Biological Invasion of Lionfish in the Atlantic

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In recent years, close examination of biological invasions shows that ecosystems around the world are subjected to loss of biodiversity as a result of the interactions between native species and the invaders (Whitfield et al. 2007). These interactions may happen naturally due to biotic dispersal, but human travel and deliberate translocation of organisms worldwide have undoubtedly accelerated this process (Morris and Whitfield 2009; Whitfield et al. 2007). Establishment of an invasive species often takes time and does not always succeed. (Whitfield et al. 2002). When invasive species do establish themselves and spread, their effects on the environment may cause large-scale changes in niche structure, on predator-prey relationships, and on physical features of the environment itself (Morris and Whitfield 2009). Recently, red lionfish (*Pterois volitans*) have been discovered in the western Atlantic along the eastern United States coast (Whitfield et al. 2007). Lacking competition and predators, invasive lionfish can quickly disperse through the eastern North American coast and invade other marine ecosystems (Whitfield et al. 2002). Atlantic ecosystems provide these invaders with favorable habitats that help facilitate their expansion. Continued spread of invasive lionfish will likely diminish biodiversity throughout ecosystems and will present a danger to both the overall structure of marine habitats and the interests of industry and public health (Arias-González et al. 2011; Côté and Maljkovic 2010; Morris and Whitfield 2009).

Lionfish were first documented to be residing in the Atlantic Ocean along North Carolina's coast in the year 2000 (Meister et al. 2005). Lionfish are native to the tropical waters of the western Pacific Ocean and eastern Indian Ocean (Meister et al. 2005). Prized as aquarium fish, they have often been brought to the United States in large numbers (Hamner et al. 2007). Multiple theories exist regarding their introduction (Whitfield et al. 2002), but accidental release from aquaria via Hurricane Andrew remains the most likely scenario (Meister et al. 2005; Hamner et al. 2007). In 1992, six lionfish were reported to have escaped from an aquarium after the hurricane struck (Meister et al. 2005). This suggests that these few individuals have reproduced successfully and created the invasive population. Nearly identical genetic makeups were found among most invasive lionfish members, supporting the theory of a founder effect within the invasive lionfish population (Hamner et al. 2007). Also, the free-floating nature of their eggs contributes to the spread of invasive lionfish (Freshwater et al. 2009).

Lionfish eggs drift through currents after they are spawned, facilitating a larger means of spread than by normal locomotion alone (Freshwater et al. 2009). The spread of lionfish to the north, however, is limited. Though they have been sighted as far as New York, the cooling water temperature during the winter restricts the year-round number of possible habitats for lionfish (Kimball et al. 2004). At a water temperature of 10°C, lionfish eventually die due to loss of vital behaviors, such as appetite and mechanical functions (Kimball et al. 2004). While metabolism is lost in declining water temperatures, lionfish acclimate positively in temperatures near 30°C (Kimball et al. 2004). Lionfish become more active at higher temperatures, and feeding rates also increase (Kimball et al. 2004). This suggests that as lionfish spread toward the Caribbean, their behavior will become more aggressive and their impact on ecosystems will elevate. However, the continental shelf off of the coast of Florida currently prevents the lionfish's normal spread because they cannot venture below certain depths, which restricts their overall expansion southward (Kimball et al. 2004). While this natural barrier prevents adult lionfish from swimming into the Caribbean Sea, the combined effects of southern currents and the free-floating properties of lionfish eggs may eventually allow lionfish to invade the Caribbean (Freshwater et al. 2009). There, lionfish would likely thrive due to the tropical environment and spread further towards South America (Kimball et al. 2004; Morris and Whitfield 2009). The Atlantic shelf provides a favorable habitat for invasive lionfish because the variety of reefs at different depths offers advantageous lighting as well as excellent hunting areas and shelter (Meister et al. 2005; Côté et al. 2010). Reefs provide lionfish with an easy food supply, as native fish prey are inexperienced with their lionfish predators (Côté et al. 2010). Many of the reefs are located on shelf edges at deeper depths (45-110 m) and are the habitats of larger fish as well (Meister et al. 2005). Though they may be deep, sunlight is able to reach these depths, creating a crepuscular region with some visibility (Côté et al. 2010). Lionfish are naturally active around dawn and dusk, the twilight hours, which allows them to feed on both diurnal and nocturnal prey (Meister et al. 2005). With these lighting conditions, lionfish are able populate even these deeper reefs because they mimic their natural feeding conditions (Meister et al. 2005; Côté et al. 2010). With such a large food source, lionfish are easily able to consume large amounts of fish (Meister et al. 2005). Meister et al. estimated that as few as eighty lionfish can consume as much as fifty thousand fish every year (Meister et al. 2005). With these advantages, invasive lionfish present a danger to the integrity of Atlantic ecosystems.

The success of the lionfish in the Atlantic is due in part to their unique defensive mechanisms (Meister et al. 2005; Whitfield et al. 2007). Lionfish are adorned with spines along their dorsal, anal, and pelvic fins (Whitfield et al. 2007). These spines contain a venomous neurotoxin that is lethal to most creatures (Albins and Hixon 2008). In its invasive range, lionfish have few predators because most potential predators are not evolutionarily adapted to tolerate the venom (Whitfield et al. 2007). This reduces predation on lionfish from native predators, allowing the lionfish to reproduce and spread easily (Whitfield et al. 2002). This is a likely explanation for why the six original lionfish may have been able to procreate fairly unchecked (Meister et al. 2005). Currently, the bluespotted cornetfish (*Fistularia commersoni*, the Nassau grouper (*Epinephelus striatus*), and the Tiger grouper (*Myceteroperca tigris*) are the only native fish that have been reported to successfully prey upon invasive lionfish (Meister et al. 2005; Mumby et al. 2011). This small number of predators reduces the chance of predation for lionfish considerably.

Lionfish also employ a wholly unique method of predation that is not shared by native fish (Whitfield et al. 2007). The lengthy spines of the lionfish are not only used for protection, but also for predation. In addition, lionfish are opportunistic predators that tend to prey upon smaller fish, usually teleosts or crustaceans (Morris and Akins 2009; Whitfield et al. 2002). Lionfish’s preferential hunting grounds are aggregations of small fish found around cleaner shrimp (Côté and Maljkovic 2010). When lionfish choose their target, they slowly pursue it until they have it corralled against a rock or a confined space. Then, with their fins spread widely,the lionfish move in close enough to quickly strike and consume their prey (Albins and Hixon 2008; Côté and Maljkovic 2010). Its long spines and fins allow the lionfish to occupy more space and limit possible routes of escape. This technique differs from the typical ambush style of predation that native fish are accustomed to, so lionfish have an exploitative advantage in predation (Albins and Hixon 2008; Whitfield et al. 2007).

Lionfish are successful predators in their invasive range and are well defended due to their venomous spines. The lack of strong biological constraints allows the lionfish to feed and spread more quickly than in their native range (Arias-González et al. 2011). Lionfish in the invasive range can reach populations over five times as large as populations in their native range, thus outnumbering all native fish with the exception of scamps (Arias-González et al. 2011; Whitfield et al. 2007). They have been recorded to reach population levels of 390 individuals ha^{-1} in the Bahamas and over 400 individuals ha^{-1} off of the North Carolina coast, compared to records in their invasive range of 80 lionfish ha^{-1} in the Red Sea (Arias-González et al. 2011). Such large populations naturally consume more food than a typical native population would, and since the arrival of lionfish, recruitment rates of small fish have dropped 76-80% (Albins and Hixon 2008; Arias-González et al. 2011; Morris and Akins 2009; Côté and Maljkovic 2010). A lionfish population as small as 80 individuals can consume as many as 50,000 fish in a single year (Meister et al. 2005). Lionfish have also been documented to prey upon fish that are two-thirds their own body weight, indicating that the range of possible prey is large and that many Atlantic and Caribbean fish are potential candidates (Albins and Hixon 2008). With such large lionfish populations in the invasive range, combined with their effective consumption rate and lack of predators, Atlantic and Caribbean ecosystems are threatened with drastic changes in biological composition and structure.

Small fish preyed upon by lionfish are directly affected through predation, but other organisms, such as sharks, rays, and jacks, are also affected indirectly as they compete with the lionfish for food (Arias-González et al. 2011). These larger predators are unable to prey upon or otherwise remove lionfish as a competitor due their unfamiliarity with the lionfish's toxic spines (Whitfield et al. 2007). There are only three species of fish that have been reported to successfully predate upon lionfish, two of which are groupers (Meister et al. 2005; Mumby et al. 2011). However, overfishing of groupers further diminishes natural biocontrol in the Caribbean (Whitfield et al. 2007). Loss in fish populations due to lionfish invasion may also affect the physiology of coral reefs. Parrotfish are herbivorous fish that play a crucial role in limiting the spread of seaweed (Albins and Hixon 2008). Lionfish predation upon juvenile parrotfish would inevitably restrict their growth and likely reduce their population (Albins and Hixon 2008). With a diminishing parrotfish population, seaweed may grow unchecked and begin to crowd out coral reefs (Albins and Hixon 2008). This presents not only a problem for coral, but also for the fundamental interactions among reef fish, which may also be altered by seaweed overgrowth. Reef habitats would change and put a directional pressure towards fauna that perform better in such habitats. By restricting the growth of herbivorous fish, lionfish could facilitate the replacement of coral reefs with seaweed beds.

Also, large populations of lionfish create competition for space not only between different species, but also among the lionfish themselves (Whitfield et al. 2007). This competition between lionfish mediates their dispersal to other suitable habitats (Whitfield et al. 2007), and the free-floating nature of their eggs further increases the available range for expansion (Freshwater et al. 2009). Expansion to new habitats would likely result in the decrease of biodiversity resembling that of the currently invaded regions, as the type of habitat or native populations have no effect on the lionfish's ability to reduce fish recruitment and composition (Albins and Hixon 2008).

Invasive lionfish threaten the integrity of Atlantic and Caribbean ecosystems. Human and natural control over the spread and density of lionfish is required in order to prevent further damage. Due to the high populations already present in the lionfish's invasive range, as well as their capability to spread quickly, lionfish present a difficult scenario for removal and control (Barbour et al. 2011; Morris et al. 2011). It is estimated that about twenty-seven percent of adult lionfish would need to be removed monthly from the Atlantic in order to keep their population levels below sustainable levels (Morris et al. 2011). Unchecked growth that continues to surpass an ecosystem's sustainable levels would likely diminish biodiversity and ecological structure, as well as facilitate further expansion to other ecosystems. Human removal of lionfish is one option for control, although it would present a challenge (Morris et al. 2011). In a single year, between 157 and 293 lionfish ha^{-1} need to be removed to reduce their populations to a manageable level (Barbour et al. 2011).

The use of scuba divers and spear fisherman would likely be a strong factor in lionfish management, as recent derbies and competitions have yielded over 1,400 caught lionfish in single days (Morris and Whitfield 2009). Other derbies and derby-like competitions have already been hosted in several Caribbean countries, and licenses for spearing lionfish have also been distributed (Barbour et al. 2011). This method enables divers to specifically catch lionfish where they are most prevalent. Traditional hook and line methods are largely ineffective for removal, often yielding bycatches instead of lionfish unless pheromones or other attractants are used (Morris and Whitfield 2009). However, lionfish are also able to establish themselves at deeper depths along the Atlantic coast (Côté et al. 2010). A spear fishing method of control would be ineffective in deeper depths due to scuba limitations (Barbour et al. 2011). Furthermore, locations for spear fishing and derbies could only be orientated towards areas of high lionfish concentration, where yield would be high (Barbour et al. 2011). Most other areas, whether they are deep or have lower lionfish concentrations, would offer refuge for the other lionfish (Barbour et al. 2011). This limits the total possible area for control with these methods, and would not likely lower population levels effectively. Acquiring necessary funds for sponsoring derbies and spear fishing presents yet another challenge for this method (Barbour et al. 2011).

Another possibility for human removal of lionfish would be the creation of a fishing industry that specializes in lionfish cuisine (Barbour et al. 2011; Morris and Whitfield 2009; Morris et al. 2011). Currently, there is no such industry, nor is there any particular demand for lionfish as a food resource (Barbour et al. 2011). However, much of the Caribbean has been influenced by French culture, and thus French cuisine has a strong presence in these areas. Stonefish is used in the highly popular French bouillabaisse and rascasse soups, and both dishes are in high demand in the Caribbean (Morris and Whitfield 2009). Lionfish are in the same family as stonefish and have mild, firm, palatable meat, suggesting that using lionfish instead of stonefish in the Caribbean may offer a lucrative method of lionfish control (Morris and Whitfield 2009). Not only will this aid in reducing their population to manageable levels, but demand for lionfish meat would also, in theory, boost industry and the economy. This scenario would be ideal for industry, governments, and environmental conservationists alike, so support for this method of control would likely be high. However, this method may create an incentive to release lionfish into the Caribbean to promote further catches and wealth (Morris and Whitfield 2009). This would likely fail to reduce lionfish populations effectively, or could even increase their populations. In order to prevent lionfish releases, strong regulations would be needed. If these regulations are enforced, promoting a fishing industry could be highly effective for control.

Using human intervention as a means of lionfish control could help reduce lionfish populations and be economically beneficial as well. Lack of funding and deliberate lionfish release are among the shortcomings of these methods of human intervention. Due to these shortcomings, such methods may not be entirely effective. The use of biocontrol would be a strong alternative (Mumby et al. 2011). Very few native organisms are known to successfully prey upon invasive lionfish, but strategic use of the few successful predators may strongly influence lionfish populations. Two species of Caribbean grouper, *Epinephelus striatus* and *Myceteroperca tigris*, have been documented to prey upon lionfish (Mumby et al. 2011). However, grouper is heavily fished in the Caribbean, reducing the natural means of biocontrol that already exist. In one study, grouper and lionfish biomass was documented during a twenty-year ban on fishing (Mumby et al. 2011). Comparisons of grouper and lionfish biomasses showed that there was a strong negative effect on lionfish populations as grouper populations increased (Mumby et al. 2011). If restrictions were placed upon the fishing of grouper, their numbers would increase over time, allowing grouper to act as a natural biocontrol for lionfish. The use of native grouper would also be advantageous because they would be able to hunt lionfish at deeper depths that spear fishermen have difficulty reaching. Grouper would also be able to hunt lionfish for greater periods of time than spear fishermen can, and they would likely be more efficient in their search as well.

However, widespread fishing regulations, like those restricting the fishing of grouper, would be difficult to implement (Mumby et al. 2011). Although this method may not be entirely feasible alone, it may be possible to promote the lionfish industry in conjunction with the use of grouper biocontrol. By convincing grouper fisheries to instead catch lionfish, grouper populations would increase at the expense of lionfish populations. Once lionfish have been reduced to manageable populations, there would be an abundance of grouper to be harvested by fishing industries, which could cover their expenses.

Several options to control the invasive lionfish population are present, but cooperation among industry, government, and the public is needed for proper management. Invasive lionfish have already been documented to significantly harm native fish populations and biodiversity (Albins and Hixon 2008; Arias-González et al. 2011; Côté and Maljkovic 2010; Morris and Akins 2009). Upper tier predators, which are often harvested by fishing industries, would be affected by changes in fish populations, as the presence of fewer prey would in turn decrease their populations. This in turn would affect fishing operations by decreasing their catches and thus their source of income. Explanations of such long tern effects to fishing industries could increase their support of lionfish control, and government support would likely follow. Continued environmental damage due to the lionfish invasion would likely increase the retail value of commercial fish, and thus the general public would be affected as well. Not only would the possible economic effects of the lionfish invasion be a source of public support, but the health hazard posed by their venomous spines can also endanger the well being of the public (Aldred et al. 1996). Lionfish spines contain a venomous neurotoxin that can cause many medical complications in humans, such as swelling, pain, tissue necrosis, and shock (Aldred et al. 1996). Most lionfish incidents occur from mishandling in aquariums and medical attention is typically required by those affected (Aldred et al. 1996). Further expansion of lionfish in the Atlantic and Caribbean poses a threat to public health, especially to beachgoers and divers. Through the explanation of the health and economic risks that lionfish pose, public support could also be gained.

The Atlantic and Caribbean are home to a great diversity in wildlife found nowhere else in the world. The recent lionfish invasion has already caused numerous changes in the structure of ecosystems and to the ecosystems' inhabitants. The lionfish spread quickly, and are invading more ecosystems along the Atlantic Coast and in the Caribbean. If left unchecked, they may spread even further to South America, where even more biodiversity will be threatened (Kimball et al. 2004; Morris and Whitfield 2009). Their effects on the environment would also affect private industry, as well as the public and possibly the governments throughout the Atlantic and Caribbean. Though lionfish may cause widespread changes to the environment and even to human communities, control and management of invasive lionfish can be implemented with strong support before they further damage the environment.

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