-55 meters from the Cocos-Keeling Islands and Western Australia in the eastern Indian Ocean to the Marquesas and Oeno (Pitcairn group), north to southern Japan and southern Korea, south to Lord Howe Island, northern New Zealand, and the Austral Islands.

Biology

- Replaced by the very similar *Pterois miles* from the Red Sea to Sumatra.
- Inhabits lagoons and seaward reefs from turbid inshore areas.
- Often solitary.
- Hide in unexposed places during the daytime in a position where often the head is down and the individual is practically immobile.

- Pelagic juveniles expatriate over great distances, which is one factor for their broad geographical range.
- Hunt small fishes, shrimps, and crabs at night, using its widespread pectorals trapping prey into a corner, stunning it and then swallowing it in one swipe.
- Dorsal spines are venomous; the sting can be treated by heating the afflicted part and application of corticoids.
- Popular table fish.

SPECIES ACCOUNT: Hawaiian turkeyfish (*Pterois sphex*) (Jordan & Evermann, 1903)
Source for info and photos: **http://www.fishbase.org/summary/Pterois-sphex.html**

Figure A.7: This photograph of the Hawaiian turkeyfish (*Pterois sphex*) by J.E. Randall (20 March 1969) is of a specimen from Oahu, Hawaii. It was 15.4 cm standard length and 19.3 cm total length (Fishbase, 2014)

Morphology

- Pectoral rays all unbranched, very long and free from membrane distally.
- Dorsal spines are very long, some about as long as body depth.
- Ctenoid scales with about 50-55 vertical scale rows.
- Coronal spines present; most head spines become multiple with growth.
- Supraocular tentacles banded with black, frequently tentacles absent in large specimens.
- Small specimens with fewer bars on pectoral and pelvic fins.

Distribution

- Eastern Central Pacific, Native only to the Hawaiian Islands.

Biology

- Found in lagoons and seaward reefs.
- Generally hidden beneath ledges or caves during the day.
- Nocturnal feeder on crustaceans.

SPECIES ACCOUNT: Hawaiian lionfish (*Dendrochirus barberi*) (Steindachner, 1900)
Source for info and photos:
http://www.fishbase.org/Summary/SpeciesSummary.php?ID=7781&AT=green+lionfish

Figure A.8: This photograph of the Hawaiian lionfish (*Dendrochirus barberi*) by J.E. Randall (24 November 1967) is of a specimen from Kaneohe Oahu, Hawaii. It was 10.8 cm standard length and 14.0 cm total length (Fishbase, 2014)

Morphology

- Large pectoral fins with upper rays branched distally.
- Dorsal fin spines are longer than ½ its body depth, membranes are deeply incised.
- Ctenoid scales with 50-55 vertical scale rows.
- Coronal spines are branching in some large specimens.
- Suborbital ridge is a single row of spines.
- Supraocular tentacle, when present, is short and less than the orbit diameter and is usually without a black band.
- 13 dorsal spines; 9 dorsal soft rays; 3 anal spines; and 5 anal soft rays.

Distribution

- Eastern Central Pacific, documented from the Hawaiian Islands and reported from the Johnston Islands.

Biology

- Found under ledges in turbid lagoons and clear seaward reefs.
- Collected in depths from near shore to about 50 meters.
- Benthic and hides in crevices and caves during the day but, sometimes bentho-pelagic at night.

SPECIES ACCOUNT: twospot turkeyfish (*Dendrochirus biocellatus*) (Fowler, 1938)
Source for info and photos: http://www.fishbase.org/summary/5827

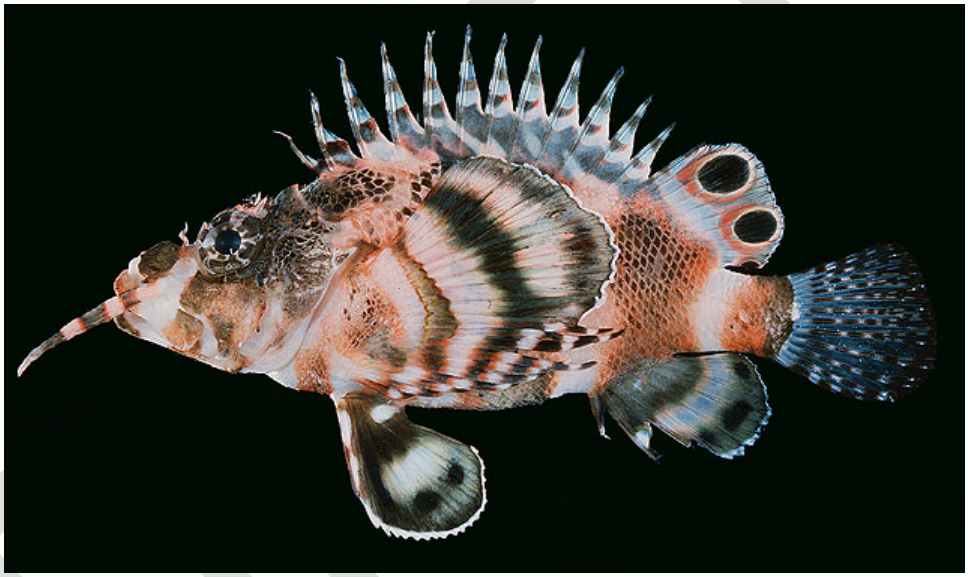

Figure A.9: This photograph of the twospot turkeyfish (*Dendrochirus biocellatus*) by J.E. Randall (26 February 1969) is of a specimen from Tahiti. It was 7.9 cm standard length and 10.0 cm total length (Fishbase, 2014).

Morphology

- Eye-like spots in the soft dorsal fin.
- Feeler-like tentacles in front of its mouth.
- Mid-dorsal spines are shorter than its body depth.
- Only species of *Dendrochirus* with a pair of distinct ocelli on the soft-rayed dorsal fin.
- 13 dorsal spines; 9 dorsal soft rays; 3 anal spines; and 5 anal soft rays.

Distribution

- Indo-Pacific, documented from Mauritius, Reunion, Maldives and Sri Lanka to the Society Islands, north to southern Japan, and south to Scott Reef.

Biology

- Found in waters 1-40 meters deep.
- Secretive and usually observed at night.
- During the day it can be found in caves and among sponges.
- Spines are venomous.

SPECIES ACCOUNT: shortfin turkeyfish (*Dendrochirus brachypterus*) (Cuvier, 1829)
Source for info and photos: http://www.fishbase.org/summary/4912

Figure A.10: This photograph of the shortfin turkeyfish (*Dendrochirus brachypterus*) by J.E. Randall (10 January 1973) is of a specimen from One Tree Island, Australia. It was 7.3 cm standard length and 10.0 cm total length (Fishbase, 2014).

Morphology

- Reddish with vague broad bars.
- Paired fins have bars, but the median fins have small dark spots.
- Mid-dorsal spines are shorter than the body depth.
- 13 dorsal spine; 9-10 dorsal soft rays; 3 anal rays; and 5-6 anal soft rays.

Distribution

- Indo-West Pacific, documented from the Red Sea and East Africa to Samoa and Tonga, north to southern Japan, south to Lord Howe Island, Mariana Islands in Micronesia, the Arafura Sea, and Australia.

Biology

- Reef-oriented species.

- Found in waters from 2-80 meters in depth.
- Found in reef flats and shallow lagoons where there are weed-covered rocks on sandy substrates Adults can be found on sponges, while juveniles are sometimes found in small aggregations on remote outcrops of coral reefs.
- Nocturnal and feeds on small crustaceans.

SPECIES ACCOUNT: zebra turkeyfish (*Dendrochirus zebra*) (Cuvier, 1829)
Source for info and photos: http://www.fishbase.org/summary/5828

Figure A.11: This photograph of the zebra turkeyfish (*Dendrochirus zebra*) by J.E. Randall (16 August 1971) is of a specimen from New Caledonia. It was 11.0 cm standard length and 14.2 cm total length (Fishbase, 2014).

Morphology

- Body is reddish with 5 dark bars and these bars are alternating with thin dark bars in large specimens.
- Median fins have small dark spots and there is a dark spot on the cheek.
- Mid-dorsal spines are longer than the body is deep.
- 13 dorsal spine; 10-11 dorsal soft rays; 3 anal rays; and 6-7 anal soft rays.

Distribution

- Indo-West Pacific, documented in tropical waters ranging in depth from 3-80 meters from the Red Sea and East Africa to Samoa, north to southern Japan and the Ogasawara Islands, south to Australia and Lord Howe Island.

Biology

- Found on coral, rubble, or rock bottoms of reef flats.
- Found on coastal to outer reef habitats in sheltered lagoons and in caves.
- Found in small aggregations.
- Pelagic stages travel great distances and have been found in sub-tropical zones.
- Spawned in captivity.

SPECIES ACCOUNT: blackfoot firefish (*Parapterois heterura*) (Bleeker, 1856)

Figure A.12: Photo of blackfoot firefish (*Parapterois heterura*). Photo by Klaus Stiefel: http://www.flickr.com/photos/pacificklaus.

Morphology

- Long filaments at the tips of the dorsal fin spines.
- Outer rays of the caudal fin.
- 13 dorsal spine; 9 dorsal soft rays; 2 anal rays; and 7-8 anal soft rays.

Distribution

- Indo-West Pacific, documented from Natal, South Africa to southern Japan.
- Range contains two populations, Western Pacific and Southeast African coast.

Biology

- Known from temperate waters ranging from 40-300 meters in depth.
- Usually found in sheltered coastal bays and areas with fine sand or muddy substrates.
- Partly bury itself in the substrate during the day, where it can be easily overlooked. When disturbed, it uses its brightly colored pectoral fins to startle predators.
- Large fins serve to corner prey when hunting.

APPENDIX 2: CURRENT RESEARCH

PEER-REVIEW JOURNAL ARTICLES FOCUSING ON PTEROIS SPECIES.

Research from the native range / Mediterranean Sea

Bariche M (2013) The presence of the invasive Lionfish Pterois miles in the Mediterranean Sea. Mediterranean Marine Science 14(2):292-294

Bernadsky G, Goulet D (1991) A Natural Predator of the Lionfish, Pterois miles. Copeia 1991(1):230-231

Church J, Hodgson WC (2002) Adrenergic and cholinergic activity contributes to the cardiovascular effects of lionfish (Pterois volitans) venom. Toxicon 40(6):787-796

Grubich JR, Westneat MW, McCord CL (2009) Diversity of lionfishes (Pisces: Scorpaenidae) among remote coral reefs of the Palau Archipelago. Coral Reefs 28(3):807

Kochzius M, Söller R, Khalaf MA, Blohm D (2003) Molecular phylogeny of the lionfish genera Dendrochirus and Pterois (Scorpaenidae, Pteroinae) based on mitochondrial DNA sequences. Molecular Phylogenetics & Evolution 28(3):396–403

Kochzius M, Blohm D (2005) Genetic population structure of the lionfish Pterois miles (Scorpaenidae, Pteroinae) in the Gulf of Aqaba and northern Red Sea. Gene 347(2):295-301

Kulbicki M, Beets J, Chabanet P, Cure K, Darling E, Floeter SR, Galzin R, Green A, Harmelin-Vivien M, Hixon M (2011) Distributions of Indo-Pacific lionfishes Pterois spp. in their native ranges. Marine Ecology Progress Series 446: 189-205

Matsunuma M (2013) Newly recognized diagnostic characters of the poorly known lionfish Pterois brevipectoralis (Scorpaenidae: Pteroinae), with notes on fresh coloration. Species Diversity 18(2):163-173

Naumann MS, Wild C (2013) Foraging association of lionfish and moray eels in a Red Sea seagrass meadow. Coral Reefs 32(4):1111

Prakash S, Balamurugan J, Kumar TTA, Balasubramanian T (2012) Invasion and abundance of reefinhabiting fishes in the Vellar estuary, southeast coast of India, especially the lionfish Pterois volitans Linnaeus. Current Science 103(8):941-944

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Turan C, Ergüden D, Gürlek M, Yağlıoğlu D, Uyan A, Uygur N (2014) First record of the Indo-Pacific lionfish Pterois miles (Bennett, 1828) (Osteichthyes: Scorpaenidae) for the Turkish marine waters. Journal of the Black Sea/Mediterranean Environment 20(2):158-163

Steinitz, H (1959) Observations on Pterois miles (L.) and its venom. Copeia 1959(2):159-161

Research from invaded range (Atlantic coast USA, Caribbean, Gulf of Mexico)

Aguilar-Perera A, Tuz-Sulub A (2010) Non-native, invasive red lionfish (*Pterois volitans* [Linnaeus, 1758]: Scorpaenidae), is first recorded in the southern Gulf of Mexico, off the northern Yucatan Peninsula, Mexico. Aquatic Invasions 5:S9−S12

Ahrenholz DW, Morris JA Jr (2010) Larval duration of the lionfish, *Pterois volitans* along the Bahamian Archipelago. Environmental Biology of Fishes 88:305−309

Albins MA (2013) Effects of invasive Pacific red lionfish *Pterois volitans* versus a native predator on Bahamian coral-reef fish communities. Biological Invasions 15:29−43

Albins MA, Hixon MA (2008) Invasive Indo-Pacific lionfish *Pterois volitans* reduce recruitment of Atlantic coral-reef fishes. Marine Ecology Progress Series 367:233−238

Albins MA, Lyons PJ (2011) Invasive red lionfish *Pterois volitans* blow directed jets of water at prey fish. Marine Ecology Progress Series 448:1-5

Albins MA, Hixon MA (2013) Worst case scenario: potential long-term effects of invasive predatory lionfish (*Pterois volitans*) on Atlantic and Caribbean coral-reef communities. Environmental Biology of Fishes 96:1151−1157

Alexander AK, Haynes JM (2011) Red Lionfish (*Pterois volitans*) Invade San Salvador, Bahamas: No Early Effects on Coral and Fish Communities. International Journal of Bahamian Studies 17:50-66

Anderson ET, Stoskopf MK, Morris JA Jr, Clarke EO, Harms CA (2010) Hematology, plasma biochemistry, and tissue enzyme activities in invasive red lionfish captured off North Carolina, USA. Journal of Aquatic Animal Health 22:266−273

Anton A, Simpson MS, Vu I (2014) Environmental and Biotic Correlates to Lionfish Invasion Success in Bahamian Coral Reefs. PLoS ONE 9(9): e106229. doi:10.1371/journal.pone.0106229

Arbeláez M N, Acero P A (2011) Presencia del pez león *Pterois volitans* (Linnaeus) en el manglar de la

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Bahía de Chengue, Caribe Colombiano. Boletín de Investigaciones Marinas y Costeras 40(2):431−435

Arias-González JE, González-Gándara C, Cabrera JL, Christensen V (2011) Predicted impact of the invasive lionfish Pterois volitans on the food web of a Caribbean coral reef. Environmental Research 111:917−925

Ascherl Z, Williams EH, Williams LB, Tuttle LJ, Sikkel PC, Hixon MA (2015) Parasitism in Pterois volitans (Scorpaenidae) from Coastal Waters of Puerto Rico, the Cayman Islands, and the Bahamas. Journal of Parasitology 101(1):50-56

Barbour AB, Montgomery ML, Adamson AA, Díaz-Ferguson E, Silliman BR (2010) Mangrove use by the invasive lionfish Pterois volitans. Marine Ecology Progress Series 401:291−294

Barbour AB., Allen MS, Frazer TK, Sherman KD (2011) Evaluating the potential efficacy of invasive lionfish (Pterois volitans) removals. PloS ONE 6(5):e19666

Bayraktarov E, Alarcón-Moscoso J, Polanco A, Wild C (2014) Spatial and temporal distribution of the invasive lionfish Pterois volitans in coral reefs of Tayrona National Natural Park, Colombian Caribbean. PeerJ. 2014; 2: e397. doi: 10.7717/peerj.397

Bejarano S, Lohr K, Hamilton S, Manfrino C (2015) Relationships of invasive lionfish with topographic complexity, groupers, and native prey fishes in Little Cayman. Marine Biology 162(2):253-266

Benkwitt CE (2013) Density-dependent growth in invasive lionfish (Pterois volitans). PloS ONE 8(6):e66995.

Betancur-R R, Hines A, Acero PA, Ortí G, Wilbur AE, Freshwater DW (2011) Reconstructing the lionfish invasion: insights into Greater Caribbean biogeography. Journal of Biogeography 38:1281−1293

Bhattacharyya J, Pal S (2011) Coexistence of competing predators in a coral reef ecosystem. Nonlinear Analysis: Real World Applications 12(2011):965−978

Biggs CR, Olden JD (2011). Multi-scale habitat occupancy of invasive lionfish (Pterois volitans) in coral reef environments of Roatan, Honduras. Aquatic Invasions 6(3):347−353

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Black AN, Weimann SR, Imhoff VE, Richter ML, Itzkowitz M. (2014) A differential prey response to invasive lionfish, Pterois volitans: Prey naiveté and risk-sensitive courtship. Journal of Experimental Marine Biology & Ecology 460:1-7

Bullard SA, Barse AM, Curran SS, Morris JA Jr (2011) First Record of a Digenean from Invasive Lionfish, Pterois cf. volitans,(Scorpaeniformes: Scorpaenidae) in the Northwestern Atlantic Ocean. Journal of Parasitology 97(5):833−837

Cerino D, Overton AS, Rice JA, Morris JA Jr (2013) Bioenergetics and trophic impacts of the invasive Indo-Pacific lionfish. Transactions of the American Fisheries Society 142(6):1522−1534

Chevalier PP, Gutiérrez E, Ibarzabal D, Romero S, Isla V, Calderín J, et al. (2008) Primer registro de Pterois volitans (Pisces: Scorpaenidae) para aguas cubanas. Solenodon 7:37−40

Claydon JAB, Calosso MC, Traiger SB (2012) Progression of invasive lionfish in seagrass, mangrove and reef habitats. Marine Ecology Progress Series 448:119−129

Côté IM, Green SJ (2012) Potential effects of climate change on a marine invasion: The importance of current context. Current Zoology 58(1):1-8

Côté IM, Maljković A (2010) Predation rates of Indo-Pacific lionfish on Bahamian coral reefs. Marine Ecology Progress Series 404:219−225

Côté IM, Green SJ, Hixon MA. (2013) Predatory fish invaders: Insights from Indo-Pacific lionfish in the western Atlantic and Caribbean. Biological Conservation 164:50-61

Côté IM, Green SJ, Morris JA Jr, Akins JL, Steinke D (2013b) Diet richness of invasive Indo-Pacific lionfish revealed by DNA barcoding. Marine Ecology Progress Series 472:249−256

Côté IM, Darling ES, Malpica-Cruz L, Smith NS, Green SJ, et al. (2014) What Doesn't Kill You Makes You Wary? Effect of Repeated Culling on the Behaviour of an Invasive Predator. PLoS ONE 9(4): e94248

Cure K, Benkwitt CE, Kindinger TL, Pickering EA, Pusack TJ, McIlwain JL, et al. (2012) Comparative behavior of red lionfish Pterois volitans on native Pacific versus invaded Atlantic coral reefs. Marine Ecology Progress Series 467:181−192

Cure K, Mcllwain JL, Hixon MA (2014) Habitat plasticity in native Pacific red lionfish Pterois volitans facilitates successful invasion of the Atlantic. Marine Ecology Progress Series 506:243-253

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Dahl KA, Patterson WF III (2014) Habitat-Specific Density and Diet of Rapidly Expanding Invasive Red Lionfish, Pterois volitans, Populations in the Northern Gulf of Mexico. PLoS ONE 9(8): e105852

Darling ES, Green SJ, O'Leary JK, Côté IM (2011) Indo-Pacific lionfish are larger and more abundant on invaded reefs: a comparison of Kenyan and Bahamian lionfish populations. Biological Invasions 13:2045−2051

de León R, Vane K, Bertuol P, Chamberland VC, Simal F, Imms E, et al. (2013) Effectiveness of lionfish removal efforts in the southern Caribbean. Endangered Species Research 22:175−182

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Elise S, Urbina-Barreto I, Boadas-Gil H, Galindo-Vivas M, Kulbicki M (2015) No detectable effect of lionfish (Pterois volitans and P. miles) invasion on a healthy reef fish assemblage in Archipelago Los Roques National Park, Venezuela. Marine Biology 162:319-330

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Fishelson L (2006) Evolution in action-peacock-feather like supraocular tentacles of the lionfish, Pterois volitans - the distribution of a new signal. Environmental Biology of Fishes 75(3):343-348

Fortunato RC, Avigliano E (2014) Presence of genus Pterois (Oken, 1817) (Scorpaeniformes, Scorpaenidae): extension of invasive range in Caribbean Sea and first published record for Los Frailes Archipelago. JournalofFisheriesSciences.com 8:1−4

Frazer TK, Jacoby CA, Edwards MA, Barry SC, Manfrino CM (2012) Coping with the lionfish invasion: can targeted removals yield beneficial effects? Reviews in Fisheries Science 20(4):185−191

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Freshwater DW, Hines A, Parham S, Wilbur A, Sabaoun M, Woodhead J, et al. (2009). Mitochondrial control region sequence analyses indicate dispersal from the US East Coast as the source of the invasive Indo-Pacific lionfish Pterois volitans in the Bahamas. Marine Biology 156:1213−1221

Fung LAH, Antoine JMR, Grant CN, Buddo DS (2013) Evaluation of dietary exposure to minerals, trace elements and heavy metals from the muscle tissue of the lionfish Pterois volitans (Linnaeus 1758). Food and Chemical Toxicology 60:205-212

González J, Grijalba-Bendeck M, Acero PA, Betancur R (2009) The invasive red lionfish, Pterois volitans (Linnaeus 1758), in the southwestern Caribbean Sea. Aquatic Invasions 4(3):507−510

González JD, Acero PA, Serrat LA, Betancur R (2011) Caracterización taxonómica de la población del pez león Pterois volitans (Linnaeus 1758) (Scorpaenidae) residente en el Caribe colombiano: merística y morfometría. (Spanish). Biota Colombiana. 12(2):15-22

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Green SJ, Akins JL, Maljković A, Côté IM (2012) Invasive lionfish drive Atlantic coral reef fish declines. PLoS ONE 7(3):e32596

Green SJ, Tamburello N, Miller SE, Akins JL, Côté LM (2013) Habitat complexity and fish size affect the detection of Indo-Pacific lionfish on invaded coral reefs. Coral Reefs 32:413−421

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Guerrero KA, Franco AL (2008) First record of the Indo-Pacific red lionfish Pterois volitans (Linnaeus, 1758) for the Dominican Republic. Aquatic Invasions 3(2):267−268

Hackerott S, Valdivia A, Green SJ, Côté IM, Cox CE, Akins L, et al. (2013) Native predators do not influence invasion success of Pacific lionfish on Caribbean reefs. PloS ONE 8(7):e68259

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Ilves KL, Kellogg LL, Quattrini AM, Chaplin GW, Hertler H, Lundberg JG (2011) Assessing 50-year change in Bahamian reef fish assemblages: Evidence for community response to recent disturbance. Bulletin of Marine Science 87(3):567-588

Johnston MW, Purkis SJ (2011) Spatial analysis of the invasion of lionfish in the western Atlantic and Caribbean. Marine Pollution Bulletin 62:1218−1226

Johnston MW, Purkis SJ (2012) Invasionsoft: a web-enabled tool for invasive species colonization predictions. Aquatic Invasions 7(3):405−417

Jud ZR, Layman CA (2012) Site fidelity and movement patterns of invasive lionfish, Pterois spp., in a Florida estuary. Journal of Experimental Marine Biology and Ecology 414–415:69−74

Jud ZR, Nichols PK, Layman CA (2014) Broad salinity tolerance in the invasive lionfish Pterois spp. may facilitate estuarine colonization. Environmental Biology of Fishes. doi: 10.1007/s10641-014-0242-y

Jud ZR, Layman CA, Lee JA, Arrington DA (2011) Recent invasion of a Florida (USA) estuarine system by lionfish Pterois volitans/P. miles. Aquatic Biology 13(1):21−26

Kimball ME, Miller JM, Whitfield PE, Hare JA (2004) Thermal tolerance and potential distribution of invasive lionfish (Pterois volitans/miles complex) on the east coast of the United States. Marine Ecology Progress Series 283: 269-278

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Layman CA, Allgeier JE (2012) Characterizing trophic ecology of generalist consumers: a case study of the invasive lionfish in The Bahamas. Marine Ecology Progress Series 448:131−141

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