

Chapter 1: Lionfish distribution, biology, and ecology

Densities and biophysical distribution of the invasion

The Indo-Pacific lionfish (*Pterois volitans* and *P. miles*) is now considered to be one of the most notorious invasive marine finfish in history (Morris et al. 2009). *P. volitans* (red lionfish) occur throughout most of Oceania, between the Marshall Islands and Fiji to French Polynesia (Schofield et al 2009). *P. miles* (devil firefish) are traditionally found between the Red Sea and the Indian Ocean; however established populations have also been documented within Sumatran coral reef ecosystems (Schofield et al. 2009).

Lionfish hold the distinction of being the first successfully established non-native marine fish both along the U.S. east coast and throughout the Caribbean Sea (Morris and Akins 2009). Although both confirmed and anecdotal invasive lionfish sightings have been reported since the 1980's, it wasn't until 2000 that lionfish sightings began to increase exponentially across the Atlantic and Caribbean (Schofield 2009). In 2000 and 2001, multiple lionfish sightings were recorded off of South Florida, Georgia, North Carolina, South Carolina, and even as far north as Fire Island, New York (Schofield 2009). By 2008, invasive lionfish had been spotted off the Turks and Caicos Islands, Cuba, the Cayman Islands, Jamaica, the Dominican Republic, the U.S. Virgin Islands, Belize, and Barbados (Schofield 2009; Schofield et al. 2011). By the end of 2010, lionfish had become established throughout the Caribbean Sea, across the Gulf of Mexico, and along the Northeastern coast of South America (Schofield et al. 2011; Aguilar-Perera and Tuz-Sulub 2010; Lasso-Alcalá and Posada 2010).

Lionfish sighted in coastal waters off New York's Long Island, Rhode Island, and Massachusetts are presumed to have been swept northward by the gulfstream current after being

spawned off the U.S. southeastern continental shelf (Kimball et al. 2004). Because lionfish have only been sighted inshore north of Cape Hatteras NC during summer months, it's hypothesized that these fish only survive in these locations until water temperatures drop below 10°C (Kimball et al. 2004). This seasonal fluctuation in the lionfish's invasive range is similar to many other species of native tropical Atlantic fish, whose juvenile populations are sighted inshore of the northeastern U.S. continental shelf during the warmer summer months (Able 1998).

Estimates for lionfish densities in the Atlantic were first compiled in 2007, where mean lionfish densities measured off the coast of North Carolina in 2004 averaged 21 individuals per hectare across 17 different locations (Whitfield et al. 2007). By 2008, mean lionfish densities in these locations had increased by approximately 130 lionfish per hectare, with some sites exhibiting over 450 lionfish per hectare in 2007 (Morris and Whitfield 2009). Lionfish density estimates within its native range (~80 adult *P. miles* in a 1-km stretch of Red Sea reef) suggest that lionfish are not only thriving in the Western Atlantic, but that their invasive populations are at least several orders of magnitude larger than those populations found within the fish's native range (Green and Côté 2009). These findings were further supported in 2009, when Green and Côté estimated that lionfish densities along the Bahamian Archipelago were five times greater than those within Red Sea reefs where lionfish naturally occur (Green and Côté 2009).

Biological and physical factors that control lionfish densities across its native Indo-Pacific range are not yet fully understood (Morris and Whitfield 2009). Lionfish are reported to have few natural predators, and Atlantic sea basses (*Centropristis striata*) have demonstrated avoidance for lionfish as prey in laboratory experiments, even after long periods of induced starvation (Morris and Akins 2009). Despite recent evidence that tiger groupers (*Mycteroperca tigris*) and Nassau groupers (*Epinephelus striatus*) may prey on lionfish, such large body

predators have been systematically overfished throughout the Caribbean, and thus are unlikely to substantially counter the invasive lionfish threat posed towards Atlantic coral-reef ecosystems (Maljković et al. 2008).

Genetics and taxonomy

“Invasive lionfish” is actually a generic term that includes two distinct species, *Pterois miles* Bennett 1828 and *P. volitans* Linnaeus 1758, the later being far more common throughout the Western Atlantic (Hamner et al. 2007). These morphologically similar sister species are distinguishable by subtle visual characteristics (*P. volitans* exhibits one additional dorsal and anal fin ray), however identifying these differences becomes increasingly difficult as meristics overlap in co-occupied areas (Hamner et al. 2007; Morris and Whitfield 2009). It is currently unknown whether *P. miles* and *P. volitans* hybridize, although the reproductive biology of both species is identical (Morris and Whitfield 2009). Recent assessments have confirmed that invasive lionfish have low genetic diversity when compared to their Indo-Pacific counterparts; a phenomenon apparent among a wide variety of invasive species undergoing the early stages of introduction (Hamner et al. 2007; Freshwater et al. 2009).

Reproductive biology

Both *P. miles* and *P. volitans* are gonochoristic pair spawners that exhibit complex courtship behavior prior to spawning (Morris and Whitfield 2009). Lionfish courtship usually occurs shortly before dark and may extend well into the nighttime hours (Fishelson 1975). Following courtship, female lionfish release two buoyant egg masses that are fertilized by the male as they ascend to the surface (Morris et al. 2009). Although the seasonality of lionfish

reproduction in their native range is unknown, lionfish collected off North Carolina and the Bahamas appear to reproduce year-round and at a frequency of approximately every four days (Morris 2009).

Early life history and larval dispersal

Dispersal of lionfish presumably occurs during the fish's pelagic larval phase (Morris et al. 2009). Recent assessments of lionfish larval duration suggests that settlement occurs around 26 days post hatch, a pelagic larval duration that facilitates dispersal via oceanographic currents such as the gulfstream, the Gulf of Mexico loop current, and the Caribbean current (Cowen et al. 2006; Ahrenholz and Morris 2010). The larval duration of lionfish is likely to vary, depending on oceanographic factors such as water temperature (Morris and Whitfield 2009).

Natural predators and predatory defenses

Lionfish rely on venomous spines as their primary means of predatory defense (Morris and Whitfield 2009). With the exception of its caudal spines, lionfish contain apocrine-type venom glands on their 13 dorsal spines, 3 anal spines, and two pelvic spines (Morris et al. 2009). Spines possessing venom are encased in an integumentary sheath or skin, and contain two glandular interlateral grooves that extend three quarters the length of the spine from its base (Halstead et al. 1955). Lionfish envenomation occurs when the spine's integumentary sheath is ruptured upon entering the victim. Upon penetration, the integumentary sheath's glandular tissue is torn and venom is diffused throughout the puncture wound (Saunders and Taylor 1959).

Lionfish venom is composed of acetylcholine and a neurotoxin that affects neuromuscular transmission (Cohen and Olek 1989). Lionfish venom has been found to cause a

variety of cardiovascular, neuromuscular, and cytolytic effects in humans, ranging in severity from minor swelling to extreme pain, bleeding, anxiety, convulsions, and paralysis (Kizer et al. 1985; Vetrano et al. 2002). The severity of lionfish envenomation reactions in humans varies depending on the amount of venom delivered into the wound, the immune system health of the victim, and the location of the sting (Kizer et al. 1985; Vetrano et al. 2002). Lionfish stings in humans can be treated either by applying heat to the affected area, or by neutralizing effects of the sting with the antivenom of the closely related stonefish (*Synanceia* spp.) (Shimomi et al. 1989; Church and Hodgson 2002; Ventrano et al. 2002).

Lionfish venom defense against predation is not well documented, nor is much understood about the feeding ecology and behavior practiced by the lionfish's natural predators. Malijković et al. (2008) reported that lionfish were found in the stomachs of groupers native to the Bahamas. This observation, however, provides no assessment of the frequency of lionfish consumption by grouper (Morris and Whitfield 2009). Additional research is needed to identify and understand the trophic relationships between lionfish and any potential natural predators, and whether such predation pressure is potentially significant enough to control invasive lionfish populations.

Feeding ecology

Lionfish are highly piscivorous but also consume crustacean prey including penaeid and mysid shrimps (Morris and Whitfield 2009). Lionfish feed on more than 40 species of small-bodied forage fishes, including apogonids, gobiids, grammatids, labrids, and pomacentrids, as well as juvenile lutjanids, mullids, serranids, and other commercially and recreationally important fish (Morris and Akins 2009). Many of these prey fish are among the most abundant

forage fishes in Atlantic and Caribbean coral reefs, and are staples in the diets of economically important species such as snappers and groupers (Morris and Akins 2009; Morris et al. 2009). Within its native Indo-Pacific range, *P. miles* also feed on benthic reef fishes including damselfish, cardinal fish, and anthias (Fishelson 1997). Estimates of daily consumption rates of *P. volitans* determined that lionfish stomachs can expand over 30 times in volume after consuming a large meal, and that a single lionfish could consume approximately 2.5-60% of its body weight per day at water temperatures between 25 and 26 °C. (Fishelson 1997).

Chapter 2: Causes and consequences of the lionfish invasion

Potential sources of introduction

The establishment of invasive marine fish populations can begin via several various pathways, including introduction into non-native environments to improve fisheries resources, range expansion through canals and channels, transport in ballast water, and intentional (or unintentional) aquarium or aquaculture releases (Baltz 1991; Courtenay 1993). Although some of the most prevalent U.S. policy regulations aimed at preventing invasive species introductions focus almost exclusively on ballast water releases, lionfish were most likely first introduced into the Atlantic through both intentional and unintentional aquarium releases (Hare and Whitfield 2003). This hypothesis is highly plausible, especially after considering that in 2003 lionfish were listed as one of the more valuable live marine fish imported into the U.S. (constituted 28% of the 36.6 million dollar aquarium trade industry for that year), with 7,562 live lionfish being shipped through the Tampa airport alone over a six month period (Balboa 2003; Ruiz-Carus et al. 2006). Genetic analysis also suggests that current invasive lionfish populations originated from Indonesia, the common country of origin for many lionfish imported into the U.S. through the overseas marine aquarium trade (Hamner et al. 2007). It's highly unlikely that lionfish were ever introduced into the Atlantic through ballast water discharge, as no other Pacific marine fish is known to have ever been introduced into the western Atlantic Ocean via this vector (Hare and Whitfield 2003).

Although lionfish were most likely introduced into the Atlantic via the aquarium trade, the specific circumstances under which the first lionfish were initially introduced remain a mystery. Regardless of the circumstances by which the first invasive lionfish were introduced,

the specific sequence of events that triggered the lionfish invasion will never be known with absolute certainty. What is known, however, is that the ornamental aquarium trade provided an ideal vector through which the lionfish invasion could begin (Hare and Whitfield 2003).

The number of lionfish reported from 1985 to 2000 in south Florida provides strong evidence that this area was the location of the first lionfish introduction(s) (Ruiz-Carus et al. 2006; Hamner et al. 2007). South Florida is a known hot-spot for other marine introductions, with over 30 species of non-native marine and estuarine fish reported there over the past decade (Schofield et al. 2009). Recent genetic research has revealed no distinction between Bahamian and Southeast U.S lionfish specimens, which helps explain the connectivity between the chronological documentation of lionfish sighting locations, and the directionality of the gulfstream, Gulf of Mexico loop current, and Caribbean currents (Hare and Whitfield 2003; Freshwater 2009).

Lionfish ecological impacts

The spread of lionfish populations across southeastern U.S. waters, throughout the Caribbean, across the Gulf of Mexico, and into the southeastern Atlantic should be of tremendous concern for fisheries and coastal managers of these regions. Coral reef environments in these areas are already under tremendous pressure stemming from coral bleaching, overfishing, pollution, disruptive algal growth, and global climate change (Wilkinson and Souter 2008). The addition of a nonindigenous predatory reef fish to these systems may cause irreparable damage to the ecological characteristics and services these areas provide.

Lionfish feed predominately on small-bodied teleost fish, which are an important component of the diet of many commercially important tropical and northwestern Atlantic fish.

The proportional importance of crustaceans in a lionfish's diet is inversely proportional to its size, as large adult lionfish feed almost exclusively on teleost fish (Morris and Akins 2009). Future monitoring of invasive lionfish feeding activity may also reveal "prey-switching" over time, whereby crustaceans would comprise a greater percentage of a lionfish's diet as teleost prey became less available, regardless of a lionfish's body size (Morris and Whitfield 2009). An increase in crustacean consumption by lionfish would further decrease the availability of prey for commercially important fish, as crustaceans are a staple in the diet of several juvenile and adult serranid species (Eggleston et al. 1998).

Lionfish represent a potentially major threat to coral-reef ecosystems in the Caribbean region by decreasing survivability of a wide variety of native reef animals through either direct predation or competition (Albins and Hixon 2011). In 2008 it was observed by Albins and Hixon that a single lionfish could reduce recruitment of reef fish populations on a Bahamian reef by 79% in just five weeks (Albins and Hixon 2008). Lionfish have also been documented preying upon several species of herbivorous fish and crustaceans, including parrotfish, surgeonfish, and cleaner shrimp, whose removal through predation may contribute to uncontrolled algal growth, increased cases of fish parasitism, and nutrient overloading of impacted coral reef ecosystems (Mumby et al. 2006; Morris and Akins 2009). Finally, because lionfish are increasingly being viewed as highly influential reef fish predators, the further dispersal and establishment of invasive lionfish populations may serve to catalyze negative trophic cascades across invaded reef habitats, where invasive lionfish successfully takeover the top-level predator niches of coral reef ecosystem formerly occupied by large native predatory species (Albins and Hixon 2011; Fishelson 1997).

These concerns are also applicable to the possible relationship that exists between invasive lionfish and species of the Southeastern Atlantic Snapper-Grouper Complex (SGC). The SGC, which consists of snappers, groupers, porgies, triggerfish, jacks, tilefishes, grunts, spadefishes, wrasses, and sea basses, is a valuable regional fishery that is heavily exploited by both commercial and recreational fishermen (Huntsman et al. 1999). The overharvesting of SGC species may provide a “niche vacancy” throughout surrounding reef fish communities (Huntsman et al. 1999). The occupation of this vacated niche by lionfish could be problematic for stock rebuilding programs presently underway for the SGC, both in the Southeastern U.S. and Caribbean regions. Not only would the establishment of lionfish as a top level reef predator increase SGC species juvenile mortality through predation by lionfish, but vital coral habitats could be degraded more quickly from more frequent predation on herbivorous fishes by lionfishes relative to native SGC species (Albins and Hixon, 2011). Lionfish impacts will likely be more apparent in those locations currently experiencing the highest levels of stress from other detrimental biological and abiotic factors, particularly in those coral reef ecosystems found throughout the Caribbean (Morris and Whitfield 2009). Understanding and predicting lionfish impacts will ultimately depend on solid baseline knowledge of the marine communities that lionfish invade. Future research emphasis and collection of this data is needed to elucidate lionfish ecological impacts, especially in locations where no estimates of the long term variability (seasonally, annually, etc.) of small-bodied finfish exist (Morris and Whitfield 2009).

Lionfish socioeconomic impacts

The socioeconomic impacts of the lionfish invasion have only just begun to be realized by marine fisheries and coastal managers, both in the U.S. and abroad (Morris and Whitfield

2009). While the vast majority of economic damage caused by invasive species (120 billion dollars within the U.S. alone in 2005) occurs within terrestrial and freshwater systems, the threat lionfish now poses to marine goods and services is substantial (Ruiz et al. 1997; Albins and Hixon 2011). Serious enough is this threat that the lionfish invasion is now recognized internationally as one of the world's most serious conservation issues (Albins and Hixon 2011). Predominate areas of concern for coastal communities and industry includes lionfish impacts on commercial fisheries, the aquarium trade, and coastal tourism (Morris and Whitfield 2009).

Although the full extent of economic damage caused by lionfish on U.S. fisheries has yet to be realized, multiple scenarios exist that could seriously hamper future fisheries management and rebuilding efforts. As invasive lionfish populations become more established, increased lionfish predation pressure could result in a significant decline in prey for commercially important native species (Morris and Akins 2009). Furthermore, lionfish have also been documented feeding directly on economically important yellowtail snapper (*Ocyurus chrysurus*) and Nassau grouper (*Epinephelus striatus*) (Morris and Akins 2009). Although these species currently seem to comprise only a small portion of the lionfish's diet, the explosion of invasive lionfish populations over the last decade suggests that direct predation on these commercially important species may become more frequent should lionfish population expansion trends continue (Morris and Akins 2009).

During the earlier stages of the lionfish invasion, instances of invasive lionfish serving as an attraction for recreational divers and coastal tourists were observed (Morris and Whitfield 2009). More recently, however, the focus amongst most dive operators has shifted toward lionfish removal rather than attraction (Morris and Whitfield 2009). The tremendous impact that lionfish can have on reef fish recruitment not only reduces commercially important fish stocks,

but also reduces overall coral reef marine biodiversity (Morris and Whitfield 2009). In heavily invaded areas such as the Bahamas, many divers are tiring of witnessing massive abundances of lionfish and relative low abundances of other species (L. Akins, REEF, pers. comm.). The increased frequency of lionfish encounters by divers and swimmers also poses a serious health risk to humans, as lionfish envenomation cases may also increase in regions economically dependent on coastal tourism (Morris and Whitfield 2009). As of 2011, several south Atlantic and Caribbean coastal resorts have gone as far to post signs along their beaches warning swimmers of possible lionfish envenomation risks (Morris et al. 2009; L. Akins, REEF, pers. comm.). Although it's uncertain whether lionfish will eventually contribute to reductions in coastal recreational activities within invaded waters should their populations continue to grow unchecked, economic losses caused by lionfish on coastal tourism and recreational industries will be largely dependent upon factors such as the prevalence of lionfish warning signs along affected beaches, the effectiveness of lionfish education and outreach, and the future management practices controlling lionfish populations within inshore waters (Morris and Akins, 2009).

It has yet to be determined whether initial aquarium sales of lionfish have fallen since the onset of the lionfish invasion (Morris and Whitfield 2009). As lionfish have become a more common sight throughout the Atlantic, it's possible that the exotic nature of lionfish as a marine ornamental fish may lose its allure to aquarists and the public alike. Given that lionfish is a valuable imported marine ornamental fish species in the U.S, the negative economic impact to the U.S. aquarium trade could be significant (Ruiz-Carus et al. 2006).

Chapter 3: The players: management authorities and supporting entities

Introduction

Between 2000 and 2010 a handful of federal offices, state agencies, international programs, U.N. protocols, and professional organizations have sought to educate the public on the severity of the lionfish invasion. While many sources of information regarding invasive lionfish ecology and distribution exist, literature that analyzes the roles and authorities of those groups or individuals currently managing invasive lionfish is limited at best.

The following chapter serves as an attempt to list and summarize major authorities involved with current invasive lionfish removal and managerial efforts within U.S. jurisdictional waters. Although every group, organization, or council mentioned here share a similar goal of limiting and/or reversing the proliferation of invasive lionfish populations, the sources and quantities of financial and political support for each group may vary. This invariably influences the priorities, methods, and interests behind each group's actions, and should be considered when identifying roles for potential managerial authorities in future invasive lionfish control plans.

Because the majority of marine and coastal governance throughout U.S. waters is divided into sectors, the authorities addressed in this chapter will be organized into sectors as well (Crowder et al. 2006). Specifically, authorities mentioned in this chapter will be categorized as representing regional fishery management councils, federal agencies, non-profit organizations, international groups, or interagency councils, thereby making the task of finding overlaps and inefficiencies between sectors more straightforward. By summarizing the roles, representation, and authority of those currently fighting against the spread of invasive lionfish populations, gaps

and overlaps in management practices can be addressed in earnest, and the transition from sector-based to ecosystem-based lionfish management can occur more smoothly.

Regional Fishery Management Councils

Caribbean Fishery Management Council

The Caribbean Fishery Management Council was created by Section 302 (a)(1)(D) of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), and is one of eight regional management councils whose purpose is to conserve and manage U.S. fishery resources within the Caribbean Sea (16 U.S.C. § 1801 et seq.). Of these eight regional management councils, the CFMC along with the South Atlantic Fishery Management Council deal directly with lionfish populations that may threaten the fishery resources over which they preside. The CFMC consists of 10 members, representing both the U.S. Virgin Islands and the Commonwealth of Puerto Rico (United States of America Regional Fishery Management Councils 2009). As with the seven other regional fishery management councils established under the MSFCMA, the primary responsibility of the CFMC is to create management plans for fishery resources (FMPs) applicable to the Exclusive Economic Zone (EEZ), seaward of all states, commonwealths, territories, and U.S. possessions within its jurisdiction (16 U.S.C. § 1801 et seq.). FMP's created by the CFMC are submitted to the US Secretary of Commerce for final approval and implementation, and FMPs currently under CFMC authority include spiny lobster, queen conch, reef fish, and coral (United States of America Regional Fishery Management Councils 2009).

Although there are currently no FMPs in place for lionfish, during the 1st Regional Lionfish Strategy Workshop in Cancun Mexico the CFMC was identified as a potential

mechanism through which support and implementation for a regional lionfish plan could be founded, in cooperation with the NOAA International Coral Reef Conservation Program (NOAA CRCP), the Western Central Atlantic Fishery Commission (WECAFC), and several other international regional authorities (Lozano 2010a). Furthermore, invasive lionfish directly compete with species managed under the CFMC reef fish FMP for food, and may influence future regulatory amendments and catch limitations set forth by the CFMC for this fishery (Morris and Akins 2009).

South Atlantic Fishery Management Council

The South Atlantic Fishery Management Council (SAFMC) is the second authoritative body created under the MSFCMA that is currently addressing the lionfish invasion, and is directly responsible for the management of the highly valuable Snapper-Grouper Complex (United States of America Regional Fishery Management Councils, 2009). In September of 2010, the SAFMC presented a collection of findings which ascertained the potential impact of non-native species to marine ecosystems falling within the SAFMC sphere of management (South Atlantic Fishery Management Council (SAFMC) 2010). From these findings the SAFMC established new policies aimed at protecting south Atlantic marine ecosystems from invasive species, and minimize the potential negative impacts invasive species could pose on the ecological and socioeconomic services these ecosystems provide (South Atlantic Fishery Management Council (SAFMC) 2010).

Besides representing a rare example where fisheries management policy is integrated with marine invasive species control strategies, these SAFMC policies also set forth regulatory guidelines pertaining directly to lionfish occurring within the south Atlantic. Not only do these

policies promote the creation of National Aquatic Nuisance Species Task Force management plans for marine invasives such as lionfish in state and near-shore waters, but the SAFMC also encourages the development of novel fishing gears (excluding SAFMC-prohibited fish traps) that effectively and unobtrusively remove lionfish from South Atlantic marine ecosystems (South Atlantic Fishery Management Council (SAFMC) 2010). The SAFMC upholds the policy of support for the harvest, eradication and/or removal of lionfish from areas of high ecological and economic importance (i.e. marine protected areas and national marine sanctuaries), and in instances where invasive species already belong to groups of organisms included in Fishery Management Units (FMU's), these species would need to be excluded from that FMU via an FMP amendment (or existing framework) before control or eradication programs for that species could be implemented (South Atlantic Fishery Management Council (SAFMC) 2010). Although this later policy was aimed particularly at species of stony corals by the SAFMC, this policy also pertains to invasive lionfish, as this policy eliminates the possibility of one day harvesting lionfish within a group of associated organisms already under SAFMC authority, such as the Snapper-Grouper Complex.

Federal Government

NOAA Center for Coastal Fisheries and Habitat Research (CCFHR)

The National Centers for Coastal and Ocean Science represents the focal point of coastal ocean science research within NOAA's National Ocean Service (NOS). Within this collection of science centers, the CCFHR provides coastal resource managers with scientific expertise on issues such as habitat restoration, spatial planning, algal bloom ecology, and shoreline response to climate change (NOAA's National Centers for Coastal Ocean Science, 2011b).

The CCFHR constitutes two separate marine laboratories. The first laboratory is based in Kasitsna Bay, Alaska, while the second laboratory is based in Beaufort, NC. Through partnerships with both the Reef Environmental Education Foundation (REEF) and the US Geological Survey (USGS), the CCFHR laboratory in Beaufort is NOAA's leading scientific resource on the lionfish invasion, and has provided scientific and managerial expertise on invasive lionfish since 2000, both domestically and internationally. As a leading source of information regarding invasive lionfish biology, ecology, distribution, and ecological/socioeconomic impacts, CCFHR scientists have authored and released over a dozen major invasive lionfish publications between the years 2002-2010 (NOAA's National Centers for Coastal Ocean Science, 2011a). CCFHR scientists have also helped train and educate scuba diving enthusiasts and the general public on the problems invasive lionfish pose to marine ecosystems, and have helped support lionfish round-up diving tournaments organized by local diving businesses.

U.S. Department of State (DOS) Office of Oceans and Polar Affairs (OPA)

The Office of Ocean and Polar Affairs (OPA) is a part of the State Department's Bureau of Oceans and International Environmental and Scientific Affairs (OES). The OPA is responsible for formulating and implementing U.S. policy on international issues concerning the oceans, the Arctic, and Antarctica, and whose primary objectives include the stewardship of the marine environment from pollution and other anthropogenic threats such as invasive species (United States State Department Office of Ocean and Polar Affairs 2011). The OPA is supervised by the Bureau's Deputy Assistant Secretary for Oceans and Fisheries, who maintains authority over the use of office resources, oversees U.S. government compliance with international agreements, and

evaluates how recent advances in ocean and fishery technology and science could affect U.S. foreign policy interests (United States State Department Office of Ocean and Polar Affairs 2011).

The OPA currently acts as an international advisory and educational resource regarding the development of the lionfish invasion (United States State Department Office of Ocean and Polar Affairs 2011). Through these offices, the State Department participates in the Global Invasive Species Programme, an international partnership that seeks to conserve biodiversity by minimizing the spread and impact of invasive species (United States State Department Office of Ocean and Polar Affairs 2011). The OPA also helps facilitate interagency coordination efforts in order to improve the efficiency of National Invasive Species Council collaboration, conferring with NOAA's technical expertise on the lionfish invasion so that the State Department can best determine how to engage other countries on the issue of lionfish management (A. Muir, OPA, pers. comm.).

Non-profit Organizations

Caribbean Oceanic Restoration and Education (CORE) Foundation

The primary mission of the Caribbean Oceanic Restoration and Education (CORE) Foundation is to promote the proactive removal of lionfish from its invasive range, while encouraging collaboration in lionfish management between other non-governmental organizations, scientists, and marine managers (Caribbean Oceanic Restoration and Education (CORE) Foundation 2011). CORE is also a strong advocate for public education and outreach regarding Caribbean coral reef environmental issues, and providing professional growth

opportunities for student coral reef conservationists (Caribbean Oceanic Restoration and Education (CORE) Foundation 2011).

A major component of the CORE foundation is the Caribbean Lionfish Response Program, whose goal is to remove as many lionfish as possible from the Caribbean Sea, including (but not limited to) the territorial waters of Puerto Rico and the US Virgin Islands (Caribbean Oceanic Restoration and Education (CORE) Foundation 2011). CORE's lionfish removal efforts thus far have generally comprised of numerous lionfish removal dives made throughout the lionfish's invaded range by trained volunteer scuba divers, who are assisted both by local dive shops and native commercial fishermen. Currently as part of a Caribbean Alliance created on March 25th, 2010, representatives of both Puerto Rico and the US Virgin Islands are working together with CORE through the Caribbean Lionfish Response Program, in order to more effectively manage lionfish that may threaten their local marine habitats (Caribbean Oceanic Restoration and Education (CORE) Foundation 2011).

Reef Environmental Education Foundation (REEF)

The Reef Environmental Education Foundation is a non-profit organization whose purpose is to link certified scuba divers to the international community of marine scientists, marine sanctuary and manager staffers, and the general public, through marine life data collection and other related activities (Reef Environmental Education Foundation 2011a). REEF achieves this primarily through its volunteer fish monitoring program, the REEF Fish Survey Project (Reef Environmental Education Foundation 2011a).

As of 2009, REEF has been directly involved in the removal of over 4,000 lionfish throughout its invaded range, and more recently have overseen the removal of nearly 2,000

lionfish from both Florida and the Bahamas during the summer of 2011 (Reef Environmental Education Foundation 2011c). REEF holds numerous workshops aimed at increasing awareness, building upon local capacity to confront the invasion directly, and help develop rapid response plans for areas of high ecological and socioeconomic value (particularly marine sanctuaries and marine protected areas throughout the Caribbean) (Reef Environmental Education Foundation 2011b). Over 600 divers have been trained in early detection, rapid response, and lionfish removal methods. REEF also serves as the mainstay of lionfish sighting data for the USGS Nonindigenous Aquatic Species database and range maps (Reef Environmental Education Foundation 2011b). New programs, including lionfish seafood marketing, removal derbies, and other novel control strategies are currently under development in cooperation with NOAA's National Centers for Coastal and Ocean Science (L. Akins, REEF, pers. comm.).

International

International Coral Reef Initiative (ICRI)

The International Coral Reef Initiative (ICRI) is a global partnership between numerous national governments, international organizations, and non-government organizations whose mission is to preserve coral reefs in accordance with Agenda 21, Chapter 17 of the U.N. Convention of the Law of the Sea (UNCLOS) (United Nations Convention of the Law of the Sea 1992). ICRI was established in response to the international recognition that coral reefs and related ecosystems found in tropical and sub-tropical oceans are facing serious threats from anthropogenic stresses such as nutrient loading and global warming (United Nations Convention of the Law of the Sea 1992). Since the mid 1990's ICRI has served as an advisory body to promote better practices in coral reef conservation efforts on a global scale, and incorporate

environmentally friendly coral reef policies into different local, regional and national coastal management plans (International Coral Reef Initiative 2011).

In response to the lionfish invasion, ICRI hosted the 1st Regional Lionfish Strategy Workshop in Cancun, Mexico (Lozano 2010a). Throughout the duration of the workshop, participating ICRI representatives assisted in providing suggestions regarding the future development of a best practices manual to serve as the foundation of a regional strategic framework for lionfish control in the wider Caribbean, Gulf of Mexico, and Atlantic Ocean (Lozano 2010a). ICRI has since urged nations affected by invasive lionfish to develop appropriate frameworks and actions at the national level to limit and control the invasion, and invite scientific institutions and private sector businesses to collaborate in region-wide lionfish response efforts (Caribbean Environment Programme 2011b).

Protocol Concerning Specially Protected Areas and Wildlife (SPAW Protocol)

On April 16th, 2003, The U.S. government ratified the Protocol Concerning Specially Protected Areas and Wildlife (SPAW Protocol), a regional agreement between 13 nations supporting biodiversity conservation across the Wider Caribbean Region (WCR) (United Nations Environment Programme 1990). Because of the large number of island nations occurring within the relatively small area of the Caribbean Sea, almost the entire WCR marine environment falls into one nation's exclusive economic zone or another, contributing to the partition of the majority of the Caribbean Sea to the authority of the Caribbean's many island nations rather than international law (United Nations Environment Programme 1990). The SPAW Protocol was therefore enacted in consideration of these regional geographic proximities, and in recognition

that regional cooperation and coordination would be essential for successful sustainable development in the region (United Nations Environment Programme 1990).

The primary objectives of the SPAW Protocol are to protect, preserve, and manage the marine habitats and threatened species of the WCR's coral reef ecosystems (United Nations Environment Programme 1990). In order to accomplish these objectives, the SPAW Protocol serves as the legal focal point through which ICRI conducts its coral reef ecosystem monitoring, management, and conservation activities, including its involvement in Caribbean lionfish monitoring and removal efforts (Lozano 2010). The U.S. government is assisted in meeting objectives set by global conventions in support of SPAW through the SPAW Sub-Programme (Caribbean Environment Programme 2011b). Global conventions that support the goals of SPAW include the Convention on Biological Diversity (CBD), the International Coral Reef Initiative (ICRI), CITES, and Ramsar (Caribbean Environment Programme 2011b).

Inter-agency councils

Aquatic Nuisance Species (ANS) Task Force

The Aquatic Nuisance Species (ANS) Task Force is an intergovernmental organization dedicated to preventing and controlling aquatic nuisance species, and implementing protocol as decreed by the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) of 1990 (16 U.S.C. § 4701 et seq.). Initially enacted to better regulate ballast water discharge protocol in U.S. ports, the NANPCA was later amended to include all aquatic nuisance species besides those introduced through ballast water, leading to the creation of the National Invasive Species Act (NISA) in 1996 (NISA; P.L. 104-332; 16 U.S.C. § 4701 et seq.). The ANS Task Force consists of 13 federal agency representatives, and is co-chaired by members of the US Fish

and Wildlife Service (USFW) and NOAA (16 U.S.C. § 4701 et seq.). The ANS Task Force coordinates government efforts dealing with aquatic nuisance species in the U.S., helping direct private sector efforts and other North American interest groups via regional panels and issue-specific committees.

The ANS Task Force has recently acknowledged lionfish as an ANS of serious environmental and social concern (South Carolina 2008; Georgia 2009). Besides promoting education and awareness amongst the public and representatives of various federal departments, the ANS Task Force also serves as the authoritative body responsible for approving state and interstate ANS management plans organized and submitted by state governors (16 U.S.C. § 4701 et seq.).

National Invasive Species Council (NISC)

The National Invasive Species Council (NISC) is an inter-departmental council that helps coordinate and ensure complementary, cost-efficient, and effective federal activities regarding invasive species. NISC was established on February 3rd, 1999 after the passage of Executive Order 13112 (64 *Fed. Reg.* 6183, Feb. 8, 1999). Council members include three co-chairs: the Secretaries of the Agriculture, Commerce, and Interior. Other council members include the Secretaries of State, Treasury, Defense, Transportation, and the Administrator of the Environmental Protection agency (EPA) (64 *Fed. Reg.* 6183, Feb. 8, 1999). Council staff which help to support all council activities includes an Executive Director, an Assistant Director for International Policy, Science, and Cooperation, and an Assistant Director for National Policy and programs.

In accordance with Executive Order 13112, the NISC is responsible for producing an integrative national management plan (NMP) for all invasive species occurring within the U.S. every two years. The Council released its first NMP in January 2001, which serves as a blueprint for all federal action on invasive species. The plan was written in association with eight invasive species working groups, including research, early detection and rapid response, leadership and coordination, control and management, information management, communication and outreach, international agreements, and prevention (National Invasive Species Council 2001).

Although the most recent NISC plan drafted for the 2008-2012 term does not cite lionfish specifically as a particular species of concern in need of addressing for targeted invasive species control and management, council members and staff representing the various departments of the federal government are becoming increasingly aware of the growing severity of the lionfish invasion. While the Council itself does not hold any actual authoritative power for invasive species action to be carried out by law, the Council does represent an inter-agency collaboration that raises awareness of invasive species issues while promoting coordination between participating departments to prevent conflicts of interest, thereby benefiting lionfish monitoring and control programs organized by NISC affiliated organizations and departments.

Chapter 4: The tools: a guide to lionfish legislative mandates and management

Introduction:

Most of the major invasive species mandates that regulate the actions of authorities mentioned in chapter 3 have only come into effect within the past 10-20 years. Although a vast majority of invasive species legislation was initially enacted to protect terrestrial and freshwater environments and services, laws addressed in this chapter can either be applied to, or directly address managing marine ecosystems and marine invasive species such as lionfish.

The following chapter provides a comprehensive listing of major federal laws and executive orders that mandate authoritative power over invasive lionfish control, or maintain strong legal authority over those marine resources directly threatened by the invasion. Descriptions regarding the purpose and relevance to invasive lionfish behind each of these laws will be provided, and legislation targeting invasive lionfish management that has yet to be presented before Congress will also be reviewed, specifically H.R. Resolution 132 on invasive lionfish submitted by Congresswoman Donna M. Christensen on March 1st, 2011.

The purpose of the following chapter is to provide the reader a foundational understanding of the laws, executive orders, and government policies that govern how, and to what extent authorities listed in chapter 3 can currently manage invasive lionfish populations. The brief descriptions provided for each of the mandates mentioned here may serve to promote future discussion and debate amongst political and managerial experts on the applicability and future direction of invasive species laws, particularly those regulating current invasive lionfish management.

Federal legislation and executive orders

Coastal Zone Management Act (1972)

The Coastal Zone Management Act (CZMA) is one potential avenue through which lionfish control and management efforts can be supported by the Department of Commerce (DOC) (16 U.S.C. § 1451 et seq.). The purpose of CZMA is to bring attention to the growing challenges facing coastal and marine ecological and socioeconomic services (DOC) (16 U.S.C. § 1451 et seq.). Federal and state governments are encouraged to work together to “preserve, protect, and whenever possible, restore and enhance the resources of the nation’s coastal zone for this and succeeding generations” (16 U.S.C. § 1451 et seq.). CZMA also promotes federal assistance in state government efforts towards achieving “wise use” of land and water resources policies across all U.S. state and territorial waters (16 U.S.C. § 1456 [Section 307]).

The CZMA protects more than 99% of the nation's 95,331 miles of coastline, and directs state and federal management of marine resources and habitats in U.S. waters (16 U.S.C. § 1451 et seq.). Resources and habitats protected under the CZMA are threatened not only by invasive lionfish, but are also threatened by global warming, ocean acidification, and coastal development (16 U.S.C. § 1451 et seq.). In December 2010, the NOAA Office of Ocean and Coastal Resource Management released a contextual indicators manual for CZMA performance measurement, whereby non-native species of invertebrates, protozoans, algae, and fungi occurring in “tidal waters” were identified as biological indicators for CZMA implementation effectiveness (United States NOAA Office of Ocean and Coastal Resource Management 2010). Although non-native marine fish are currently excluded as biological indicators from this document, their inclusion into this policy could help clarify and supplement legislative authority over invasive lionfish, and

improve lionfish management throughout invaded tidal waters (i.e. mangrove forests) (Barbour et al. 2010).

Endangered Species Act (1973)

The Endangered Species Act (ESA) provides a federally supported program for the conservation of threatened and endangered species, including fish that are preyed upon by invasive lionfish (16 U.S.C. § 1531 et seq.). The ESA also provides the USFWS and the National Marine Fisheries Service (NMFS) the authority to consult other federal agencies whose actions or policies may otherwise jeopardize the continued existence of an endangered plant or animal (16 U.S.C. § 1531 et seq.). As lionfish predation on endangered species such as the Nassau Grouper becomes a more frequent and observable occurrence, the ESA may provide the legal justification to improve invasive lionfish removal and eradication measures both in scope and effectiveness. Furthermore, should presently non-threatened lionfish prey species become endangered in the future due to increased lionfish feeding activity, section 4 of the ESA outlines the protocol by which a species can be classified as “endangered” from resulting natural and man-made factors, including predation by invasive species (16 U.S.C. § 1533).

Executive Order 13112 (1999)

On February 3rd, 1999, former president Clinton signed Executive Order 13112, revoking former president Carter’s 1977 Executive Order 11987 on exotic species management. The primary purpose of Executive Order 13112 was to prevent future introduction of invasive

species onto U.S. territory, and have the technical expertise in place to control invasive species populations should they become established (64 *Fed. Reg.* 6183, Feb. 8, 1999). To best achieve the aims set forth by this executive order, the National Invasive Species Council (NISC) was created. Co-chaired by the Secretaries of Agriculture, Commerce, and the Interior, the Council's membership includes the Secretaries of Defense, Health and Human Services, State, Transportation, and Treasury, as well as the administrators of the Agency for International Development and the EPA.

In bringing together these federal constituents under the NISC, invasive species issues, concerns, and suggestions could be shared in an open forum, and gaps and overlaps in policy between federal agencies could be minimized or avoided altogether (64 *Fed. Reg.* 6183, Feb. 8, 1999). Because of Executive Order 13112 and the establishment of the NISC, federal policies and actions across multiple departments can be coordinated and implemented more smoothly, as representative authorities become more aware of how their actions might either curtail or unintentionally exacerbate the lionfish invasion.

National Invasive Species Act (1996)

The National Invasive Species Act (NISA) is a reauthorized and amended version of the Non-Indigenous Aquatic Nuisance Prevention and Control Act (NIANPCA) of 1990 (NISA; P.L. 104-332; 16 U.S.C. § 4701 et seq.). The NIANPCA created a national Task Force co-chaired by the Director of the U.S. Fish and Wildlife Service (USFW) and the Undersecretary of Commerce for Oceans and Atmosphere (16 U.S.C. § 4701 et seq.). This Task Force was charged with developing and implementing a program to prevent the unintentional introduction and dispersal of aquatic nuisance species through improved ballast water management policies (16

U.S.C. § 4701 et seq.). The Task Force was also directed to develop and implement a program for U.S. state waters to prevent the introduction and dispersal of aquatic nuisance species, and to monitor, control and study such species should they become established (16 U.S.C. § 4701 et seq.).

States, through their respective governors, may submit their own comprehensive management plans to the Task Force for approval. These management plans identify areas or activities within each state or the surrounding region involving the reduction or elimination of risks associated with aquatic nuisance species.

National Marine Sanctuary Act (2000)

The National Marine Sanctuary Act (NMSA) established the National Marine Sanctuary System, the purpose of which is to improve the conservation, understanding, management, and sustainable use of marine resources (16 U.S.C. § 1431 et seq.). The U.S. network of National Marine Sanctuaries serves to enhance public awareness, understanding, and appreciation for the marine environment, and to maintain for future generations “the habitat and ecological services of the natural assemblages and living resources that inhabit these areas” (16 U.S.C. § 1431 et seq.).

The NMSA requires that the DOC take action promoting and coordinating the use of marine sanctuaries for research, monitoring, and education (16 U.S.C. § 1431 et seq.). In addition, the DOC may issue special use permits for specific activities, and if necessary establish conditions of access and use of any sanctuary resources in order to promote better public use and understanding of that resource (16 U.S.C. § 1431 et seq.).

A major key in successful lionfish management regards the appropriate allocation and use of finite resources and support. It is for this reason why managing lionfish populations effectively in the most ecologically and economically important U.S. coastal and marine habitats (i.e. National Marine Sanctuaries) is so vital. Section 304 of the NMSA provides NOAA's National Marine Sanctuary Program with the authority necessary to issue regulations specifying the types of lionfish management activities in these areas, and requires the periodic update of management plans that guide the day-to-day activities within each sanctuary (16 U.S.C. § 1431 et seq.).

Upcoming legislation addressing invasive lionfish

H.R. 132 (2011)

On March 3rd 2011, U.S. Virgin Islands delegate to Congress Donna M. Christensen submitted a resolution to Congress expressing the need to raise awareness and address the lionfish invasion. H.R. 132 of the 112th Congress was referred to the House Committee on Natural Resources, and specifically called for three national actions to be taken as soon as possible. First, the resolution urges for the development of a comprehensive, scientifically based region-wide strategy for addressing lionfish in the Atlantic that includes actions such as local management plans and international partnerships (H.RES.132.IH). Second, the resolution supports scientific research and capacity building to develop and implement responses to the lionfish invasion (H.RES.132.IH). Lastly, the resolution encourages raising public awareness about the lionfish invasion across the United States and its territories, especially in affected coastal communities through outreach and education (H.RES.132.IH).

Although having been submitted too recently for Congress to respond as of this analysis, this resolution is still an unprecedented victory for raising awareness on invasive lionfish issues and management. The resolution stands as the first example of a single political figure calling for effective targeted action against invasive lionfish in the form of a formal resolution to Congress. At the very least, the submittal of H.R. 132 to Congress may encourage further public and professional awareness of the invasive lionfish issue, and may encourage other congressional representatives or political leaders to take similar stances against lionfish.

Chapter 5: Invasive lionfish management options: state and territorial waters

Introduction

The ability of U.S. states and territories to safeguard marine ecosystems from invasive lionfish is directly related to how effectively and collaboratively all involved agencies implement their authorities at international, national, regional, state, and local levels. While federal agencies and non-profit organizations such as NOAA and REEF have helped pioneer lionfish control and management practices throughout federally managed national marine sanctuaries, the contributions and leadership provided by U.S. state and territorial authorities should not be discounted. Just as international organizations such as the International Coral Reef Initiative (ICRI) are helping to organize joint-Caribbean national invasive lionfish management plans, the improved coordination of lionfish control efforts outside the authority of the federal government could be a potential option for future U.S. lionfish management practices and policy.

According to the Submerged Lands Act of 1953, the majority of coastal U.S. states and the U.S. Virgin Islands territory are granted jurisdiction over a region extending 3 nautical miles seaward from their shores (United States Commission on Ocean Policy 2004). For historical reasons, the state waters of Texas, the gulf coast of Florida, and Puerto Rico are characterized as spanning 9 nautical miles from shore (United States Commission on Ocean Policy 2004). Although the federal government retains power to regulate matters of national security, commerce, and power generation throughout state waters, states are given the authority to manage and lease marine resources throughout the water column, and on/or beneath the seafloor spanning these designated areas (United States Commission on Ocean Policy 2004).

The seasonal variation of inshore water temperatures is a limiting factor for lionfish distribution across the U.S. east coast (Kimball et al. 2004). U.S. state seaward boundaries during warmer summer months, however, are unprotected from the potential ecological and socioeconomic damage lionfish could inflict. From 1992 to 2011, over 240 lionfish sightings occurred along a 175 mile stretch of Florida coastline between Palm Bay and Miami Beach, all of which took place within 5 miles from shore (Schofield et al. 2011). Besides being associated with rocky and coral reefs, lionfish have also been associated with inshore mangrove habitats, seagrass beds, and man-made canals (Morris and Akins 2009; Barbour et al. 2010). These inshore sightings typically constitute juvenile lionfish spawned by breeding populations established along the U.S. Atlantic continental shelf, where winter minimum temperatures rarely drop below 16 °C (Morris and Whitfield 2009). The increased likelihood of lionfish envenomations in humans during summer months may persuade coastal communities reliant on marine tourism to formulate management strategies for lionfish control within their state's jurisdictional waters.

The purpose of this chapter is to organize and present lionfish management options that can be utilized at state and territorial levels. The organization and analysis of state and territorial management options for lionfish is necessary for successful lionfish population control practices in the future, both between neighboring state authorities and in collaboration with federal and non-governmental agencies.

Three options for lionfish management in state waters are: 1) To augment independently formulated lionfish management plans such as those seen in Florida and invaded U.S. territorial waters, 2) Develop lionfish management strategies within state ANS task force sponsored plans, and 3) Develop a regional ANS task force sponsored lionfish management plan. While none of

these options alone provide solutions of universal appeal to all U.S. shareholders connected to the lionfish invasion, the discussion and analysis of these options do provide insights regarding the predominate complexities that challenge invasive species managers at the state and territorial level. As with all policy issues in ocean governance, management plans invariably have negative tradeoffs no matter how ingenious and beneficial the strategy (M.K. Orbach, DUMML, pers. comm.). It is therefore the primary objective of this analysis to provide an unbiased, in-depth look at the pros and cons behind each available option, so that future state and territorial managers can weigh the qualities of these options against their specific socioeconomic and environmental circumstances.

Option #1: Develop independent lionfish management plans

Current state and territorial management plans for aquatic invasive species such as lionfish fall into two general categories. The first category constitutes interstate invasive species management plans organized and approved by interstate or inter-territorial authorities. U.S. states and territories currently implementing such plans include Florida, Puerto Rico, and the U.S. Virgin Islands (Kojis 2009; Lozano 2010b; McCawley 2010).

Florida state waters extend 9 nautical miles offshore into the Gulf of Mexico, and 3 nautical miles offshore into the Atlantic Ocean (United States Commission on Ocean Policy 2004). Outside of federally managed marine parks and protected areas, invasive lionfish occurring within this designated area fall primarily under the authority of the Florida Fish and Wildlife Conservation Commission (McCawley 2010). Since 2007, the FWC has taken several major steps to address the lionfish invasion in Florida's state waters, including enforcing prohibition of releasing privately owned lionfish into the wild without a permit, and the drafting

of lionfish handling and collection protocol in Florida state waters as top priority for the 2011-2012 Florida Division of Marine Fisheries Management (DMFM) Work Plan (McCawley 2010). Although sources of stakeholder support and funding for lionfish management programs proposed in the DMFM work plan have yet to be identified, these proposed strategies place a higher interest in managing lionfish specifically than previously seen in other more generalized state invasive species management plans (McCawley 2010). Furthermore, Florida interstate management of lionfish is also unique in that it addresses preventing the introduction of lionfish into the Atlantic through the enforcement of a permit system, historically limited to only freshwater nonnative species.

Lionfish management off the coasts of Puerto Rico and the U.S. Virgin islands has also been put into effect through the implementation of regionally supported management plans, in collaboration with their island's divisions of planning and natural resources, federal agencies such as NOAA, and non-government stakeholders such as REEF, CORE, and ICRI (Lozano 2010b). While Puerto Rico currently has no formal lionfish management plan written up, lionfish management strategies and practices in Puerto Rico's territorial waters are currently being implemented under the supervision of the Puerto Rico Department of Natural Resources (DNER) (Lozano 2010b). These management practices include the prohibition of live lionfish importation onto the island, the regular monitoring and removal of invasive lionfish by DNER response teams across San Juan's public beaches and bridge support areas, the promotion of lionfish sale and consumption, and the support of lionfish education and research in Puerto Rico by DNER, REEF, and other organizations (Lozano 2010b). Lionfish management in Puerto Rico has thus far achieved some limited successes in disseminating information about the lionfish invasion and controlling populations of lionfish in limited areas, however many challenges still remain

including focusing fishing efforts on lionfish without increasing fishing effort on overfished stocks, and a need for funding to further promote lionfish derbies and purchase deep water collection gear for divers (\$5000 was provided to the DNER lionfish removal effort by the Caribbean Fisheries Management Council for the 2010-2011 fiscal year) (Lozano 2010b).

Lionfish management and control within coastal waters of the U.S. Virgin Islands primarily constitutes strategies presented within the territory's 2009 Lionfish Response Management Plan, funded under the Island's Experimental Program to Stimulate Competitive Research (EPSCoR) (Kojis 2009). The strategies presented in this plan are unique to other interstate and territorial plans because specific objectives for lionfish education, monitoring, and removal efforts are listed, and managerial authorities are indicated and committed to specific managerial tasks within specific areas over specified windows of time (Kojis 2009). Although the organization of proposed lionfish management effort in the Virgin Islands since 2009 is substantial, sources of funding are limited and sporadic (Kojis 2009). The National Park Service on St. Croix has committed to provide funds necessary to support several 1-2 member scuba lionfish monitoring teams for 12 days in 2010; however the majority of lionfish sighting and monitoring strategies outlined in this plan rely heavily on volunteer divers trained through collaborating nonprofit diving organizations like CORE and REEF (Kojis 2009).

Option #2: Develop lionfish management strategies through state ANS plans

Clearly there are a number of issues which limit state and territorial governments from effectively addressing the lionfish problem on their own, particularly due to the lack of available staff and funding necessary to take full advantage of existing state laws, regulations, and programs. To address these issues, Congress passed the Nonindigenous Aquatic Nuisance

Prevention and Control Act of 1990 (later amended in 1996 to the National Invasive Species Act), which provided guidance for the establishment of state aquatic nuisance species (ANS) management plans (Aquatic Nuisance Species Task Force 2010). A major benefit available to states provided by the NANPCA is outlined Section 1204, where governors of states and interstate entities may submit comprehensive ANS management plans to an ANS task force for funding approval (Aquatic Nuisance Species Task Force 2010). If the plan is approved, the state or interstate entity who submitted the plan becomes eligible for federal financial assistance for up to 75% of costs incurred to implement all proposed management plan objectives (Aquatic Nuisance Species Task Force 2010).

Currently the lionfish-invaded coastal states of Louisiana, Georgia, and South Carolina have ANS Task force approved plans in place, while Texas, Mississippi, Alabama, and North Carolina still have plans under development. Of the three states with approved ANS plans, Georgia and South Carolina list lionfish specifically as a high priority species in need of immediate attention by state authorities (South Carolina 2008; Georgia 2009).

State's currently (or in the process of) implementing state ANS plans have the advantage of receiving federal financial assistance within 90 days after submitting a proposed plan to the ANS Task Force (Aquatic Nuisance Species Task Force 2010). Unfortunately, funds provided by the federal government to support these state plans must be divided amongst all ANS listed species for that state. Georgia's ANS management plan, for example, lists 27 additional species of fish, invertebrates, plants, etc., in addition to lionfish, in need of immediate managerial attention (Myszewski 2009). Furthermore, an interstate lionfish management plan has yet to be drafted and submitted to the ANS Task Force for approval. This lack of information regarding specific cost-effective lionfish management action and managerial authority, from the Task

Force's perspective at least, may further divert funds away from specific lionfish management needs proposed in all current and upcoming ANS state plans.

Option #3: Develop a regional (ANS) lionfish-specific management plan

A third viable option currently under discussion is the feasibility of implementing an ANS approved regional lionfish management plan across all invaded state and territorial waters. Although such an ANS sponsored plan for an invasive marine finfish would be unprecedented, species-specific ANS regional plans have been proposed for freshwater invasive fish, most notably for Asian Carp in the Great Lakes region in 2007 [(Bighead carp (*Hypophthalmichthys nobilis*), Silver carp (*Hypophthalmichthys molitrix*), Black carp (*Mylopharyngodon piceus*), and Grass carp (*Ctenopharyngodon idella*)]. Using both the ANS regional management plans for Asian Carp and the European Green Crab as a model, an ANS approved regional lionfish plan could a) evaluate the feasibility of management options for the eradication and control of invasive lionfish in U.S. state waters, b) identify the acting lionfish authorities and legislation currently in place that should be consulted and collaborated with, and c) provide a structured, phased implementation plan that includes approximate timetables and costs of priority for lionfish monitoring, control, and eradication tasks (Grosholz and Ruiz 2002; Conover et al. 2007).

The contents of this document, along with other professional lionfish management publications and discussions, could help establish a working foundation for meeting the first two objectives listed above. Unfortunately, the current extent and nature of the lionfish invasion may make achieving objective (c) difficult within state waters. The ecological and socioeconomic impacts lionfish may have on inshore marine habitats could be both devastating and far-reaching,

however it has already been determined that lionfish occurring within these waters are likely the offspring of adult lionfish populations established along the gulfstream and offshore reefs, usually well outside of state jurisdictional waters. Furthermore, the seasonal variation in near shore water temperature makes the potential threat lionfish pose to state marine resources highly variable, particularly in waters outside of the lionfish's established invasive range such as north of Cape Hatteras, NC. The huge expanse of potentially threatened coastal areas, the seasonal and environmental variability posed by lionfish within these areas, and the location of the source of the problem (i.e. breeding adults) outside of state jurisdiction, all contribute to making the creation of a stable, cost-effective regional lionfish management strategy infinitely more complicated, and fails to curtail the introduction of invasive lionfish into state waters at the source.

Chapter 6: Invasive lionfish management options: federal waters and fisheries

Introduction

Official management considerations for lionfish occurring in U.S. waters has until now been viewed predominately as a federal government issue, both by marine policy makers and marine scientists alike. Because established invasive lionfish populations occurring along both the gulfstream and within National Marine Sanctuaries currently represent the greatest cause of concern for marine managers, lionfish have only recently received attention by state-governments after individual fish have “spilled-over” from established offshore populations into state jurisdictional waters. Although state and independent lionfish management efforts have progressed rapidly over the past several years, it’s important to note that the overwhelming majority of these efforts have been supported at some capacity by NOAA or another federal government department or agency.

Management actions that focus on the early detection and rapid response of an invasive species before it becomes established have historically proven to be the most cost effective and successful (Simberloff 2009). As a result, the federal government has until now focused the majority of its resources into 1) invasive lionfish education and outreach, 2) Lionfish data collection and scientific research, 3) lionfish collection and handling education, and 4) coordination of early detection and rapid response by both federal employees and non-governmental organizations (Morris and Whitfield 2009). As well-intentioned these efforts may be, these types of programs are most effective in areas undergoing initial and early stages of invasive lionfish establishment. No successfully-proven management strategies for areas

experiencing intermediate/advanced stages of lionfish establishment are currently being implemented by any U.S. government authority.

So if lionfish are here to stay in U.S. waters, what can the federal government do to best manage these established lionfish populations while minimizing the negative ecological and socioeconomic impacts these marine invaders cause? As was made clear in chapters 3 and 4 of this analysis, much of the federal organization and legal infrastructure needed for more aggressive lionfish control and management exists, however overlapping objectives and unspecific language expressed by these authorities and laws may require some re-examining if they are to become even more efficient and successful in the future. Furthermore, the federal government and other lionfish management authorities are also faced with complex dilemma of whether or not to encourage the development of a lionfish seafood market. Although a lionfish “fishery” by definition under the Magnuson-Stevens Fishery Conservation and Management Act would automatically invoke protection of the lionfish stock under this Act, would creating a sustainable market demand for lionfish, with or without MSFCMA protection, be a good idea if the overarching goal for marine managers is to eliminate lionfish from U.S. waters entirely (16 U.S.C. § 1801 et seq.)?

The purpose of this chapter is to present options for lionfish management in U.S. waters from the authority of the federal government, and examine the option of establishing a lionfish fishery as a tool for managing invasive populations, both from a lionfish stock-protected and stock-unprotected approach. These options as presented in this chapter are as follows: 1) Fill policy and management gaps within current authorities and laws, 2) Create a lionfish fishery management plan, and 3) Develop a lionfish fishery without a fishery management plan. As was the case in chapter 5, the primary objective of this analysis to provide an unbiased, in-depth look

at the pros and cons behind each available option, and serve as a motivational tool for developing and implementing successful federal lionfish management practices in U.S. waters.

Option #1: Fill policy and management gaps within current authorities and laws

Despite the broad diversity of professional sectors currently addressing the lionfish invasion, the functions and roles practiced by each authority within these sectors are remarkably similar. While nonprofit organizations such as REEF do organize lionfish removal programs with the support of federal authorities like NOAA's CCFHR, many authorities currently addressing the lionfish invasion serve specifically to educate and advise others of the potential dangers lionfish pose to the marine environment. The reorganization of resources currently used to address invasive lionfish to a more balanced distribution between advisory authorities (NISC, the State Department, etc.) and management/action authorities (National Marine Sanctuaries, NOAA, etc.) may help make management action against lionfish in U.S. waters more likely to occur, especially in those waters under federal jurisdiction where lionfish are most established.

Federal mandates that affect lionfish management efforts could also be re-examined for their applicability and relevance. The Coastal Zone Management Act for example, while a foundational piece of legislation for its call to better organize and coordinate management of U.S. coastal and marine resources, does not specifically include invasive marine fish as a biological indicator for CZMA implementation success. Furthermore, aquatic invasive biological indicators mentioned in association with CZMA protocol for measuring federal management success are limited only to "tidal waters", overlapping federal authority with state and territorial government authorities, along with ANS Task Force approved state and regional management plans. The inclusion of lionfish occurring in offshore federal jurisdictional waters into NOAA's

CZMA performance measurement manual may help both clarify and improve upon CZMA relevance towards invasive lionfish management issues.

Also worth reexamining are provisions set forth by the National Invasive Species Act (NISA), which was reauthorized in 2007 to the National Aquatic Invasive Species Act (NAISA) (S.725 [110th] 1S). Although again focusing predominately on ballast water regulation policies as was the case with the NISA, NAISA accounts for policy gaps evident in its predecessor by assigning invasive species pathway risk assessment analysis to specific agencies with specific budgets. For example, the Aquatic Nuisance Species (ANS) Task Force was (among other things) responsible for conducting introductory pathway analysis of invasive species in order to identify the highest risk pathways for aquatic invasive species introduction into US waters, and to implement management strategies with state governments to reduce the frequency of these introductions (S.725 [110th] 1S). The National Invasive Species Council on the other hand, would establish a federal rapid response team to implement eradication and control responses in federal waters, and provide training for aquatic species invasion responders (S.725 [110th] 1S).

To account for the severe lack of funding for U.S. invasive species management programs, NAISA also includes an authorization of appropriations, and allocates a specific budget to specific invasive species programs. For each fiscal year from 2006 to 2010, \$39.5 million was allocated to federal authorities specializing in early detection and rapid response of aquatic invasive species (Office of Sen. Carl Levin 2007). A review of the geographic distribution and frequency of invasive lionfish during this period of time, combined with a thorough financial review of if and how a percentage of these funds benefited federal lionfish management efforts from 2006-2010, could help reveal and correct policy gaps within the

NAISA authorization of appropriations, and clarify the extent of federal support required to effectively counter the lionfish invasion.

Option #2: Create and a lionfish fishery management plan

Another management option explored by several recent reports and publications has been to develop a lionfish seafood market, and consume the invasive fish out of existence throughout its invasive range (Morris and Whitfield 2009; Albins and Hixon 2011). This can be accomplished through the development of either a “managed” or “unmanaged” fishery. For the purposes of this analysis, managed fisheries will be defined as the regulated capture of fish and other aquatic species in accordance with the guidelines and regulations set forth by the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). The MSFCMA is essentially a “sustainable use” Act for living marine resources, by which fisheries within federal waters are regulated via fisheries management plans (FMPs) drafted by regional fishery management councils. The development of a lionfish FMP is a plausible option for removing harvesting pressure from other overfished native stocks such as the Snapper-Grouper Complex, while simultaneously controlling non-native lionfish populations (Morris and Whitfield 2009). Major social and economic challenges currently facing both fishers and seafood dealers may also be alleviated, such as lionfish serving as a new source of economic profit for declining fishing industries, or gaining support from historically resistive and critical environmental groups (Hadley and Crosson 2010).

Of course the idea of drafting and implementing a lionfish FMP is not without potential drawbacks, since under the MSFCMA lionfish would have to be harvested within their biological maximum sustainable yield (MSY) as a Fishery Management Unit (FMU) (Kalo et al. 2007).

Furthermore, the precedent of establishing a managed fishery for an invasive marine fish could also illicit future introductions of lionfish into U.S. waters, with the purpose of helping sustain an economic dependence on an ecologically harmful invasive species (Morris and Whitfield 2009). Recent marine invasive species policies set forth by the South Atlantic Fishery Management Council must also be accounted for when trying to understand the consequences for implementing such a management option in the future. As of September 2010, should lionfish ever be characterized as a Fishery Management Unit (FMU) within a south Atlantic regional fishery management plan, the fishery would have to be disbanded before further funding and support could be provided to current lionfish eradication and removal efforts, both at the state and federal levels (South Atlantic Fishery Management Council (SAFMC) 2010).

The apparent drawbacks inherent to this option may make gaining support for implementing this option difficult, at least in the immediate future. Even though lionfish would most likely be added as an FMU to the Snapper-Grouper Complex FMP rather than represent a whole new fishery with its own unique management plan, writing a formal amendment to the Snapper-Grouper FMP would be a time consuming process that might not be approved and implemented in a timely manner (Wallace and Fletcher 2001). Nevertheless, regional fishery management councils (i.e. the Southeast Atlantic and Caribbean Councils) along with the federal government (NOAA/NMFS) may want to reconsider the validity of this option in upcoming years, especially if lionfish become more pervasive throughout U.S. waters and public demand for a lionfish market increases.

Option #3: Develop a “lionfish fishery” without a fishery management plan

A third option stemming from the theory that fisheries can function as tools for aquatic invasive species management is that lionfish can be harvested as an “unprotected” stock that is exempt from MSFCMA authority. Despite the complexities underlying creating an invasive species market such as a commercial or recreational lionfish fishery, harvest enhancement of lionfish in U.S. is likely one of the only management strategies that can substantially lower invasive lionfish populations over the near term. Currently there are no existing regulatory impediments against selling lionfish commercially in the U.S., nor are there federal regulations in place concerning the landing and sales of lionfish fished from its invasive range. There are, however, federal and state regulations concerning diving and commercial licensing for marine fish occurring across U.S. state, territorial, and federal jurisdictional waters.

The promotion of lionfish catching and consuming lionfish out of existence without the goal of eventually establishing a fishery under MSFCMA is not without precedent, and has been the focus of NOAA’s “Eat Lionfish!” campaign for the past several years (NOAA’s National Centers for Coastal Ocean Science 2011c). In concert with restaurant lionfish tasting events, members of this campaign have provided important information to the public on issues such as safe capture and handling techniques of lionfish, regulatory requirements for landing and sales, where to fish for lionfish, and updated information on lionfish population densities (NOAA’s National Centers for Coastal Ocean Science 2011c).

A major challenge facing the implementation of this option is how to “control the lionfish market”, or minimize environmental harm inherent to concentrated fishing efforts while simultaneously not allowing consumers to overdevelop a socioeconomic dependence on a harmful invasive species. One possible approach would be to focus the promotion of lionfish

market development within smaller coastal communities, particularly those communities adjacent to areas of critical fish habitat or National Marine Sanctuaries. Because lionfish established in the southeast Atlantic have been found to live at depths up to several hundred meters, problems of accessibility to lionfish by fishers can be improved through further research in gear evaluation and harvest method effectiveness (Albins and Hixon 2011). Due to the extensive geographic range now evident in the case of invasive lionfish, a major key for future success against these invaders may center on the identification of areas of marine habitat that are both vital to stock rebuilding efforts for overharvested fisheries (such as the Snapper-Grouper Complex), and are most threatened by lionfish (either by the area's lionfish population densities, or by the area's overall environmental susceptibility to stress). Supervised harvesting at limited scales is already being practiced in the Florida Keys National Marine Sanctuary, and such efforts may be worth considering further in others areas of critical fishery habitat. These practices could be conducted with the sole intent of developing enough of a market demand to harvest lionfish out of existence, however they can just as easily be organized and implemented as a policy and management byproduct of currently more pressing marine conservation issues, such as habitat and fishery stock protection within National Marine Sanctuaries.

Conclusions

The lionfish invasion of Atlantic and Caribbean marine ecosystems is now recognized as a major global conservation issue (Sutherland et al. 2010). Lionfish possess a wide variety of physiological and behavioral traits that make them particularly successful invaders, as is clear by the rapidity at which invasive populations have spread and become established over the past several decades (Albins and Hixon 2011). In the absence of any major anthropogenic pressure, and the ongoing spread of lionfish across the Caribbean Sea, Gulf of Mexico, and the Atlantic Ocean will ultimately be controlled either by lionfish starvation after all available prey have been removed, or by native species providing biotic resistance to the invasion either through predation, competition, or parasitism (Albins and Hixon 2011).

Considering humanities track record of fishery overexploitation to the point of economic and ecological extinction, the technology and available manpower required to at least seriously reduce invasive lionfish populations is certainly available. Our current scientific understanding of the biology and ecology of invasive lionfish is significant, and future research on trophic relationship lionfish share with their predators and prey may help the scientific community to identify biological controls for lionfish propagation throughout its invaded range. Authorities responsible for directly managing lionfish exist, and are being assisted in their duties by other organizations and groups not mentioned in previous chapters. The United States Geological Survey (USGS) for example, has proven invaluable in the compilation and organization of lionfish monitoring data collected by REEF and NOAA. Even more noteworthy, are the efforts of those on the “front lines”: scuba diving enthusiasts and private dive companies that actually carry out lionfish removal programs and derbies.

Invasive lionfish challenges current facing marine managers, along with those challenges that will develop in the future as the lionfish invasion progresses, are daunting. State and territorial roles and responsibilities in managing lionfish in U.S. waters have until now been less clear than those of federal agencies such as NOAA's National Ocean Service Department. Even within the federal government, the debate regarding creating a lionfish seafood market is complicated and ongoing, regardless of the findings presented from this analysis.

The attempt of this document to clarify the issue, identify and define authorities, and present options for multiple levels of government, are not intended to promote controversy, but rather to educate and encourage constructive communication between those currently struggling to find management solutions for this environmental crisis. Particularly during periods of economic difficulty and limited financial resources, cost-effective solutions that are successful over large marine and coastal areas of overlapping jurisdictional authority will require everyone involved in lionfish management to coordinate their efforts, and invest their collective resources into managing lionfish in areas of concentrated ecological and socioeconomic value. Gear and harvest methods for lionfish can continue to be tested in order to minimize their bycatch and unintentional habitat damage, and at the very least the federal government, along with the regional fishery management councils, may increasingly need to factor lionfish predation and stress into set annual catch limits for affected fisheries like the SGC. Ultimately, the successful distribution of resources and effort towards lionfish research and management, along with a controlled lionfish removal and harvesting effort supported by authorities with clearly defined roles and jurisdictions, will determine whether or not negative lionfish management tradeoffs can be successfully minimized or mitigated in the future.

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