An Integrated Assessment of the Introduction of Lionfish (*Pterois volitans/miles* complex) to the Western Atlantic Ocean

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An Integrated Assessment of the Introduction of Lionfish (*Pterois volitans/miles* complex) to the Western Atlantic Ocean

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Executive Summary

Lionfish (*Pterois volitans/miles* complex) are venomous coral reef fishes from the Indian and western Pacific oceans that are now found in the western Atlantic Ocean. Adult lionfish have been observed from Miami, Florida to Cape Hatteras, North Carolina, and juvenile lionfish have been observed off North Carolina, New York, and Bermuda. The large number of adults observed and the occurrence of juveniles indicate that lionfish are established and reproducing along the southeast United States coast.

Introductions of marine species occur in many ways. Ballast water discharge, a very common method of introduction for marine invertebrates, is responsible for many freshwater fish introductions. In contrast, most marine fish introductions result from intentional stocking for fishery purposes. Lionfish, however, likely were introduced via unintentional or intentional aquarium releases, and the introduction of lionfish into United States waters should lead to an assessment of the threat posed by the aquarium trade as a vector for fish introductions.

Currently, no management actions are being taken to limit the effect of lionfish on the southeast United States continental shelf ecosystem. Further, only limited funds have been made available for research. Nevertheless, the extent of the introduction has been documented and a forecast of the maximum potential spread of lionfish is being developed. Under a scenario of no management actions and limited research, three predictions are made:

- With no action, the lionfish population will continue to grow along the southeast United States shelf.
- Effects on the marine ecosystem of the southeast United States will become more noticeable as the lionfish population grows.
- There will be incidents of lionfish envenomations of divers and/or fishers along the east coast of the United States.

Removing lionfish from the southeast United States continental shelf ecosystem would be expensive and likely impossible. A bounty could be established that would encourage the removal of fish and provide specimens for research. However, the bounty would need to be lower than the price of fish in the aquarium trade (~$25-$50 each) to ensure that captured specimens were from the wild. Such a low bounty may not provide enough incentive for capturing lionfish in the wild. Further, such action would only increase the interaction between the public and lionfish, increasing the risk of lionfish envenomations.

As the introduction of lionfish is very likely irreversible, future actions should focus on five areas. 1) The population of lionfish should be tracked. 2) Research should be conducted so that scientists can make better predictions regarding the status of the

invasion and the effects on native species, ecosystem function, and ecosystem services. 3) Outreach and education efforts must be increased, both specifically toward lionfish and more generally toward the aquarium trade as a method of fish introductions. 4) Additional regulation should be considered to reduce the frequency of marine fish introduction into U.S. waters. However, the issue is more complicated than simply limiting the import of non-native species, and these complexities need to be considered simultaneously. 5) Health care providers along the east coast of the United States need to be notified that a venomous fish is now resident along the southeast United States.

The introduction and spread of lionfish illustrates the difficulty inherent in managing introduced species in marine systems. Introduced species often spread via natural mechanisms after the initial introduction. Efforts to control the introduction of marine fish will fail if managers do not consider the natural dispersal of a species following an introduction. Thus, management strategies limiting marine fish introductions need to be applied over the scale of natural ecological dispersal to be effective, pointing to the need for a regional management approach defined by natural processes not by political boundaries.

The introduction and success of lionfish along the east coast should change the long-held perception that marine fish invasions are a minimal threat to marine ecosystems. Research is needed to determine the effects of specific invasive fish species in specific ecosystems. More broadly, a cohesive plan is needed to manage, mitigate and minimize the effects of marine invasive fish species on ecosystems that are already compromised by other human activities. Presently, the magnitude of marine fish introductions as a stressor on marine ecosystems cannot be quantified, but can no longer be dismissed as negligible.

Cover photo: Adult lionfish on a wreck off the North Carolina coast. Tomtate (*Haemulon aurolineatum*) are in the background. *Photo taken by Paula Whitfield, NOAA Beaufort Laboratory.*

Lionfish juvenile in an aquarium after collection off Long Island, New York. *Photo taken by John Morrissey, Hofstra University.*

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Glossary of Terms

Adult – a stage in the life history of an organism during which reproduction occurs

Anadromous – a species which migrates from the ocean to freshwater to spawn

Aquaculture - the cultivation of freshwater or marine plants and animals for food or other purposes

Aquarium Trade – the trade of aquatic life for public or private display

Ballast water – water used as weight to improve stability in vessels

Benthic – pertaining to the sea floor; organisms that live on the sea floor

Biogeographic boundaries – defined separations between biogeographic provinces

Biogeographic provinces – spatial areas that contain species with similar distributions

Biological Classification –
the hierarchical grouping of organisms into categories on the basis of evolutionary relationships. Seven hierarchical levels are commonly used, and the classification of lionfish is shown as an example.

Kingdom – Animalia
Phylum - Chordata
Class – Actinopterygii
Order - Scorpaeniformes
Family - Scorpaenidae
Genus - *Pterois*
Species – *volitans/miles*

Community - an association of living organisms that have mutual relationships among themselves and to their environment and thus function, to some degree, as an ecological unit

Conspecifics – individuals of the same species

Dispersal – the spread of a species, population, or individual's progeny over time

Ecology – the study of the relationship among organisms and between organisms and their environment

Economic Exclusion Zone – zone extending from the shoreline out to 200 nautical miles in which a nation has the exclusive right to conduct certain activities such as fishing

Ecosystem – ecological communities together with their physical environment

Environment – the physical and biological conditions that surround an organism or a group of organisms

Eutrophication – a type of water pollution caused by excess nutrients that plants needs to grow

Evenomation – the process by which venom is injected from a venom gland into the recipient

Exotic species – a species that has been transported by human activities, either intentional or accidental, into a region where it does not naturally occur

Introduction – an exotic species entering an ecosystem owing to human actions

Invasive species – a species that has been transported by natural processes or human activities, either intentional or accidental, into a region where it did not occur previously

Juvenile - a sexually immature organism that resembles an adult

Larva – an early life stage in many marine organisms that is discrete in appearance and form from the juvenile and adult stage

Larval duration – the time duration of the larval stage

Larval transport – the movement of pelagic larvae by oceanographic and behavioral processes

Overfishing – fishing a population below its reproductive capacity to replenish itself

Pelagic – pertaining to the water column; organisms that live in the water column

Stressor – five stressors are identified as affecting coastal and marine ecosystems: pollution, invasive species, climate change, extreme events, and land and resource use

Introduction

A number of stressors are adversely affecting marine ecosystems, as well as the services that these ecosystems provide. Overfishing is threatening the sustainability of the nation's fisheries (Shimada et al., 1998); of the 259 major fishery stocks of the United States, 16.6% are overfished, 45.2% are not overfished, and the status of the remaining 38.2% is unknown (NMFS, 2003). Population growth and development in coastal areas continues to damage many habitats (Culliton et al., 1990) and contributes to coastal pollution and eutrophication; the Gulf of Mexico 'Dead Zone', which has been linked to nutrient pollution, was the largest recorded during the summer of 2002[1]. Climate change also affects marine ecosystems and services; long-term changes in ocean temperatures have influenced the distribution of fish species in their native range (Murawski, 1993; Mountain, 2002). Finally, extreme events may be increasing in frequency; the North Atlantic may be entering a regime of more frequent major hurricanes (Elsner et al., 2000), which have broad affects on coastal ecosystem (Simpson, 2002).

Invasive species are also important stressors on marine ecosystems. In a review of non-indigenous species in Chesapeake Bay, Ruiz et al. (1999) concluded that invasive species are a significant stressor on ecosystem functions. Invasive species also can interact with other stressors (e.g., climate change), and the ecosystem consequences of these interactions are even more poorly understood than the consequences of invasive species alone (Ruiz et al., 1999; Harris and Tyrell, 2001; Stachowicz, 2002). Although the effect of marine invasive species on ecosystem function and services are difficult to quantify, the magnitude of these effects will continue to increase as more marine invasions occur (Cohen and Carlton, 1998; Ruiz et al., 2000).

Although invasive species are recognized as having negative impacts on marine ecosystems, invasions of marine fish are not generally considered as important stressors. First, marine fish invasions are relatively rare. Of the more than 550 fish introductions reported in the United States, less than 30 were marine fishes introduced to marine environments (Table 1). Similarly, of the more than 200 established exotic species in the San Francisco Bay watershed (both freshwater and marine components), only six are marine and estuarine fish species (Cohen and Carlton, 1998). Second, most marine fish introductions resulted from intentional releases for fishery purposes, and were viewed as 'improvements' to the ecosystem, not stressors upon the ecosystem (Table 2). Third, few adverse effects of marine fish introduction on marine ecosystems are documented, leading to the conclusion that marine fish introductions have no effect. Randall (1987) reviewed marine fish introductions around Hawaii and noted few negative impacts, but few if any studies have evaluated the impacts of marine invasive fish on Hawaiian marine ecosystems (but see Friedlander et al., 2002). Further, little or no research has been conducted in others marine systems, and the effects of invasive marine fish species on marine ecosystems remain largely unstudied and unknown.

[1] Louisiana Universities Marine Consortium Press Release. July 26, 2002. Summer 2002 hypoxia. (http://www.lumcon.edu/news/pressrelease/02hypoxia.html; last accessed May 15, 2003)

Two recent introductions are changing the view that marine fish invasions are a minor threat to coastal resources and ecosystems. First, Atlantic salmon (*Salmo salmo*) escaped from fish farms on the west coast of North America and are likely spawning in western rivers (Volpe et al., 2000). Atlantic salmon are anadromous and their introduction may impact both freshwater and marine ecosystems on the west coast of North America. Atlantic salmon may compete with native salmon for limited spawning sites, thereby adversely affecting native stocks (Volpe, 2001). Several native salmon stocks have been listed as threatened or endangered under the Endangered Species Act[2] and even minor adverse effects could have large consequences. Although Atlantic salmon spend only part of their life cycle in marine waters, the potential threat to native salmon raises serious concerns about the consequences of the introduction to coastal ecosystems.

Table 1. Summary of fish introductions in the United States. Data from the U.S. Geological Survey (USGS, 2001). Many of the marine introductions to land locked brackish waters occurred into the Salton Sea in southern California.

Introduced Habitat of Exotic Species	Native Habitat of Exotic Species		
	Freshwater	Brackish	Marine
Freshwater	485	10	3
Brackish	1	4	0
Land-locked brackish	2	0	28
Marine	0	0	22
Total	488	14	53

Table 2. Reported method of introduction of native marine fish into marine habitats in the United States. Data based on USGS (2001) and review of Randall (1987).

Method of Introduction	Number of Species
Ballast water	1
Aquarium release	5
Aquarium release / or accidentally stocked	1
Accidentally stocked	2
Intentionally stocked	13
Total	22

A second recent introduction involves lionfish (*Pterios volitans/miles* complex) in the western Atlantic Ocean (Whitfield et al., 2002). Lionfish are native to the Indian and western Pacific oceans, and the introduction could negatively impact coastal ecosystems and the services these ecosystems provide. The purpose of this integrated assessment is to summarize what is known about the introduction of lionfish, to identify the potential effects on marine ecosystems, to discuss management and policies related to the introduction of lionfish, and more generally, to address the threat of marine fish invasive species.

[2] United States Fish and Wildlife Service. Species Information: Threatened and endangered animals and plants (http://endangered.fws.gov/wildlife.html; last accessed May 15, 2003)

Documentation of status and trends

Schultz (1986) considered lionfish (*Pterois volitans/miles* complex) to comprise two allopatric sibling species. *P. miles* occurs in the Indian Ocean from South Africa, northward to the Red Sea and Persian Gulf and eastward to Sumatra. *P. volitans* occurs from Indonesia, northward along the Japanese coast, southward along the east coast of Australia and eastward into the South Pacific. Recent genetic work (Kochzius et al., 2003) confirmed genetic differences between *P. miles* and *P. volitans*, but was inconclusive regarding the existence of two species or two populations of one species. Owing to the uncertainty of species status, lionfish will be used as a common name for the *Pterios volitans/miles* complex.

Lionfish have been observed sporadically off the east coast of Florida by divers since 1994[3]. Several lionfish were released into Biscayne Bay, Florida when a private aquarium was destroyed by Hurricane Andrew in 1992 (Courtenay, 1995). Substantiated observations of adult lionfish were documented by Whitfield et al., (2002), ranging from the east coast of Florida to Cape Hatteras, North Carolina. Following a NOAA press release and publication of a peer-reviewed article describing the substantiated observations (Whitfield et al., 2002), a number of additional sightings were reported (Figure 1). These observations demonstrate that lionfish adults are distributed along the southeast United States continental shelf from south Florida to Cape Hatteras.

Figure 1. Locations where lionfish have been reported as of May 15, 2003. Reports include specimen collection (8 locations), video and photo documentation (17 locations), and visual observation (15 locations). Data collated from reports made to Paula Whitfield, NOAA Beaufort Laboratory.

Evidence indicates that the number of lionfish is increasing, but it is impossible to account for varying observational effort between years. Lionfish were reported from three locations in 2000, 12 locations in 2001, and 41 locations

[3] James Abernethy, SCUBA Adventures, Palm Beach, Florida, personal communication

in 2002. Although these numbers suggest an increase in lionfish abundance, they may also reflect greater public awareness and reporting, as well as a greater effort to observe lionfish. A statistically valid monitoring program is needed to determine if the number of lionfish is indeed increasing.

Juvenile lionfish have been found off of Long Island, New York and Bermuda. The juvenile fish caught in Long Island were smaller than is typically available in the aquarium trade, indicating that these fish originated from spawning on the southeast United States continental shelf, where adults have been observed. Juveniles of many native tropical fish are found in inshore waters of the northeast United States continental shelf during the summer (Able and Fahay, 1998). Larvae are transported from the southeast United States continental shelf to inshore waters of the northeast United States continental shelf via the Gulf Stream, warm-core rings, and cross-shelf movement (Hare and Cowen, 1991, 1996; Hare et al., 2002). Larvae are transported from the southeast United States continental shelf to Bermuda similarly, but cold-core rings are involved rather than warm-core rings (Schultz and Cowen, 1994). The occurrence and distribution of juvenile lionfish provide strong evidence that lionfish are reproducing on the southeast United States continental shelf and larvae are transported to Long Island and Bermuda.

The northern limit of the invasion coincides with the northern limit of the native western Atlantic warm-temperate and sub-tropical fish fauna (Briggs, 1974). Adult lionfish are distributed as far north as Cape Hatteras, North Carolina, and Bermuda, with juveniles extending further north in the summer. As water temperatures cool in the fall, juveniles of warmer water species either return south of Cape Hatteras (e.g., bluefish, Kendall and Walford, 1979) or remain and perish (e.g., butterflyfish, McBride and Able, 1998). Because lionfish are thought to be relatively stationary (Fishelson, 1975), an analogy with butterflyfish is appropriate (see McBride and Able, 1998). Larval butterflyfish settle in structured nearshore areas during the summer. As water temperatures cool in the fall, juvenile butterflyfish remain near their settlement location, and when temperatures reach the thermal minimum, they die. Based on this analogy, the current hypothesis is that the northern and inshore range of lionfish are restricted by winter bottom water temperatures.

The southern limit of the invasion is more difficult to determine. Four sightings have been reported from south of Miami, Florida: one off Cancun, Mexico, two off St. Kitts, and one off Puerto Rico. Given the amount of recreational diving that occurs in the Caribbean and along the Florida Keys, two inferences can be made from lack of observations: lionfish are observed and not reported or lionfish are very rare or do not occur south of Miami. Outreach is imperative to educate the diving public to report sightings in these areas. Such outreach efforts would either discount the possibility of lionfish observations not being reported or lead to reporting of lionfish sightings south of Miami. Either outcome would strengthen conclusions regarding the southern limit of the invasion.

Description of causes and consequences of trends

Lionfish Ecology and Life History

Lionfish are solitary and defend their home range against conspecifics (Fishelson, 1975). Groups of adult lionfish are typically observed only during mating (Fishelson, 1975). Lionfish have a complex mating behavior during which the female releases a mucous balloon of eggs that is fertilized externally. The egg mass floats and deteriorates over time, releasing the eggs into the water column. No information exists on the larval stage except for the description of five individuals collected in the water column off of northwestern Australia (Imamara and Yabe, 1996). Based on the spawning information and the collection of larvae from the water column, lionfish likely have a pelagic larval stage similar to many other marine fish species.

The early life history stages of lionfish are poorly known. Lionfish settle from the water column to benthic habitats at about 12 mm. Laidig and Sakuma (1998) reported a larval growth rate of 0.3 mm per day for *Scorpaena*, a genus in the same family as lionfish, Scorpeanidae. Using this growth rate, the estimated larval duration of lionfish is 25 to 40 days, which means that larvae are in the water column and susceptible to transport by ocean currents for approximately one month.

Ecology of the adult stage is only partially known. Adults eat a wide variety of smaller fishes, shrimps and crabs (Fishelson, 1975), and in their native range, lionfish occupy the upper levels of the food chain (Fishelson, 1997). Bernadsky and Goulet (1991) reported that the Pacific cornetfish eat lionfish, but few other predators are known. Age at sexual maturity and lifespan are also unknown.

Lionfish are best known for their venomous dorsal, anal, and pelvic spines. A pair of venom glands is associated with each spine, and each spine is covered by a loose sheath (Gallagher, 2001; Plantz, 2001; Vetrano et al. 2002). When the spine punctures tissue, the sheath moves down the spine compressing the venom glands (Gallagher, 2001). Venom then travels up a groove in the spine into the wound (Gallagher, 2001). Most lionfish envenomations are reported by home aquarists who keep lionfish in their tanks (Gallagher, 2001). Of 101 described cases of lionfish envenomations, none were fatal. In summary, Gallagher (2001) states "… the vast majority of lionfish stings [envenomations] appear to result in uncomplicated wounds with severe local pain that is responsive to immersion therapy." However, in some cases patients do not respond to immersion therapy (Vetrano et al., 2002).

Method of introduction

Invasions of marine fish occur via several mechanisms including natural range extensions, deliberate introductions to improve fisheries, movement of fishes through canals, transport in ballast water, and unintentional or intentional aquarium or aquaculture releases (Baltz, 1991; Courtenay, 1993). The U.S. Geological Service inventory of fish introductions in the United States indicates that intentional stocking and aquarium releases are the most common methods for marine fish introduction (Table 2).

Natural range extensions, movement through canals, deliberate release to improve fisheries and aquaculture releases are easily rejected as the method of lionfish introduction. Because there are several biogeographic provinces between the native range of lionfish and observations in the western Atlantic Ocean (Briggs, 1974), a natural range extension is not possible. Lionfish were not introduced through the Panama Canal because they are not known from the eastern Pacific nor from the western Caribbean. Lionfish have moved from the Red Sea through the Suez Canal into the eastern Mediterranean (Golani and Sonin, 1992), but the eastern Mediterranean is biogeographically separated from the western North Atlantic. There is no evidence of a deliberate act to establish lionfish for fishery purposes in the western Atlantic Ocean. Finally, there are no known aquaculture operations producing lionfish in the United States. Thus, ballast water and aquarium releases are the remaining potential methods of introduction.

Ballast water has led to the introduction of approximately 35 fish species worldwide (Wonham et al., 2000). Most successful introductions are of species in two families: Gobiidae and Blenniidae (Wonham et al., 2000). Two individual scorpaenids have been found in ballast water (Wonham et al., 2000), and lionfish are reported from several harbor areas (Schultz, 1986) making an introduction of lionfish via ballast water possible. Further, one adult scorpionfish (genus *Sebastiscus*), an Asian species, was collected in Sydney Harbor and ballast water is a likely mechanism of introduction[4]. However, two lines of evidence indicate that ballast water is not the method of lionfish introduction in the western Atlantic Ocean. First, after more than 100 years of global ballast water movement, no scorpaenids are known to have been introduced and become established by this means. Second, in the entire marine region from Bermuda to Florida, no introductions of Indo-Pacific fish species via ballast water

Evidence for the aquarium trade as the vector for the introduction of lionfish

- Lionfish are popular in the North American aquarium trade
- Lionfish were released from an aquarium in Florida waters
- Other marine aquarium fish have been introduced in Florida waters
- Color patterns of lionfish off the southeast United States are similar to those from the Philippines where many are collected for the aquarium trade
- Globally, no successful introductions of scorpaenids are known to have occurred via ballast water
- In more than a century, no Pacific marine fish are known to have been introduced into the western Atlantic Ocean via ballast water

[4] William Eschmeyer, Department of Ichthyology at the California Academy of Sciences, personal communication

are known.

All evidence to date supports the conclusion that the introduction of lionfish resulted from a release from the aquarium trade. First, lionfish is a popular aquarium fish (Thresher, 1984). Second, lionfish were accidentally released from an aquarium into Biscayne Bay, Florida in 1992 (Courtenay, 1995). Third, a number of other aquarium fish also have been observed off the coast of Florida (Semmens et al., in review). Fourth, the pigmentation pattern of lionfish specimens collected off the coast of North Carolina and Georgia are typical of individuals from the central portion of the native range, which includes the Philippines and Indonesia [5]; 85% of marine aquarium fishes imported into the United States come from the Philippines and Indonesia (Baquero, 1999).

Although lionfish were apparently introduced from the aquarium trade, the specific manner in which lionfish were released remains unknown. An unintentional release did occur in 1992 (Courtenay, 1995), but it is impossible to determine if these fish were the cause of the lionfish invasion. Home aquarists could have released lionfish that became too large for their aquariums or for other reasons. In the end, the specific sequence of events that led to the invasion of lionfish will never be known with absolute certainty, but all evidence points to the aquarium trade as the initial cause.

Ecosystem effects

Lionfish could impact native ecosystems through predatory interactions. Lionfish feed on a wide variety of smaller fishes, shrimps and crabs (Fishelson, 1975; Sano et al., 1984). These prey items are abundant on southeast United States shelf reefs and wrecks (Wenner et al., 1983). The style of lionfish predation, (i.e., ambush predator) is not unique on southeast United States reefs and wrecks (e.g., red grouper, frog fish, scorpion fish), but the lack of experience of prey species with lionfish specifically, may increase the predation efficiency of lionfish. Without knowledge of diet, dietary preferences, and foraging requirements, the impact of lionfish on prey populations and potential competitors for food cannot be evaluated. Similarly, interactions between lionfish and their potential predators are unknown. Few predators of lionfish have been reported within the native range (Bernadsky and Goulet, 1991). Moreover, predators along the southeast United States have no experience with the venomous spines of the lionfish (Ray and Coates, 1958; Halstead, 1967). Thus, the potential role of predation in decreasing the number of lionfish is unknown, as is the potential adverse effect of lionfish on predators.

The southeast United States continental shelf ecosystem is already undergoing change. Many important reef fish predators are overfished (Huntsman et al., 1999). In the Snapper-Grouper Management Unit of the South Atlantic Fisheries Management Council, approximately half of the stocks for which the status is known are classified as overfished (Figure 2). The reef fish fauna of the southeast United States continental shelf is also becoming more tropical (Parker and Dixon, 1998). From the 1970's to the 1990's, the number of tropical species and the abundance of individual tropical species increased

[5] William Eschmeyer, Department of Ichthyology at the California Academy of Sciences, personal communication

off the coast of North Carolina. Both of these large-scale changes favor the continued growth and dispersal of the lionfish population along the southeast United States. Thus, at this time, negative effects on the ecosystem are unlikely because lionfish are relatively rare, but tropical and subtropical reef communities in the western Atlantic Ocean may be affected in the future if lionfish reproduction and dispersal results in population growth.

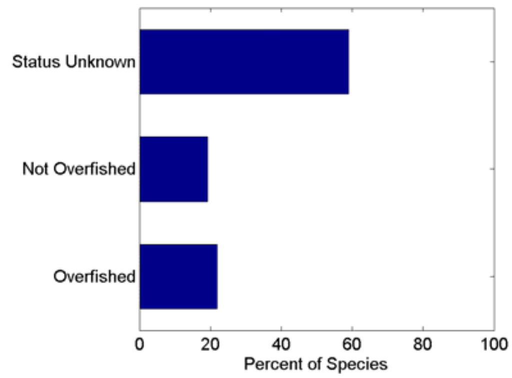

Figure 2. Population status of the 73 species in the snapper-grouper management unit in 1999 as determined by the Snapper Grouper Assessment Group (SGAG, 2001).

Prediction of future outcomes with no action

There is very little information from which to base predictions for future effects of lionfish in the western Atlantic Ocean. The ecology of lionfish is only partially known from the native range, and has not been investigated in its introduced range. The southern limit of the invasion is unclear. The factors controlling the extent of the invasion are proposed, but untested. Lionfish are likely reproducing along the east coast of the United States, but spawning has not been observed and reproductive studies have not been conducted. Only qualitative estimates of lionfish abundance have been made. This lack of information precludes well-supported predictions. However, even with very little information, three general predictions can be made.

- With no action, the lionfish population will continue to grow along the southeast United States shelf.
- Effects on the marine ecosystem of the southeast United States will become more noticeable as the lionfish population grows.
- There will be incidents of lionfish envenomations of divers and/or fishers along the east coast of the United States.

The lionfish population will continue to grow along the southeast United States - Lionfish were observed at three locations in 2000, 12 locations in 2001, and 41 locations in 2002. Although these data are confounded by a probable increase in reporting, there is evidence of an increase in abundance. At one wreck off of North Carolina, one lionfish was observed in 2001, and seven lionfish were observed in 2002, and diving frequency likely did not vary between years [6]. Similarly, scientists on submersible dives during the NOAA Ocean Exploration cruises observed no lionfish in 2001, and observed 18 lionfish

[6] Paula Whitfield, NOAA Beaufort Laboratory, personal observation

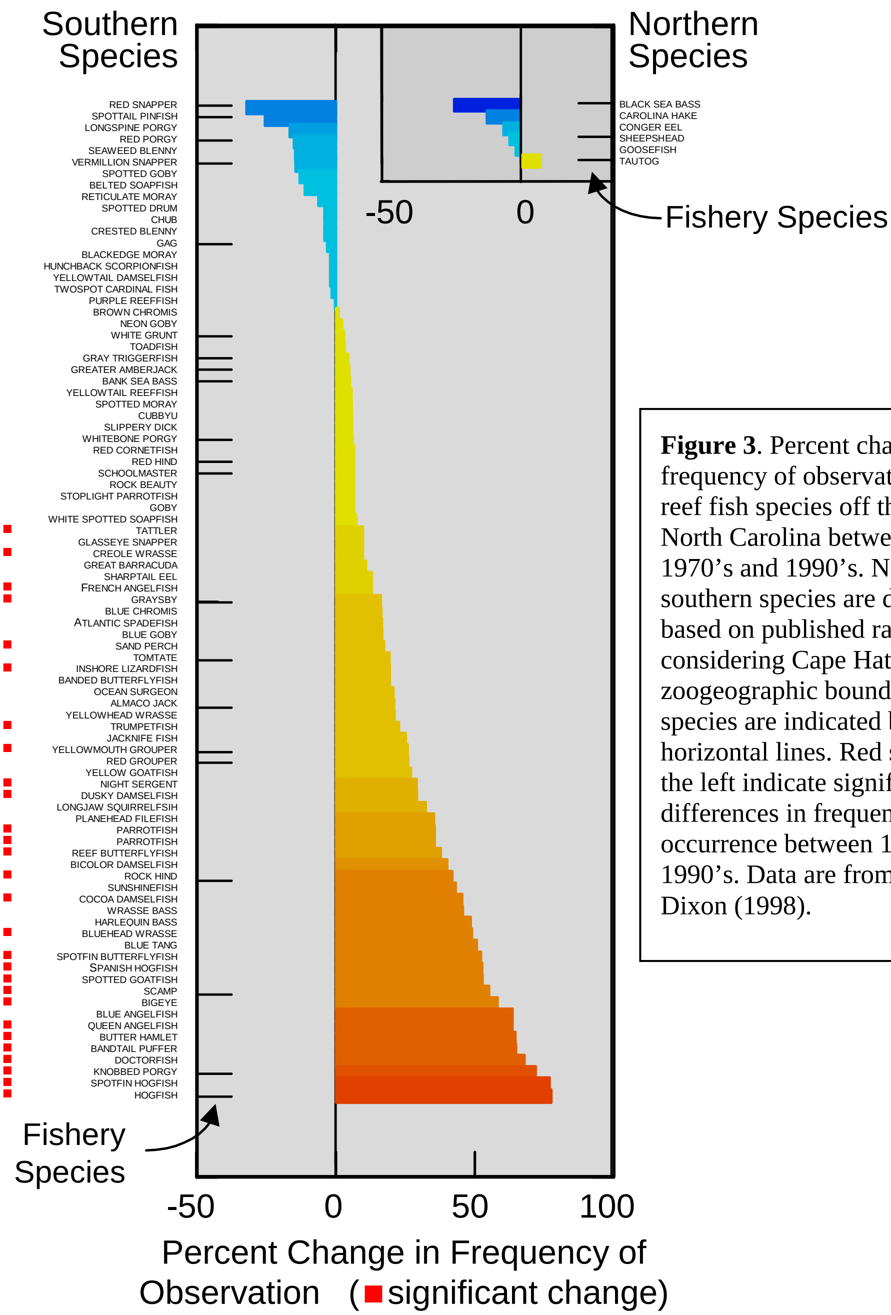

Figure 3. Percent change in frequency of observation of 93 reef fish species off the coast of North Carolina between the 1970's and 1990's. Northern and southern species are defined based on published ranges, and considering Cape Hatteras as a zoogeographic boundary. Fishery species are indicated by horizontal lines. Red squares to the left indicate significant differences in frequencies of occurrence between 1970's and 1990's. Data are from Parker and Dixon (1998).

in 2002[7]. These data support the hypothesis that the lionfish population is growing and will likely continue to increase.

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[7] George Sedberry, Marine Resources Research Institute, South Carolina Department of Natural Resources, personal communication

Effects on the ecosystem of the southeast United States will become more noticeable as the population grows - Potential effects on the southeast United States ecosystem can be proposed, but no definitive information exists. Lionfish could decrease prey population abundance and/or compete with other mid-level predators. Additionally, higher level predators that attempt to prey on lionfish (e.g., grouper, shark) could be adversely affected (e.g., envenomation). In freshwater environments, introduced fishes have been implicated in the decline and displacement of native fish populations (Marchetti 1999; Godinho and Ferreira 2000; Stapp and Hayword 2002; Taniguchi et al., 2002). Moreover, community-level effects beyond the replacement of native fishes have also been described (Miller et al., 1989; Flecker and Townsend 1994; Jude et al., 1995; Englund 1999; Godinho and Ferreira 2000; Stapp and Hayword 2002).

Along the southeast United States coast several other stressors are already impacting the ecosystem, and attributing ecosystem changes to lionfish will be difficult without experimental exclusion studies or comparisons among multiple sites with and without lionfish. However, as the lionfish population grows, the ecosystem effects will become more apparent, whether these effects are mild or extreme.

***Lionfish envenomations will occur as the number of interactions in the wild increase* -** As the lionfish population grows, the number of interactions between people and lionfish in the wild will increase, and eventually, someone will experience an envenomation. Because the majority of lionfish on the east coast of the United States are observed in waters deeper than 100 ft, SCUBA divers are the most likely to encounter lionfish. For SCUBA divers, the effect of a lionfish envenomation will potentially be exacerbated by depth and distance from medical facilities. Lionfish also will be caught by recreational and commercial fishers.

Provision of guidance for potential actions

Specific guidance for lionfish invasion of the southeast United States

Three actions should be considered to minimize the effects of lionfish on the southeast United States continental shelf ecosystem and the public: reduce its population abundance, increase outreach and education efforts, and conduct more research to better understand lionfish and their potential effects on the ecosystem.

***Reducing population abundance* –**An obvious approach to limit ecosystem and public health effects is to attempt to eliminate lionfish from the ecosystem. Although straightforward in principle, eradicating lionfish from the western Atlantic Ocean is not practical. Lionfish are now distributed along the entire southeast coast (Figure 1) at depths between 80 - 250 ft. The wide geographic range and broad depth range make complete eradication of lionfish nearly impossible. A bounty could be established to encourage divers or fishers to catch lionfish. The amount of a bounty would be limited by the price of lionfish in the aquarium trade (~ $25-$50 per fish), because a difference may encourage some to turn in aquarium lionfish for the bounty. A bounty also would lead to more interaction between lionfish and the public, thus increasing the risk of envenomations. Rather than attempting eradication, funds should be used to minimize the direct effects of lionfish on the American public, to promote outreach and education concerning marine invasions, and to support research that promotes the understanding, management, and mitigation of marine invasions.

Outreach and Education - The public in the United States and throughout the Caribbean needs to be informed that lionfish have been introduced in the western Atlantic and that any sightings should be reported to the NOAA Beaufort Laboratory[8]. These reports would contribute to range and abundance information. Further, the public should be made aware of the health risks and be told not to handle the fish. Medical professionals, boat captains and life guards should be instructed on how to treat a lionfish envenomation. These efforts at outreach and education would greatly raise public awareness and improve the response of health care providers. In addition, lionfish could be used as an example to educate the aquarium industry and public about the dangers of intentional or unintentional aquarium releases.

Research - Our ability to predict future lionfish population abundance and the effects of lionfish on the ecosystem is greatly hindered by a lack of knowledge. Research needs to be conducted to define the lionfish population's ability to survive, reproduce and increase along the southeast United States. In addition, the potential for further spread and the potential effects of the species on the ecosystem need to be investigated. Specifically, documenting the spatial extent of the introduction and estimating the number of living individuals are important goals for future research. Efforts should concentrate on reefs and wrecks on the southeast United States continental shelf in depths less than 100 m. Further, reproductive studies should be undertaken. The identification of spent gonads, which is indicative of spawning, would provide further evidence of reproduction, and fecundity estimates would help determine the potential reproductive output of lionfish. Efforts to find lionfish juveniles along the east coast of the United States and Bermuda should also continue. Combining temperature data with information on reef and wreck locations will refine our understanding of the potential habitat distribution of lionfish. Experiments underway at the NOAA Beaufort Laboratory to determine temperature tolerance of lionfish will further define potential range distribution along the southeast United States shelf. Bioenergetic studies would provide more detail of the physiological tolerances of lionfish and provide estimates of consumption, which could be used to estimate the effects of lionfish on prey populations along the southeast United States shelf. Genetic studies similar to Planes and Lecaillon (1998) can provide information regarding the effective population size and genetic variability of the introduced population. Additionally, genetic studies may be able to identify the source region of the native range (Hauser et al., 1998). Finally, circulation modeling and/or drifter studies could be undertaken to estimate the transport of lionfish from observed locations and to better predict areas that may receive recruits (Hare et al., 1999, 2002).

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General guidance for marine fish invasive species

The lionfish invasion of the southeast United States continental shelf raises general concerns about the risk of marine fish invaders to marine systems in the United States. Five general issues need to be considered. First, additional regulations on the aquarium trade may be needed. Second, the role of aquaculture in producing marine fish for the aquarium trade needs to be evaluated. Third, regional management institutions need to address marine fish introductions and subsequent natural dispersal. Fourth, education and outreach about marine fish invaders must be increased. Fifth, in addition to specific research on lionfish, research is needed to determine the general causes and consequences of marine fish introductions.

The Aquarium Trade - The aquarium trade poses the largest potential risk of marine fish invasions to marine waters of the continental United States. The presence of several non-native marine fish off the east coast of Florida has been linked to the aquarium trade (Semmens et al., in review). The marine fish trade into the United States was valued at US$ 8.9 million in 1994 (Basleer, 1994), with a global import value of fish in 2001 estimated at about US$ 28-44 million (Wood, 2001). The collection of fish for marine aquariums can be very destructive to habitat (Wood, 2001), and can reduce the population abundance of targeted species (Tissot and Hallacher, in review). Importation restrictions or bans, such as those in place in Bermuda and Hawaii (see below), limit the risk of invasion, but can also increase the demand on local fish populations for the aquarium trade. Bermuda has also restricted collection methods to decrease the effect on local habitats and populations. Thus, to limit the effect of marine fish invaders on marine systems of the United States, two issues need to be dealt with in unison: regulating the importation of marine aquarium fish into the United States and regulating the collection of aquarium fish in the United States.

Aquaculture of Native Marine Ornamental Fish - The aquaculture of native species to be sold for aquaria may help alleviate some of the problems caused by the aquarium trade (see Wood, 2001). Culture of individuals reduces the pressure on wild populations and decreases the collateral damage to habitats. Using native fish also eliminates the risk of invasion by non-native species. However, should cultured fish escape, wild populations may be effected. Such issues have developed in salmon culture on both the east and west coasts of North America (Waples, 1991; Volpe, 2001). Further, the culture of marine fish with pelagic eggs and larvae is more difficult than the culture of freshwater fish with demersal eggs and well-developed larvae. Culture facilities also can create environmental problems themselves and locating aquaculture facilities becomes an issue. Finally, if the aquarium trade comes to rely on cultured specimens, they will be less likely to promote the protection of natural habitats (Wood, 2001).

Regional Management – Beyond the general conclusion that lionfish were released from the aquarium trade, the specific sequence of events leading to the introduction will likely never be known. Yet, since the introduction, lionfish have become established along the entire southeast coast of the United States, a range that exceeds the initial introduction location. Further, lionfish juveniles have been collected off of Long Island, New York and Bermuda, likely the result of spawning on the southeast United States shelf and subsequent larval transport (Hare and Cowen, 1991; Schultz and Cowen, 1994; Hare et al., 2002). Thus, the current distribution of lionfish results from the introduction followed by natural dispersal processes.

Bermuda strictly regulates the import of live fish (see below) to protect against introductions. However, Bermuda cannot protect against the natural dispersal of a species introduced elsewhere. The natural dispersal of lionfish after their introduction leads to the concept that to be effective, management strategies limiting marine fish introductions need to be applied over the scale of natural ecological dispersal. A first step is to roughly define the scales of natural ecological dispersal. Second, representatives from the political entities included in the scale of natural ecological dispersal need to be brought together. This representative group would develop background information on marine fish invasions and outline a regional strategy to limit the effects of marine fish introductions. Third, additional research should be aimed at a better understanding of dispersal mechanisms and quantifying the connectivity between various locales. The overall goal of the research should be to provide a strong scientific framework for the implementation of the regional management strategies.

Education and Outreach – The problems associated with marine fish introductions need to be conveyed to the public and various sectors of business. Home aquarists need to know that the accidental or intentional release of fish from aquaria threatens native species and ecosystems. The aquarium industry should be urged or required to distribute information warning against releasing live fish from aquariums. Such notices could also raise awareness about the ecological problems associated with invasive species. Portions of the aquarium industry have a voluntary code of ethics (Wood, 2001), so there is already a forum through which the industry can educate their customers not to release aquarium fish. Similarly, aquaculture facilities need to protect against releases. Atlantic salmon now inhabit the Pacific coast, which is a direct result of releases from aquaculture operations (Volpe, 2001).

Research - Research in general is needed to determine the causes and consequences of marine fish invaders in waters of the United States. Lionfish are visible and recognizable. How many other invasive marine fish species are established along the southeast coast of the United States but presently unrecognized? How many invasive marine fish species are established in other marine waters of the United States Economic Exclusive Zone? Fifteen non-native marine fish species have been observed off the east coast of Florida (Semmens et al. in review). Do these sightings represent released individuals, or established and reproducing populations? Marine invasive species monitoring sites could be established where invasive species are searched for, identified, and quantified. This work would provide baseline data as to the magnitude of the problem created by invasive marine fishes in United States waters and serve as a starting point to examine the consequences to the natural, social, and economic components of the United States.

Research should also investigate the risk of marine fish invaders to ecosystems throughout the United States. Randall (1987) summarized marine fish invaders in Hawaii and commented on the effects of these introductions on the natural ecosystem, but no detailed studies have been conducted to quantify the impacts. Further, Randall (1987) mentioned that some illnesses have been linked to consumption of introduced fish (e.g. ciguatera and clupeoid poisoning) but again these effects on human health have not been quantified. With documented marine fish invaders in Hawaii and along the southeast United States shelf, targeted studies could be conducted to determine the effects of marine fish invaders on marine ecosystems. In short, there is little or no scientific evidence to address the effect, either detrimental or beneficial, of marine invasive fish species on marine ecosystems nor the services these ecosystems provide. Thus, the magnitude of marine fish introductions as a stressor on marine ecosystems cannot be quantified, but must be determined and can no longer be dismissed as negligible.

Determination of success of past management actions

Lessons from Hawaii

The State of Hawaii regulates the importation of non-domestic animals including marine fish[9]. Hawaii's reef and shore fish fauna is 29% endemic (Randall, 1987), and the state has an interest in protecting these unique resources. Some fish species, including species of the genus *Pterois*, are banned from importation. Importation of non-banned species requires a permit. A number of invasive marine fish species have been noted in Hawaii (Randall, 1987), and the majority resulted from purposeful or accidental releases for fishery purposes from the 1900s to the 1970s. However, Hawaii's combination of import restrictions and permitting has helped prevent further invasion of marine fish into the Hawaiian Islands marine ecosystems.

Lessons from Bermuda

Bermuda also has a number of endemic fish species (Smith-Vaniz et al., 1999), and strict regulations are in place to protect Bermuda's natural fish fauna from invasive species[10]. Live marine fish cannot be imported into Bermuda. Although lionfish have been collected in Bermuda waters, the most likely method of introduction was natural dispersal from the introduced population along the southeast United States coast (Schultz and Cowen, 1994; Whitfield et al., 2002). Bermuda's laws have kept out marine fish invaders via direct human introductions. However, the potential for natural extensions following an introduction in an oceanographically connected ecosystem raises questions about regional management for marine invasive fish species.

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[9] Hawaii Administrative Rules. Title 4 Department of Agriculture. Subtitle 6 Division of Plant Industry. Chapter 71 Plant and non-domestic animal quarantine non-domestic animal import rules.

[10] Title 25 of the Fisheries Regulation of 1972. Bermuda Statutory Instrument SR & O 25/1972, Regulation 20A, a prohibition against introducing live or unfrozen and uncooked fish into waters of Bermuda.

Lessons from Ballast Water

Transport in ballast water is the dominant mechanism of introduction of marine invertebrates (Ruiz et al., 2000). In response, the shipping industry is using voluntary ballast-water exchange to reduce the number of non-native species that are transported (IMO, 1991; Wonham et al., 2000). While the vessel is underway, coastal ballast water is replaced with ocean water, which is believed to flush out coastal organisms and kill some remaining organisms by the change in condition (Wonham et al., 2001). In a study examining the effectiveness of open-ocean exchange, Wonham et al. (2001) concluded "open-ocean exchange represents an additional selective filter in the ballast invasion pathway, that reduces but does not eliminate coastal taxa". Ballast water exchange as a management action is partially effective in reducing the rate of marine introductions.

Lessons from the Snakehead (Pisces, Channidae)

All species in the family Channidae (snakehead fishes), which are native to Africa, Asia, Malaysia and Indonesia, were added to the list of injurious wildlife species under the Injurious Wildlife Provisions of the Lacey Act[11]. This act prohibits the importation and transportation of snakehead fishes in the United States, the District of Columbia, Hawaii, the Commonwealth of Puerto Rico, or any territory or possession of the United States. Under the terms of the Lacey Act, the Secretary of the Interior is authorized to prohibit by regulation certain activities involving wild mammals, wild birds, fish (including mollusks and crustaceans), amphibians, and reptiles that are injurious to human beings, to the interests of agriculture, horticulture, or forestry, or to wildlife and wildlife resources of the United States. As of October 2002, four groups of fish (including mollusks and crustaceans) were listed: walking catfish of the family Clariidae, mitten crabs of genus *Eriocheir*, zebra mussels of the genus *Dreissena*, and snakehead fishes of the family Channidae. The rationale for listing snakehead fishes was " to protect wildlife and wildlife resources from the purposeful or accidental introduction and subsequent establishment of snakehead populations in ecosystems of the United States" [12].

Declaring a species injurious involves a five-step process: petition, notice for information, record of compliance, proposed rule, and final rule. As was the case with snakeheads, the United States Fish and Wildlife Service may initiate a proposed rule without a petition or notice for information if the scientific data support a listing. A proposed rule was published by the Fish and Wildlife Service on July 26, 2002[12], indicating the intention to list snakehead as a injurious species under the Lacey Act. Comments were taken until August 26, 2002, and the final rule was issued on October 4, 2002[13]. Whether listing snakehead fishes as an injurious species will prevent additional

[11] Lacey Act footnote (18 UNITED STATES C. 42) 50 CFR Ch. 1 § 16.13 Importation of live or dead fish, mollusks, and crustaceans, or their eggs.

[12] 67 FR 48855-48864 (July 26, 2002) available at http://policy.fws.gov/library/02fr48855.pdf (last accessed May 15, 2003)

[13] 67 FR 62193-62204 (October 4, 2002) available at http://policy.fws.gov/library/02fr62193.pdf (last accessed May 15, 2003)

introductions and subsequent establishment is unknown at this point, but the case serves as an example of a rapid regulatory response to a threat posed by an invasive species to the wildlife resources of the United States.

Conclusions

Management actions can decrease the risk of marine fish invasions. Bermuda's approach, a strict ban on import of live fish, is the most effective way to reduce the risk of aquarium releases. Hawaii's review and permitting process at least allows tracking of the imported fish, and likely has prevented the introduction of marine fish since the law was enacted. The changing of ballast water reduces but does not eliminate the risk of invasion. The Lacey Act provides a mechanism to prohibit the import of species that are injurious to wildlife and wildlife resources of the United States.

The introduction of lionfish is irreversible, but hopefully it will prompt the development and implementation of effective management strategies to reduce adverse ecological and ecosystem effects of marine fish invaders.

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Have you seen me?

Photo of adult lionfish (6 inches long)

Divers, Your help is needed!
'Lionfish' are native to the sub-tropical and tropical regions of the Indian and Pacific Ocean including the Red Sea. Since August 2000, lionfish have been reported in increasing numbers along the Atlantic Coast of the United States from Florida to Cape Hatteras, North Carolina. Juvenile lionfish have also been found off Long Island, New York and Bermuda (photo below). NOAA is interested in any information concerning the location of lionfish in Atlantic and Caribbean Waters.

Please report any lionfish sighting to Paula Whitfield at the NOAA Beaufort Laboratory, (252) 728-8714 or email paula.whitfield@noaa.gov. Video and photographs are encouraged. Any other information regarding the number of lionfish, depth, latitude and longitude, or behavioral observations such as feeding and courtship behavior are also welcome.

Habitat: Lionfish have been found in water depths from 85 to 260 ft on hard bottom, coral reefs and artificial substrate, sometimes found under ledges and hiding in crevices.

Identification: Lionfish have distinctive red, maroon, and white stripes; fleshy tentacles above eyes and below mouth; fan-like pectoral fins; long separated dorsal spines; dorsal spines 13; dorsal soft rays 10-11; anal spines 3; anal soft rays 6-7. An adult lionfish can grow as large as 18 inches while juveniles (see right) may be as small as 1 inch or less.

Special Precautions: **All of the spines on a lionfish are venomous!** This fish can give a painful, venomous sting with its dorsal, anal and pelvic spines. Please exercise extreme caution.

For more information and to print out additional flyers go to:
http://shrimp.ccfhrb.noaa.gov/lionfish/lionfish.html

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