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Sea Change in Management Strategies: The implications of global climate change on policy conceptions of and responses to invasive marine species

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Sea Change in Management Strategies

The implications of global climate change on policy conceptions of and responses to invasive marine species

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*"When the Cup is brim full before,
the last (though least) added drop is charged alone
to be the cause of all the running over."*

Thomas Fuller, 1655

Table of Contents

Acknowledgments

My peers within the Public Policy & Law program often refer to our major as a community primarily because of the intimate nature of the material and of the assignments by which we are all challenged. We spend countless nights in the library articulating and rehearsing case law in preparation of formal oral arguments as part of Professor Cabot's class. We scour coverage of current events from every perspective, arming ourselves with intellectual munition for when we are inevitably called upon by Professor Fulco to share our personal take on policy issues. We identify commons problems with Professor Chambers and craft policy responses to them. With Professor Horowitz, we rigorously evaluate the legal contours of ongoing disputes. If nothing else, this major is about broadening our horizons and seeing beyond presuppositions, analyzing points of contention to discern the best resolution, and relying on our colleagues to invoke our best. The Public Policy & Law program reifies our sense of personal efficacy to do good in this world, and the formation of a community within the major comes naturally through this camaraderie.

Thank you to my parents for their unwavering support, unconditional love, and lifelong investment in my academic and personal development. Thank you to my brother whose guidance — whether solicited or not — has always led me down the right path. Thank you to Chris and Pam Maxey who sowed the seeds of my curiosity in environmental studies and who instilled in me the confidence to effect positive change. Thank you to Sharon Jarboe for her bottomless well of wisdom and compassion. Finally, I am especially appreciative of Professor Adrienne Fulco for her guidance and understanding as my advisor, for her unending enthusiasm as an educator, for her refreshing candor, for her tireless authorship of recommendation letters, and, ultimately, for her friendship.

Introduction

For the past four summers, I have had the pleasure of working alongside inspiring educators and researchers at the Island School and the Cape Eleuthera Institute on the southern tip of Eleuthera, Bahamas. At once small and mighty, the shared campus of both organizations serves as a locus of curiosity and oceanic discovery for students of every age. I first met the researchers of CEI during the Island School Fall 2011 semester; my peers and I were assigned to PhD's and PhD candidates who were in the vanguard of regional conservation research. Most of these researchers were in the Bahamas collecting field data through hard–won grants from their home universities. As such, these individuals were savvy and scrappy, able to rig up research equipment using inexpensive materials to meet unique needs. I admired their capacity to solve problems with zip ties, PVC tubes, and duct tape. Ambitious graduate students taught us how to catch deep–water sharks, how to herd sea turtles in seine nets, and how to safely spear invasive lionfish.

I had known of the Caribbean–Atlantic lionfish epidemic before arriving. By that time, my father had been directing a sustainable seafood company, which would later be designated by Greenpeace as the #1 most sustainable and ethical tuna brand in the U.S. To say that I was tuned into issues affecting our global fisheries would be an understatement — fisheries management was a dinner table topic for my family. I had seen lionfish in aquaria, but never in the wild. When confronted with lionfish along the reefs of southern Eleuthera, I was taken aback by just how prevalent they indeed were. I would quickly learn more about the invasive lionfish's deleterious effects throughout the Caribbean–Atlantic: outcompeting native species, reducing biodiversity, and threatening local fisheries. Even after returning home that winter to the U.S. west coast, far from the turquoise Bahamian waters, these issues continued to concern me.

Over the subsequent years, I would discover my passion for environmental policy. I was drawn toward cases of fishery collapse and threatened fish stocks, especially those aggravated by the effects of global climate change. Pursuing these concerns, I dedicated my academic years to public policy and sustainable development courses, while my summers were spent teaching a course entitled Tourism & Development at the Island School Summer Term. Tourism & Development is a course in which our students explore Eleuthera — both its physical locations and its history — and the underlying socioeconomic factors that have impacted its development. The central motif of the course is an examination of tourism's influence on the island's culture and development — a relationship that is simultaneously symbiotic and paradoxical. Through teaching this course, I became intensely intrigued by the status fishermen hold in Bahamian society and, accordingly, the threat lionfish pose to their livelihood.

When our federal agency charged with protecting the environment is led by individuals skeptical of climate change's implications (let alone its anthropogenic origins),[1] it has become increasingly important to directly link the phenomenon of climate change to threats against our national security and economy. To do so may be our only hope of rationalizing protective environmental measures for our current federal leadership. In pondering the paradox that has become the EPA leadership, I returned to the issues presented by invasive lionfish. What does it mean for subsistence communities — which compose much of the affected Caribbean–Atlantic countries — to compete with an invasive species for food? How have local and federal governments responded to the invasion of the lionfish in the Caribbean–Atlantic region? Has

[1] Coral Davenport, "E.P.A. Head Stacks Agency With Climate Change Skeptics," *The New York Times*, US, Politics, Climate, March 7, 2017, https://www.nytimes.com/2017/03/07/us/politics/scott-pruitt-environmental-protection-agency.html?_r=0 (accessed March 8, 2017).

climate change accentuated the lionfish invasion, and, if so, what can policy–makers learn as they consider other ecological threats?

This thesis is my exploration of the issues mentioned above. By dissecting a seemingly local issue, I hope to uncover solutions — or at least key ingredients of solutions — with global utility. After discussing the introduction of the lionfish to the Caribbean–Atlantic and its efficacy at rapid dispersal, I describe how climate change participates in the spread of the lionfish invasion. Specifically, I discuss how factors attributed to climate change have and will continue to amplify the lionfish problem. Through evaluating the establishment of lionfish within the region, I assess the threats posed to native species and, thereby, the very real risks to local economies. I present the lionfish case as a metaphor for policy problems in an era of climate change, a phenomenon that will undermine current policy conceptions of invasive species and hinder future control strategies (a concept inspired by my research on "invasivity"[2] at University of St Andrews' School of Geography and Sustainable Development). The examination reviews marine policy responses and makes recommendations for future actions that seek to prevent or mitigate similar situations in the future. Ultimately, this thesis serves to make sense of the diminishing schism between nativism and invasivity catalyzed by climate change.

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[2] For the purposes of this work, "invasivity" shall refer to a species' capacity to become invasive within the recipient ecosystem and the likelihood of its establishment within that locale.

Chapter One: The Lionfish Invasion

The dispersal of lionfish across the Caribbean–Atlantic reverberates throughout the region's public policy, conservation efforts, and economic concerns. To appreciate the consternation surrounding this flamboyant aquarium fish and to understand how the surrounding crisis can inform future public policy, one must first become familiar with the lionfish — its origins, its competitive advantages, and the factors that have enabled its incredible success at overtaking a novel range. The invasion of lionfish is significant precisely because it presents unprecedented deleterious effects to the Caribbean–Atlantic. As Morris and Whitfield (2009) note, "[i]nvasive species are capable of competing with native organisms, altering habitats (Mack et al. 2000; Kolar and Lodge 2001; Rahel 2002; Olden et al. 2004), reducing biodiversity (Olden et al. 2004), and even causing extinctions of indigenous plants and animals (Clavero and García-Berthou 2005)."[3] Frighteningly, lionfish have accomplished all but that final prophecy in a matter of just several decades.

This chapter begins with a brief overview of the scientific community's discourse in the early years of the lionfish invasion. It highlights the uncertainty of the situation, and it targets the aquarium trade as the most likely vector for the introduction of the invasive species. Section B pivots around the biological and physiological traits that have empowered the lionfish to successfully establish itself throughout the Caribbean–Atlantic, stressing that the species' versatility has been fundamental to its rapid geographic dispersal. Section C steers the conversation toward climate change, framing the phenomenon as one that will amplify the lionfish's prosperity well into the future and as one that necessitates immediate intervention by authoritative decision–makers. Section D explores other abiotic factors that have set the stage for the lionfish takeover.

[3] J.A Morris and P. E. Whitfield, "Biology, Ecology, Control and Management of the Invasive Indo–Pacific Lionfish: An Updated Integrated Assessment," NOAA Technical Memorandum NOS NCCOS 99 (2009) : 1.

By examining a myriad of human activities, we see that anthropogenic forces have effectively given lionfish carte blanche with respect to habitat and prey.

A. Genesis Story: Introduction of Lionfish into the Caribbean–Atlantic

Lionfish are native to the warm, tropical waters of the Western Pacific and Indian Oceans (*i.e.,* the Indo–Pacific region), including the Red Sea (see Figure I.1). With a broad range, they occupy territory stemming from western Australia and Malaysia east to French Polynesia and the United Kingdom's Pitcairn Islands, north to southern Japan and the Yellow Sea and south to Lord Howe Island off the east coast of Australia and the Kermedec Islands of New Zealand. Lionfish remain in waters contiguous to southern Asia and eastern Africa as far south as the southern end of Madagascar.[4]

The first reported sighting of lionfish in the United States came from a lobster fisherman in 1985 off the Atlantic coast of Florida, near Dania Beach.[5] Morphology and meristics (quantification of fish traits such as fin spines) aided in establishing this specimen's identity. There were no more sightings of lionfish in the region until October 1992, after six lionfish escaped a seaside aquarium in Biscayne Bay, Florida as a result of Hurricane Andrew in August of that year. These lionfish were observed on shallow–water reefs off of Palm Beach.[6] According to P. J. Schofield's chronology of the invasion of lionfish, the next recorded sighting of lionfish occurred

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[4] National Ocean Service, "Lionfish Invasion," National Ocean and Atmospheric Administration, http://oceanservice.noaa.gov/education/stories/lionfish/media/supp_factc.html (accessed September 29, 2016).

[5] J. A. Morris Jr. and J. L. Akins, "Feeding ecology of invasive lionfish (Pterois volitans) in the Bahamian archipelago," *Environ Biol Fish* 86 (2009) : 389; Florida Fish and Wildlife Conservation Commission, "Lionfish — Pterois volitans," Florida Fish and Wildlife Conservation Commission, Wildlife & Habitats, Nonnative Species, Marine Species, http://myfwc.com/wildlifehabitats/nonnatives/marine-species/lionfish/ (accessed November 6, 2016); P. J. Schofield, "Geographic extent and chronology of the invasion of non–native lionfish (Pterois volitans [Linnaeus 1758] and P. miles [Bennett 1828] in the Western Atlantic and Caribbean Sea," *Aquatic Invasions* 4, no. 3 (2009) : 474.

[6] W. R. Courtney Jr., "Marine fish introductions in southeastern Florida," *American Fisheries Society Introduced Fish Section Newsletter* 14 (1995) : 2–3.

in 2000, when four were seen off the coast of Florida, one was seen off of South Carolina, and three were reported on the North Carolina coast. The next year, in 2001, five specimens were spotted in Floridian waters, three off of Georgia, fourteen–plus off North Carolina, and two as far north as Fire Island, New York.[7] In 2004, the lionfish reached the Bahamas. In the several years following, the lionfish would come to populate the waters of nearly every Caribbean nation (Figure I.2).[8]

In 2002, the U.S. National Oceanic and Atmospheric Administration (NOAA) published the first scientific article on the presence of lionfish in the Western Atlantic Ocean.[9] "This article qualified the lionfish as invasive based on its foreignness and dispersal throughout the U.S. East Coast and Bermuda."[10] Scientists qualified the non–nativeness of the species by the absence of any data of reported lionfish sightings in the Western Atlantic Ocean before the 1980s. Moreover, because the fish was known to inhabit the Western Pacific and Indian oceans, the scientific community and others accepted the non–nativeness of lionfish in the Western Atlantic Ocean as fact. Lionfish, as a venomous scorpionfish native to the Indo–Pacific, are officially classified invasive by the U.S., as per the Invasive Species Executive Order No. 13112,[11] due to their probable impacts to native reef fish communities[12] and to human health.[13]

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[7] Schofield (2009), 474.

[8] R. R. Betancur et al., "Reconstructing the lionfish invasion: insights into Greater Caribbean biogeography," *Journal of Biogeography* 38, no. 7 (2011) : 1283.

[9] P. E. Whitfield et al., "Biological invasion of the Indo–Pacific lionfish Pterois volitans along the Atlantic coast of North America," *Marine Ecology Progress Series* 235 (2002) : 289–297.

[10] Carballo–Cárdenas (2015), 24.

[11] William J. Clinton, "Executive Order 13112 of February 3, 1999: Invasive Species," Presidential Documents, Federal Register, 64, no. 25 (1999) : 6183–6186.

[12] M. A. Albins and M.A. Hixon, "Worst case scenario: potential long–term effects of invasive predatory lionfish (Pterois volitans) on Atlantic and Caribbean coral-reef communities," *Environ Biol Fish, Springer Science* (2011); J. A. Morris, Jr. et al., "Biology and ecology of the invasive lionfishes, Pterois miles and Pterois volitans," *Proceedings of the Gulf and Caribbean Fisheries Institute* 29 (2009) : 409–414.

[13] S. J. Vetrano, J. B. Lebowitz, and S. Marcus, "Lionfish envenomation," *Journal of Emergency Medicine* 23 (2002) : 379–382.

So, how is it that lionfish came from the Indo–Pacific to the Western Atlantic in the first place? During the 1990's and early 2000's, scientists debated various different means by which the fish arrived, and much has been written on this matter of the species' introduction vector.[14] Initial hypotheses ranged dramatically, but some tended toward the notion of natural range expansion, or "autonomous migration" without any human intervention: "natural dispersal through the Panama Canal or across the Atlantic from the Mediterranean Sea, where lionfish had also been sighted."[15] This theory was soon discarded "because the distance was deemed too large and the ecological barriers, insurmountable. Moreover, later studies showed that genetic data did not match the data from those areas."[16]

While proponents of natural dispersal theories propagated their research throughout the scientific community, evidence suggesting a human–mediated introduction accumulated. The most common causes of nonindigenous marine fish introductions (contributing to the hundred–plus documented cases thereof) are transplantations, canal construction, and ballast water releases from cargo or cruise ships,[17] and these phenomena were likely candidates for the lionfish introduction vector.[18] Ultimately, the aquarium trade was identified as the most probable vector for lionfish introductions. Lionfish are very popular in the aquarium trade. A variety of sources reported concurring data explicitly implicating aquaria,[19] including data collected since 1993

[14] J. A. Hare and P. E. Whitfield, "An integrated assessment of the introduction of Lionfish (Pterois volitans/miles complex) to the Western Atlantic Ocean," *National Oceanic and Atmospheric Administration (NOAA) Technical Memorandum NOSE NCCOS 2* (2003) : 1–21.

[15] Carballo–Cárdenas, 24, *citing* D. Golani and O. Sonin, "New records of the Red Sea fishes, Pterois miles (Scorpaenidae) and Pteragogus pelycus (Labridae) from the eastern Mediterranean Sea," *Ichthyological Research* 39, no. 2 (1992) : 167–169.

[16] *Ibid.*

[17] D. M. Baltz, "Introduced fishes in marine systems and inland seas," *Biological Conservation* 56 (1991) : 151–177.

[18] Carballo–Cárdenas (2015), 24.

[19] *See* B. X. Semmens et al., "A hotspot of non–native marine fishes: evidence for the aquarium trade as an invasion pathway," *Marine Ecology Progress Series* 266, no. 1 (2004) : 239, which relies upon "…a large spatially explicit marine fish database to show that there are a surprising number of non–native fishes on the reefs of southeast Florida, USA…Data on international shipping patterns and marine fish imports were used to evaluate the

through sport diver volunteer fish surveys conducted by the Reef Environmental Education Foundation (REEF), along with its online "exotic species reporting page" since 2002. Despite the early affinity for pegging the invasion on the release of six lionfish resulting from the destruction of the seaside aquarium in Biscayne Bay in 1992, this theory has been ultimately debunked by Morris & Akins (2009), which cited the documented lionfish sighting of 1985 (pre–dating Hurricane Andrew by seven years) in Dania Beach,[20] with the respective specimen being preserved by the U.S. Geological Survey (Nonindigenous Aquatic Species database ID no. 261964):[21]

> The first time the mistaken link was suggested between Hurricane Andrew and lionfish was in 1995 (Courtenay 1995), but Courtenay said to a reporter in 2010 that he would like to "put this idea to rest. … It was secondhand information … which unfortunately continues to spread, so that [Hurricane] Andrew is often mentioned as the reason for the catastrophic lionfish invasion."[22]

Further evidence refuting the "hurricane myth" arrives in the form of mitochondrial data.[23] DNA analysis of captured specimens indicates that lionfish within the Western Atlantic have significantly less genetic diversity than those within their native Indo–Pacific waters.[24] "This lack of genetic diversity confirms a strong founder effect (the founder effect describes the phenomenon of a few individuals becoming isolated from a larger population and establishing a new population whose gene pool differs from the source population)."[25] Betancur et al. (2011) analyzed the "chronology of the invasion in conjunction with the genetic data in order to provide real–time

culpability of [ballast water releases and the aquarium trade]. Our results suggest that the introductions are the result of aquarium releases."

[20] Morris and Akins (2009), 389.

[21] Betancur et al. (2011), 1289.

[22] Carballo–Cárdenas (2015), 24, *citing* Virginia Morell, "Mystery of the lionfish: don't blame Hurricane Andrew," *Science Insider*, April 29, 2010, http://www.sciencemag.org/news/2010/04/mystery-lionfish-dont-blame-hurricane-andrew (accessed November 10, 2016).

[23] Betancur et al. (2011), 1289.

[24] Betancur et al. (2011), 1281.

[25] Nichola Clark, "Invasion of Reservation: U.S. policy responses to the invasive lionfish within Marine Protected Areas," Senior Theses, Trinity College, Hartford, CT (2012) : 15.

assessments of hypotheses of marine biogeography."[26] The study established that, despite low levels of genetic diversity, the invasive lionfish mitochondrial data indicates that there must have been between eight and twelve individual founding specimens to account for the genetic diversity in the entirety of the invasive lionfish population of the Caribbean–Atlantic.[27] Compounded by the 1985 documentation, this finding removes the culpability for the invasion from just the six releases following Hurricane Andrew, though it remains entirely possible that these six made up one–half to three–quarters of the founding individuals.[28]

Betancur et al. (2011)'s comprehensive study of the lionfish invasion biogeography determined that the ubiquity of lionfish within the region was the "result of range expansion from the original location of the introduction (*i.e.,* the U.S. east coast), a scenario consistent with the chronology of occurrences" (Figure I.2).[29] Based on genetic testing, as above, the study found that the lionfish invasion was not the product of "multiple independent introductions at various locations throughout the [Western Atlantic]," which would have reflected an increase in genetic diversity.[30] Moreover, Morris and Whitfield (2009) cites evidence of "larval connectivity between Florida and the Bahamas," stating that, at least up to 2009, "lionfish dispersal southward into the Caribbean follows a pattern that closely resembles the Caribbean connectivity model developed by Cowen et al. (2006) for damselfish."[31]

While the exact and full mechanism of introduction will likely never be known, the majority of scholars currently agree that the presence of lionfish in the Caribbean–Atlantic is a direct result of intentional and unintentional releases from Florida aquaria. Historically, aquarium

[26] Betancur et al. (2011), 1281.
[27] Betancur et al. (2011), 1289.
[28] Clark (2012), 16.
[29] Betancur et al. (2011), 1284.
[30] *Ibid*.
[31] Morris and Whitfield (2009), 15.

releases have "consistently been found to be among the top sources for the introduction of non–native aquatic species."[32]

Knowing the means of the species' introduction to the region is critical in evaluating the sectors and policies in need of redress; by understanding the source of the lionfish invasion, policy–makers can seek affirmative solutions to prevent future takeovers by non–natives. Moreover, for the case of the lionfish specifically, determining their introductory vector and range helps scientists discern the rate at which lionfish spread, as well as the factors that enable more rapid dispersal (and, by contrast, the factors that limit expansion). This information is key as authoritative decision–makers representing as–of–yet unaffected waters craft management programs in preparation of the invader's arrival.

B. The Invasion Spreads: Fecundity and Efficient Predation Enable Explosive Dispersal

The lionfish invasion in the Caribbean–Atlantic represents "one of the most rapid marine finfish invasions in history."[33] Interestingly, "this is not the first documented invasion of *Pterois* sp. as Golani and Sonin (1992) reported a Mediterranean invasion of *P. miles* from the Indian Ocean via the Suez Canal."[34] Especially since 2005, the species' distribution has increased rapidly in the Caribbean–Atlantic region. Based on contemporary sea surface temperature constraints and lionfish physiological demands, Morris and Whitfield (2009) projected the potential year–round invasive range of adult lionfish as extending from Cape Hatteras, North Carolina in the Northern Hemisphere to the southern border of Brazil in the Southern Hemisphere. In addition to the reefs of Caribbean islands, lionfish have been documented along nearly the entire coastline of the Gulf

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[32] Rebecca Bratspies, "Lionfish as a Metaphor for Governance in an Era of Climate Change," *New York Law School Law Review* 58 (2014) : 836.
[33] Morris et al. (2009), 409.
[34] Morris et al. (2009), 410.

of Mexico, Central America, Columbia, and Venezuela, with the highest reported densities situated along the coral reefs of the Bahamas.[35] So how is it that lionfish — in less than two decades — have taken over the million–plus square miles of the Caribbean Sea? To answer this question, one need look no further than the physical characteristics of lionfish.

Maroon–brown in color with white stripes or bands, the lionfish exhibits thirteen dorsal spines, ten to eleven dorsal soft rays, three anal spines, six to seven anal soft rays, fan–like pectoral fins, and tentacles above their eyes and under their mouth (Figure I.3).[36] Absolutely unique in their appearance (hence their popularity in the aquarium trade), the lionfish's spines are all encompassing, radiating dorsally in nearly all directions, with the large pectoral fins extending laterally and ventrally. Able to grow as large as eighteen inches, lionfish are intimidating creatures. Lionfish are active hunters who "ambush their prey by using their outstretched, fan–like pectoral fins to slowly pursue and corner them, often using reef rugosity to entrap prey."[37] Once herded, lionfish attack their prey with a rapid strike.[38] Recent additions to this novel range, lionfish likely use this distinctive hunting technique as a means of capitalizing on prey naïveté, a hypothesis that posits that "naïve, native prey that lack evolutionary history with non-native predators suffer heavy predation because they exhibit ineffective antipredator responses to novel predators."[39]

Indicative of the species' predatory prowess, a 2009 study established that lionfish consume high numbers of large prey, including prey up to half the individual's own size.[40] Within

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[35] I. M. Côté and S. J. Green, "Record densities of Indo-Pacific lionfish on Bahamian coral reefs," *Coral Reefs* (2009) 28 : 107; Morris and Whitfield (2009), 8.

[36] National Ocean Service, "Lionfish Biology Fact Sheet," National Ocean and Atmospheric Administration, http://oceanservice.noaa.gov/education/stories/lionfish/factsheet.html (accessed September 17, 2016).

[37] National Ocean Service, "Lionfish Biology Fact Sheet."

[38] Albins and Hixon (2008), 233–238.

[39] Andrew Sih et al., "Predator–prey naïveté, antipredator behavior, and the ecology of predator invasions," *Oikos* 000 (2009) : 1–12.

[40] Morris and Akins (2009), 389–398.

the same study, researchers observed a single adult lionfish consume twenty small wrasses (a family of brightly colored fish) within a thirty–minute period. While only a single observation, this anecdote illustrates the capacious appetite of lionfish. A study from the same year corroborates this report, establishing that lionfish consume between 2.5 to 6 percent of their body weight every day.[41] Moreover, despite a high daily intake, lionfish are able to survive for twelve weeks without food, thereby contributing to scientists' understanding of their utter resilience.[42]

Revealing of their "deadliness," lionfish are capable of reducing reef recruitment of native fishes by approximately 79% during a five–week period.[43] This statistic has perhaps become the most oft–cited ecological impact data in the lionfish discourse by scientists and nonscientists alike.[44] Lionfish are, based on this assessment, dominant in the novel environment of the Caribbean–Atlantic. Two Bahamian studies have linked lionfish to an overall reduction of fish biomass and diversity on coral reefs in the region, which in the latter case preceded a shift to algal dominance.[45]

Their lethal efficiency has been observed in visual census surveys, which indicate that — even just two decades after their initial sighting in 1985 — lionfish maintain population densities capable of removing all of the forage fish biomass in some reef systems.[46] "A 2006 study estimated that lionfish were present in the Western Atlantic at densities of twenty–one lionfish per hectare. Two years later, studies found that average lionfish densities were in the range of 150 to 350

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[41] Morris et al. (2009), 409–414.
[42] Morris et al. (2009), 409–414.
[43] Albins and Hixon (2008), 233.
[44] Carballo–Cárdenas (2015), 24.
[45] M. P. Lesser and M. Slattery, "Phase shift to algal dominated communities at mesophotic depths associated with lionfish (*Pterois volitans*) invasion on a Bahamian coral reef," *Biological Invasions* 13, no. 8 (2011) : 1855–1868; S. J. Green et al., "Invasive lionfish drive Atlantic coral reef fish declines," *PLoS One* 7, no. 3 (2012) : e32596.
[46] Morris and Whitfield (2009), 16.

lionfish per hectare."[47] In fact, current lionfish densities in the Atlantic exceed lionfish densities in the species' native habitat by orders of magnitude.[48] Part of this success may be due to the lack of predation by indigenous fish, who are unaccustomed or ill–equipped to hunt lionfish within this novel range, a theory assessed later in this section. Nonetheless, reef fish consumption has been so extensive that lionfish may end up resorting to "prey switching" whereby "more crustaceans enter their diet as forage fish abundance declines. An increase in crustacean consumption by lionfish could directly impact some economically important species as crustaceans are a staple in the diet of some juvenile and adult serranids."[49] In such a situation, lionfish could suppress the abundance or alter the behavior of crustaceans, thereby releasing lower trophic levels from predation and potentially leading to a trophic cascade that ultimately fosters explosive algal growth, coral disease, or significantly altered food webs within reef ecosystems.

Defensively, lionfish primarily rely on venomous spines that radiate outwards from their body. Each of the lionfish's eighteen spines are encased in an integumentary sheath (or "skin") containing two grooves of glandular epithelium that comprises the venom producing tissue. The venom is a combination of a neuromuscular toxin, a protein, and a neurotransmitter called acetylcholine.[50] "Lionfish envenomation occurs when the spine's integumentary sheath is depressed as it enters the victim. This process tears the glandular tissue allowing the venom to diffuse into the puncture wound."[51] Given the neurotoxin that affects neuromuscular transmission, lionfish venom has been found to cause cardiovascular, neuromuscular, and cytolytic effects

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[47] Bratspies (2014), 837.

[48] Michael Kulbicki et al., "Distributions of Indo–Pacific Lionfishes *Pterois* Spp. in Their Native Ranges: Implications for the Atlantic Invasion," *Marine Ecology Progress Series* 446, no. 189 (2012) : 200.

[49] *Ibid*.

[50] A. S. Cohen and A. J. Olek, "An extract of lionfish (Pterois volitans) spine tissue contains acetylcholine and a toxin that affects neuro–muscular transmission," *Toxicon* 27 (1989) : 1367–1376.

[51] Morris et al. (2009), 411. Here, Morris et al. cite: P. R. Saunders and P. B. Taylor, "Venom of the lionfish Pterois volitans," *American Journal of Physiology* 197 (1959) : 437–440.

ranging from mild reactions such as swelling to "extreme pain and paralysis in upper and lower extremities."[52] The severity of sting reactions in humans depends on a variety of factors, including location of the sting, the amount of venom delivered, and the immune system of the victim. While lionfish are rarely aggressive to humans unless provoked, swimmers and divers must exercise caution whilst exploring reefs or other likely lionfish habitat. In this way, lionfish present a risk to recreational pursuits related to the tourism industry within the Caribbean–Atlantic — a matter explored in the next chapter.

Lionfish are also slow–moving and conspicuous, and they "rely on their unusual coloration and fins to discourage would–be predators from eating them,"[53] which is a highly effective mechanism within novel ranges. Put simply, indigenous species are unfamiliar with lionfish; they keep away from the lionfish's distinctive patterning. Lionfish in their native Indo–Pacific are successfully ingested by predators with the requisite protective mucus lining throughout the digestive tract. Regardless, there is evidence that at least *some* predation by native species of the Caribbean–Atlantic has occurred; sharks, eels, groupers, frogfish, and scorpionfish have all been observed to successfully consume lionfish within the region.[54] It is entirely possible that "nature will run its course," and that native species will slowly learn to identify lionfish as prey and, importantly, become immune to the venom through adaptation. Until then, lionfish are currently enormously successful in their ability to defend themselves within this novel range.

In addition to their incredible predatory and defensive capabilities, lionfish exhibit tremendous reproductive capacity:

[52] Morris et al. (2009), 411. Here, Morris et al. cite: K. W. Kizer et al., "Scorpaenidae envenomations: A five–year poison center experience," *Journal of the American Medical Association* 253 (1985) : 807–810.

[53] National Ocean Service, "Lionfish Biology Fact Sheet."

[54] Nigel Coles, "What eats lionfish?" Lionfish Hunting, Facts, July 18, 2015, http://lionfish-hunting.com/what-eats-lionfish/ (accessed December 17, 2016).

> The reproductive characteristics of lionfish have been identified by ecologists as key to its rapid and wide–ranging spread: lionfish may become sexually mature within their first year of life, present yearlong spawning at a frequency of more than two million eggs annually, and reproduce by releasing free–floating egg masses that are dispersed by ocean currents and subsequently develop into planktonic larvae.[55]

Such immense fecundity compounded by the radical distributive efficiency of the Caribbean, Florida, Gulf, and Yucatan currents enables widespread dispersal of the lionfish larvae. Because this trait enables lionfish populations to self–regenerate, it also poses massive complications to regional management efforts: if State A rids its waters of lionfish through successful culling efforts but an upcurrent country (State B) remains infested, State B's lionfish may produce larvae that navigate to State A, thereby "refouling" State A's waters. This propensity manifests as a key motivator for expanded regional control efforts, a topic explored in Chapter Two.

The high physiological resilience that lionfish exhibit is likely another contributing factor to the species' rapid establishment in the Caribbean–Atlantic. The physiology of lionfish prefers warm waters proximal to the equator, and lionfish can occupy waters ranging in depth from one to one thousand feet. While lionfish in the Western Atlantic have been reported as far north as Massachusetts, it is believed that lionfish are incapable of overwintering due to thermal intolerance and are therefore not yet considered established in the northeastern U.S.[56] — a condition that may well change in the coming decades as ocean water temperatures rise.

The lionfish is a remarkably versatile species. Multiple studies have contributed to the body of knowledge and data of the lionfish's capacity to handle a variety of differences in habitat and water conditions. "The fish were observed in a great variety of habitats (reefs, mangroves, rocky

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55 Carballo–Cárdenas (2015), 24, *citing* Morris and Whitfield (2009), 1.

56 M. E. Kimball et al., "Thermal tolerance and potential distribution of invasive lionfish (Pterois voiltians/miles complex) on the east coast of the United States," *Marine Ecology Progress Series* 283 (2004) : 269–278.

bottoms, seagrass beds, estuaries), showing high range tolerance to depth (1 m up to > 300 m), temperature, and salinity."[57] This ecological flexibility allows for a generalist diet. Moreover, realities inherent to the recipient ecosystem of the invasive lionfish, including comparatively weak competitors, prey naïveté, and overfished native predators (*i.e.,* grouper) inexperienced with lionfish have further enabled rapid dispersal throughout the Caribbean–Atlantic.[58]

C. *Expanding Isotherms: Climate Change as a Contributor to the Invasion*

The effects of climate change will accentuate the lionfish's already fantastic capacity to spread throughout the Caribbean–Atlantic region. In fact, much research has concluded that warming ocean conditions will facilitate more rapid establishment and spread of invasive species.[59] Various mechanisms of facilitation have been identified by researchers, chief among them, expanding isotherms: the geographic boundaries of a locale as determined by a common temperature or temperature range at a given time. In the specific matter at hand, "isotherm" refers to the geographic range hospitable to the lionfish's physiological thermal demands. Lionfish exhibit a lethal thermal minimum temperature of 10°C, and their eventual distribution is "likely to be restricted by thermal tolerance."[60] As such, projections estimate that the current isotherm–

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[57] Carballo–Cárdenas (2015), 24, *citing* M. E. Kimball et al., 269–278; Claydon et al., "Progression of invasive lionfish in seagrass, mangrove and reef habitats," *Marine Ecology Progress Series* 448 (2012) : 119–129; Jud et al., "Broad salinity tolerance in the invasive lionfish Pterois spp. may facilitate estuarine colonization," *Environmental Biology of Fishes* 98, no. 1 (2015) : 135–143.

[58]I. M. Côté et al., "Predatory fish invaders: insights form Indo–Pacific lionfish in the western Atlantic and Caribbean," *Biological Conservation* 164 (2013) : 50–61.

[59] L. G. Harris and M. C. Tyrrel, "Changing community states in the Gulf of Maine: Synergism between invaders, overfishing and climate change," *Biol. Inv.* 9 (2001) : 9–21; M. Saunders and A. Metaxas, "Temperature explains settlement patterns of the introduced bryzoan *Membranipora membranacea* in Nova Scotia, Canada," *Mar. Ecol. Progr. Ser.* 344 (2007) : 95–106; J. J. Stachowicz et al., "Linking climate change and biological invasions: Ocean warming facilitates nonindigenous species invasions," *Proc. Nat. Acad. Sci. USA.* 99 (2002) : 15497–15500; B. P. Agius, "Spatial and temporal effects of pre–seeding plates with invasive ascidians: Growth, recruitment and community composition," *J. Exp. Mar. Biol. Ecol.* 342 (2007) : 30–39; J .P. Abraham et al., "A Review of Global Ocean Temperature Observations: Implications for Ocean Heat Content Estimates and Climate Change," *Reviews of Geophysics* 51 (2013) : 450–483.

[60] Morris and Whitfield (2009), 13.

determined range of lionfish within the Caribbean–Atlantic could extend from the coast of Uruguay up north to Virginia given current regional water temperatures (Figure I.4). Compounded by rising ocean water temperatures attributed to climate change, lionfish will continue to spread to non–native waters even beyond these current boundaries.[61] As the isotherm shifts north and south in the two hemispheres, the geographic limits of the lionfish will expand accordingly:

> [P]reviously thermally inhospitable habitats may become suitable for invaders at higher temperatures. Such expansions of the potential range of invasive species are almost certain to be realized if invaders have unconstrained access to all suitable areas. As such, one of the most concrete ecological consequences of climate change will be distribution ranges which are larger than they are today for a number of current invasive species.[62]

Rising ocean water temperatures by even just a few degrees Centigrade would see the potential range available to lionfish expand south to Argentina and north to Maine and Nova Scotia (Figure I.4).[63]

The scientific community has long been concerned with interactions between invasive species and other exacerbating stressors, particularly the looming effects of climate change. Within aquatic ecosystems, rising water temperatures has been identified as a critical issue, especially given how small changes of the same can influence the "invasiveness" of non–natives. The most poignant example of this in recent history is that of the lizardfish (*Saurida undosquamis*):

> After being introduced into the Mediterranean via the Suez Canal, the lizardfish exhibited a rapid increase in abundance in 1955, which has been attributed largely to a 1–1.5°C rise in seawater temperature. … Lizardfish in the eastern Mediterranean displaced the native hake (*Merluccius merluccius*) and became so abundant that they

[61] NOAA, "Ecosystem Advisory for the Northeast Shelf Large Marine Ecosystem," National Oceanic and Atmospheric Administration, http://www.nefsc.noaa.gov/cosys/advisory/current/advisory.html (accessed February 4, 2017).

[62] Côté and Green (2012), 6.

[63] William W.L. Cheung et al., "Signature of Ocean Warming in Global Fisheries Catch," *Nature 365* 497 (2013) : 365–368.

> constituted more than one fifth of the total landings along the Mediterranean coast of Israel.[64]

With forecasts projecting continued increases in seawater temperature owing to global climate change,[65] policy–makers and economies concerned with fisheries ought to seriously consider the implications poised against native and non–native fish stocks alike. Small changes in water temperature "could influence both the abundance and scale of impacts of invasive species. Understanding the likelihood of non–natives becoming invasive will require an integrated approach, encompassing many aspects of biology, ecology, and their interactions with abiotic influences."[66] In short, complex models are needed.

One such integrated analysis came in 2012. Investigating "temperature–dependent aspects of lionfish life–history and behavior," Côté and Green concluded that warmer water temperatures resulted in lionfish spending less time as plankton.[67] This shortened pelagic larval duration manifests a concomitant reduction in potential dispersal distance. In effect, warmer temperatures lead to increased local retention of larvae, thereby concentrating the lionfish populations within locales and exacerbating predation on local fauna.

It is important, however, to distinguish between the natural reproductive success of lionfish and the acceleration of that reproduction due to warming water temperatures. Côté and Green (2012) established that while increasing temperature is expected to "worsen the current imbalance between rates of prey consumption by lionfish and biomass production by their prey, leading to a heightened decline in native reef fish biomass…, the magnitude of climate–induced decline is predicted to be minor compared to the effect of current rates of lionfish population increases (and

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[64] Morris and Whitfield (2009), 4–5.
[65] Abraham et al. (2013), 450–483.
[66] Morris and Whitfield (2009), 5.
[67] I. M. Côté and S. J. Green, "Potential effects of climate change on a marine invasion: The importance of current context," *Current Zoology* 58, no. 1 (2012) : 1.

hence overall prey consumption rates) on invaded reefs."[68] Even with this caveat, continued temperature increases will worsen the negative effects of lionfish within novel ranges. As the lionfish invasion continues to expand, the applied metabolic theories within Côté and Green (2012) make clear that lionfish population densities will increase proportionally to decreases in native biomass (or more simply: as lionfish continue to takeover, native fish populations will decline accordingly). Given this, the call to action is immediate and clear: without organized, effective intervention, the harmful effects of lionfish will only become more severe and more widespread as their habitable range expands throughout the western Atlantic.

While obvious, it is worth noting that expanding isotherms do not solely affect non–natives. Rather, the phenomenon is experienced by all thermosensitive organisms within the affected region. Looking beyond the lionfish narrative and the analogies such a case presents, one quickly finds evidence of fishery–dependent economies experiencing direct impact from climate change and its associated rise in ocean water temperatures. In New England, native fish stocks (upon which coastal communities rely) are migrating north as their previously occupied region becomes intolerably warm; the phenomenon has "pushed the longtime mainstays of Connecticut fishing, like winter flounder and most notably lobster, north to deeper and colder waters."[69] In the Connecticut–native species' place, fish historically typical of southern states' coastlines — themselves also affected by the warming ocean water temperatures — are taking refuge in Connecticut's waters.

While this shift of species distribution certainly presents ecological consequences, it likewise introduces negative economic impacts. The problem is that due to quota–based

[68] Côté and Green (2012), 1.

[69] Jan Ellen Spiegal, "Above the waves, Connecticut fishermen struggle to hang on," *Connecticut Mirror*, August 30, 2016, https://ctmirror.org/2016/08/30/above-the-waves-connecticut-fishermen-struggle-to-hang-on/ (accessed April 14, 2017).

management systems, Connecticut fishermen are unable to catch the fish that have migrated north from those southern waters in search of more hospitable conditions. As the *CT Mirror* explains,

> trawlers from North Carolina are traveling all the way to the ocean waters in Connecticut's backyard and catching what used to be off their own coast — summer flounder, scup and the very valuable black sea bass — while Connecticut fishermen can only watch; throwback tons of fish — most of which will die; or risk a costly, difficult and long trip to where the fish they are allowed to catch in larger numbers are now.[70]

The subheadline of the same *CT Mirror* article put it best: "[a]s climate changes, so do fish populations — but not the rules for catching them."[71] Indeed, the antiquated policies constraining fishing off the coast of New England are worthy of an exploratory work on their own.[72] Given the legal barrier between fishermen and the fish that are actually out in the traditional fishing grounds, the economic impact has been dramatic. "Data supplied by NOAA show the overall economic impact of the fishing industry (excluding oysters and clams) has dropped to its lowest point since 2007, less than [US]$50 million in 2014 (the most recent year available). The total was nearly [US]$73 million in 2012."[73]

In summary, expanding isotherms present specific problems inherent to the lionfish epidemic that are paradigmatic of the impacts management experts, policy–makers, and

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[70] *Ibid*.

[71] *Ibid*.

[72] Future research on the topic may include: the quasi–governmental 1940s–era Atlantic States Marine Fisheries Commission, which oversees fifteen Atlantic coastal states to regulate near–shore fishing; the overarching Magnuson–Stevens Fishery Conservation and Management Act (passed in 1976, revised in 2007), which serves as the central authority for fishing in federal waters (those 3—200 miles from shore); or the eight regional councils (*e.g.,* the Mid–Atlantic Fishery Management Council and the New England Fishery Management Council) that are authorized under the standards established in Magnuson–Stevens. From Spiegal, "The councils create fishery management plans that include how much fish can be caught based on national standards set out in Magnuson–Stevens. As long as the management plans are legal, the National Oceanic and Atmospheric Administration's National Marine Fisheries must approve them, even if they don't agree with them. Whether the commission or a council regulates allocations for a particular fish, and if it's a council — which one does it — is based on where a species is most prevalent, though some fish are jointly managed between a council and the commission or two councils. Allocations are based on historic catches."

[73] Spiegal (2016).

economists can expect as thermal boundaries move north and south. This phenomenon will enable more widespread distribution and, therefore, impact by non–native species. Even irrespective of the consequences non–natives present to this issue, economies will suffer under the new regime of broadening isotherms. Given the robust nature of most eastern U.S. states' economies, they will survive despite impacts on their fisheries. The same cannot be confidently said for Caribbean and Western Atlantic nations that rely on their fishermen's nets and lines. Subsistence communities in the region may be devastated. We'll return to this in Chapter Two.

D. *Adding Insult to Injury: Lionfish Compound Preexisting Environmental Damages*

Coral reefs are rich in productivity and biodiversity, and they are wellsprings of food and income for millions of coastal people within the Caribbean–Atlantic. They execute a great number of economically important services: attracting tourists, snorkelers, and divers; buffering storm surges; generating sand for tourist beaches; serving as nurseries for commercially valuable species; and providing habitat for primary producers.

Despite coastal populations' reliance on coral reef systems, human activity has presented a myriad of threats to coral reefs around the world. A 2011 report indicated that "more than 60% of the world's reefs are under immediate and direct threats from one or more local [unsustainable activities]," a number that jumps to 75% when local threats are combined with [global ones].[74] Every day, 90 million tons of carbon pollution are dumped into the atmosphere, one–third of which goes into the ocean.[75] This saturation of carbon accelerates ocean acidification, which contributes to coral bleaching, a phenomenon in which coral reefs are stripped of their algal pigmentation,

[74] Lauretta Burke et al., "Reefs at Risk: Revisited," (Washington, D.C.: World Resources Institute, 2011) : 3.

[75] Burke et al. (2011), v.

leading to the loss of endosymbiotic algae and exposing the coral's white skeleton. While the coral continues to live, bleaching compromises the coral's physical integrity and growth rate.[76] Moreover, organisms reliant on the coral's algae are effectively expelled from the area as they search for more productive areas in which to survive. Reefs weakened by acidification are less capable of buffering coastlines against hurricanes, which, due to climate change, have increased in occurrence and intensity.[77] In short, reefs globally have become less able to support and protect life.

While widespread global phenomena like ocean acidification and warming waters certainly harm reefs, they do not undercut the effects of more intensive local activities, such as overfishing. In fact, thermal stress only compounds integrated local threats (Figure I.5). For example, harvesting of reef invertebrates in Florida increased tenfold over the past twenty years, raising concerns about a potential ecological collapse.[78] Caribbean–Atlantic reef systems are particularly at risk, given high population densities within small islands, the successful coastal tourism trade within the region, and the general demand for seafood (Figure I.6**)**. Upwards of 75% of Caribbean and Western Atlantic reefs are degraded or threatened.[79] Coastal overdevelopment plays a massive role in the region's reef trauma. Dredging for cruise ship channels requires the excavation of material (including coral) to a depth of 90 feet; this degrades water quality by stirring up detritus, lowering oxygen levels, reducing circulation, and blanketing surrounding corals in thick sheets of sand that obstruct sunlight and that prevent photosynthesis. Such was the case for Freeport, Grand Bahama — the island's main commercial ship harbor.

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[76] *Id.* at 2.

[77] Leonard Nurse, "The Implications of Global Climate Change for Fisheries Management in the Caribbean," *Climate and Development* 3, no. 3 (2011) : 232.

[78] Andrew Rhyne et al., "Crawling to Collapse: Ecologically Unsound ornamental Vertebrate Fisheries," *PLoS ONE* 4, no. 12 (2009) : e8413.

[79] *Id.* at 3.

The Mesoamerican barrier reef system (a UNESCO World Heritage Site that stretches from Honduras up through Belize to the tip of the Yucatán Peninsula) faces a "suite" of local threats, including coastal overdevelopment, destructive fishing practices and overfishing, and pollution. "This combination of local and global threats leaves reefs increasingly susceptible to damage from storms, infestations, and diseases. The cumulative effect of these multiple stressors undermines the social and economic security of the communities that rely on the reef."[80]

Because coral reef environments within the Caribbean basin are already under stress due to anthropogenic and environmental factors including pollution, overfishing, global climate change, coral bleaching, development projects, disruption by shipping channels, and disruptive algal growth,[81] the reefs' ecological issues are merely compounded by the addition of a nonindigenous, predatory reef fish. The combination of all this is likely to cause irreversible changes to these reef systems:

> Probable impacts include a reduction of forage fish biomass (Albins and Hixon 2008), possible increase in algal growth owing to herbivore removal by lionfish (Morris 2009), and competition with native reef fish. Lionfish are considered to be among the influential reef predators known to impact prey community structure (Fishelson 1997). This influence could cause cascading trophic impacts on economically important species and result in niche takeover by lionfish.[82]

The decreased productivity of the coral reefs combined with historical overfishing of large predator populations in the Caribbean–Atlantic[83] opened a formerly occupied ecological niche — a niche in which the lionfish effortlessly established itself. An aggressive invasive species like the

[80] Bratspies (2014), 841.
[81] Morris and Whitfield (2009), 16.
[82] Morris and Whitfield (2009), 16.
[83] Christopher Stallings, "Fishery–Independent Data Reveal Negative Effect of Human Population Density on Caribbean Predatory Fish Communities," *PLOS One* 4, no. 5 (2009), 3.

lionfish only adds to the pressure on local stocks already imposed by subsistence and commercial fishermen:

> Lionfish are piscivores and thus could compete with other native reef fish for food resources. The Snapper–Grouper Complex (*i.e.*, snappers, groupers, porgies, triggerfish, jacks, tilefishes, grunts, spadefishes, wrasses, and sea basses) is heavily exploited by commercial and recreational fisheries … resulting in niche vacancy in the reef fish community (Huntsman et al. 1999). The occupation of this vacated niche by lionfish [is] problematic for stock rebuilding programs presently underway for the Snapper–Grouper Complex of the Southeast U.S.A. and Caribbean. There are classic examples of niche takeover by one fish species following the removal of another (Botsford et al. 1997). It is unclear if niche takeover by lionfish will impact stock recovery of threatened species such as Nassau grouper. Lionfish impacts [are] the highest in locations that are heavily stressed, such as coral reef environments of the Caribbean.[84]

Anthropogenic activity facilitated the lionfish invasion not only by introducing the creature to the region in the first place, but also by shaping the ecological conditions that enabled the rapid invasion we have observed over the past two decades. Lionfish, in a way, can be thought of as the organic embodiment of a problem long in the making; they accentuate a problem driven by anthropogenic factors and thrive in the degraded reef environment human activity has eroded. Lionfish, therefore, illuminate a great failure in public policy: the inability to adequately protect and manage reef ecosystems. If the reefs had been healthier and more resilient to threats, lionfish would not have waltzed into and settled throughout the Caribbean–Atlantic so easily. As CUNY law professor Rebecca Bratspies writes,[85]

> [i]t is no wonder that these overstressed reefs have little resilience left to weather the lionfish invasion. As a result, in just a few short years, the lionfish invasion has become a major additional threat that not only overlays and intensifies pressure from these preexisting issues, but also poses an independent, immediate threat to the core stability of coral reefs. National Public Radio has analogized the

[84] Morris and Whitfield (2009), 17.
[85] Bratspies (2014), 842.

lionfish invasion to a “living oil spill.”

It is at this point that we recognize lionfish as — potentially — the last drop that makes the cup run over. NOAA scientists call lionfish “the most significant change in biodiversity and community structure of reef fish since the beginning of industrialized fishing.”[86] The phenomenon of the lionfish overtaking the Caribbean–Atlantic has been so severe, so sudden that it must serve as a wake–up call to key authoritative decision–makers who previously wavered on environmental protection. Climate change and its consequences have only been illuminated by this invasion. The lionfish epidemic must serve as a catalyst for change, activating regional policy–makers and global scholars to acknowledge our dependence on a healthy environment and to reconsider the architecture of collaborative management efforts in order to secure human prosperity.

[86] J. A. Morris, ed., *Invasive Lionfish: A Guide to Control and Management* (Marathon, Florida: Gulf and Caribbean Fisheries Institute Special Publication Series, 2012), 1.

Chapter Two: The Marine Policy Crisis

The ecological threats that lionfish pose are deeply worrisome. The species' rapid expansion and decimation of native reef fish populations throughout the Caribbean–Atlantic are indeed cause for concern. Beyond ecological considerations, the lionfish case presents a tumultuous future for Caribbean–Atlantic fishing economies. In fact, lionfish threaten the long–term security of human communities throughout the affected region. By looking at the lionfish case as but one example of how climate change will implicate invasive marine species and their distribution, and then evaluating that example through the lens of relevant policy frameworks, we recognize the utter magnitude of this situation. In short, current policy conceptions of and responses to invasive marine species are inadequate in addressing this significant threat — especially when the threat is compounded by the effects of climate change.

Chapter Two begins with a brief assessment of the economic threats presented by lionfish. By looking at fishing economies and the impacts lionfish have had within them, one quickly recognizes the severity of this situation and its implications on the viability of future generations throughout the region. Section B shifts the conversation to U.S. federal policy conceptions of invasive species. Specifically, this section probes the inadequacies of U.S. statutory efficacy in regulating the lionfish (and other highly invasive marine species like it). Section C returns to the aquarium trade, pegging it as a key industry in need of more rigorous scrutiny and government oversight. The section identifies the U.S. policy lapses noted in Section B and makes recommendations for future legislative actions. Section D expands the scope of focus from solely U.S. policy and instead offers a more holistic review of international treaties relevant to the management of marine pests. After determining that international agreements fall flat in tackling the lionfish crisis, the examination moves to regional policy frameworks. Section E explores the utility and promise of these regional management structures. This final section concludes with a determination that regional conservation efforts including culling, outreach, and education are all successful mechanisms in thwarting the invasion — but only when accompanied by strong and coordinated local responses.

A. Lionfish Invasion as a Policy Issue: The Effects on Human Economies

While lionfish have only been legitimately established in the Caribbean–Atlantic since the early 2000's, Albins and Hixon have concluded that "the Indo–Pacific lionfish has a direct negative effect on Atlantic coral–reef fish populations."[87] Even in the invasion's relative infancy, the scientific community was considering the threats actuated by lionfish. "After 2007, the tone of the scientific discourse shifted from cautious to alarmist following reports that in some sites along the U.S. coast lionfish were starting to dominate native communities."[88] Elsewhere, the takeover was observed to be even more hostile; the Bahamas would quickly report record–high densities along its reefs.[89] The socio–economic impacts of lionfish extend to the commercial fisheries and coastal tourism industries of the Southeast United States and Caribbean.[90] "In a region where more than forty–two million people depend on coral reefs for food and income, the lionfish invasion has very serious socioeconomic implications."[91]

As noted in Chapter One, lionfish manifest as a significant threat to reef biodiversity and biomass, and they therefore pose significant risks to local fisheries. Fishing plays a fundamental role in the culture and history of many Caribbean nations, so much so that many countries bear

[87] Albins and Hixon (2008), 237.
[88] Carballo–Cárdenas (2015), 24.
[89] Côté and Green (2009), 107; Morris and Whitfield (2009), 8.
[90] Morris and Whitfield (2009), 17.
[91] Bratspies (2014), 842.

nautical references within their flags and government emblems. For example, the Bahamian coat of arms (Figure II.1) is a showcase of Bahamian marine life: a marlin on the left erupts from the sea, a flamingo stands along a shoreline, and a conch rests at the crest of the arms. Conch — perhaps *the* symbol of Bahamian nationhood and a signature ingredient of local cuisine — is ironically one of the most dramatically overfished species in the region, and while its status is not officially classified as endangered at the moment, it is certainly overexploited. The conch example serves as a metaphor for other exploited staple species in the Caribbean–Atlantic: Nassau grouper, snappers, sea basses, and many others. And so there exists this dreadful situation for non–industrialized and developing Caribbean nations in which their economic and cultural reliance on failing fish stocks is completely unsustainable.

Troubling to commercial fisheries is the lionfish diet; lionfish feed on juveniles of some "commercial fishery species such as yellowtail and vermilion snapper and at least one threatened species, Nassau grouper. Attributing declines in these or other economically important species to interactions with lionfish is difficult given high annual variability in recruitment and fishing pressure."[92] Regardless, the density of lionfish within Caribbean reef ecosystems — especially in the Bahamas — is cause for concern: the diet of the invasive species may shift as native reef forage fish are outcompeted or otherwise eradicated by the lionfish, which could mean that lionfish begin targeting juvenile economically important species.

The flat topography characteristic of many Caribbean islands (*e.g.,* Grand Turk, the Cayman Islands, and the Bahamian archipelago) hinders soil production and retention; without major dips and valleys, soil is washed out to sea with the rain. For some Caribbean islands, like the Bahamas, the substrate of the land is calcium carbonate (limestone). This porous rock limits

[92] Morris and Whitfield (2009), 17.

freshwater accumulation, thereby limiting agricultural capacity. Given this, many island nations are highly dependent on foreign imports to secure food for their growing populations. According to a 2014 report, the Bahamas imports "more than US$250m–worth of foodstuffs per year, representing about 80% of its food consumption."[93] Countries already reliant on foreign exchange must seek to promote food security and to preserve every bit of independence as possible so as to prioritize domestic affairs.

Even beyond the issue of food security, underdeveloped Caribbean nations rely on tourism for much of their economies. Most tourism in these Caribbean nations is concentrated along the coast. In addition to their warm climates and sunny beaches, these destinations flaunt abundant reef life as a key attraction. Reef–related activities, like scuba diving and snorkeling, are the most popular activities in countries like Belize, Bonaire, the Bahamas, Cayman Islands, and Turks and Caicos. However, as Morris and Whitfield (2009) note, in "heavily invaded areas such as the Bahamas, many divers are tiring of witnessing the large abundance of lionfish and relative low abundance of other native species. Further, some resort locations have now posted signs warning swimmers of possible envenomation risks."[94] Negative experiences like these may dissuade tourists from visiting or revisiting particular islands or island nations particularly afflicted by lionfish. The World Travel and Tourism Council (WTTC) estimates that the tourism industry accounted directly for 28.2% of GDP and 34.3% of total employment in the Bahamas in 2014. "If indirect contributions are included, the industry contributed 46% of GDP in 2013 and 54.5% of total employment (around 102,500 jobs) in 2011."[95] Not only is the protection of marine life a

[93] Inter–American Development Bank, "Private Sector Assessment of Bahamas," October 10, 2014, 11.
[94] Morris and Whitfield (2009), 18–19.
[95] *Ibid*.

matter of subsistence and food security, but it stands as a keystone for an industry controlling half the economy.

Given these conditions, lionfish pose a tremendous threat to the future security of Caribbean nations' economies and subsistence communities. Tourism and fishing "represent the entry point for many of these small, developing states into the global economy."[96] While foci of tourism and related service industries are accompanied by high employment and access to goods, many periphery islands and remote communities continue to rely on the fruits of the sea. For example: Spanish Wells — a tiny island located off the northern tip of Eleuthera known as the "fishing capital of the Bahamas." Spanish Wells fishermen catch 60–70% of all lobster exported from the Bahamas. Most of the Spanish Wells fleet sell their catch to Ronald's Seafood, the island's lobster processing plant, which is the main supplier of crawfish for the U.S.–based Red Lobster chain.[97] During the summer of 2016, I spoke with four Spanish Wells fishermen who stated that they had observed a noticeable increase in the number of lionfish at popular lobster fishing grounds over the past decade. While their observations about lionfish were anecdotal and lacking of statistical support, the fishermen spoke with a sense of apprehension about the aquatic newcomer. As noted in Chapter One, lionfish may likely switch their diet to crustaceans if other prey (including the commercially important snapper and grouper) populations are thoroughly depleted. Given this, lionfish may interfere with the lobster industry of Spanish Wells, an industry that has served as the island's primary economic wellspring for at least thirty years.[98] Such an example is an extreme one, but the prophecy resonates throughout other smaller, more vulnerable

[96] Bratspies (2014), 842.

[97] Fishermen's Fest, "About Us," Fishermen's Fest, Spanish Wells, Bahamas, 2013, http://www.fishermensfest.com/aboutus.html (accessed February 26, 2017).

[98] James Kerr, "Way Out Is In An Island Rich In Peace And Quiet," SunSentinel, October 27, 1985, archived at http://articles.sun-sentinel.com/1985-10-27/features/8502170513_1_spanish-wells-bahamian-family-island-bahamas (accessed March 9, 2017).

fishing economies elsewhere in the Caribbean. The invasive species will compound deleterious factors already plaguing the region's reefs, and lionfish will further complicate the ability of small island nations to secure economic independence through foreign exchange and tourism. Lionfish, therefore, are "a profound threat to development in countries that have yet to reap much of the touted dividends of free trade."[99]

Impoverished nations simply do not have the infrastructure or resources to adequately fight against invasives and the ecological and economic threats they present. Costs to mitigate the negative effects of invasives are extraordinarily high:

> Extreme economic costs have resulted from many invasions, *e.g.*, Formosan termite, which causes an estimated [US]$300 million in damage annually in New Orleans alone (NISC 2001). Recent estimates suggest that the cost of invasive species to the U.S. economy is [US]$137 billion annually (Pimentel et al., 2000; 2005).[100]

Invasive species have "generated global environmental and economic costs estimated to exceed US$1.4 trillion annually (Pimental et al., 2001)."[101] Because of the costs connected to reactive "clean–up" efforts, it can be highly cost–effective for countries to implement proactive educational and defensive measures to prevent establishment (or at least dense populations) in the first place.

The fishery implications of the lionfish–climate change complex are not a plight exclusive to the Caribbean. While acidification attributed to climate change implicates the integrity of coral reefs, rising ocean water temperatures have direct ramifications on the survivability of important U.S. commercial fisheries, including those of Connecticut (discussed in Chapter 1, Section C) and Maine lobster. A 2016 University of Maine study found that while acidification (high pCO_2) had

[99] Bratspies (2014), 843.

[100] Morris and Whitfield (2009), 1.

[101] Frazer et al., "Coping with the Lionfish Invasion: Can Targeted Removals Yield Beneficial Effects?" *Reviews in Fisheries Science* 20, no. 4 (2012) : 185.

almost no effect on the survival of lobster larvae, elevated water temperature was extremely lethal. Lobster larvae reared in water 3°C higher than the current temperature of 16°C struggled to reach the final larval stage of development; the control group reared in water that matched current temperatures typical of the western Gulf of Maine exhibited a statistically significantly lower mortality rate. The 3°C temperature increase reflected projections for the Gulf of Maine's average temperature increase by 2100.[102] Lead author of the study, Jesica Waller, notes that "these short–term experiments don't account for the possibility that lobster populations may adapt to changing conditions over many generations. We need to do much more research to understand that."[103] While true that species may "rise to the challenge" through adaptation and resilience, the threat climate change poses to fisheries is momentous. University of Maine research professor (and Waller's co–adviser and co–author of the paper) Rick Wahle highlights the state's reliance on the lobster fishery:

> Last year, Maine harvested nearly half a billion dollars in lobsters. With lobsters now comprising over 80 percent of the state's overall fishery value, Maine's coastal economy is perilously dependent on this single fishery. We only need to look to the die-offs south of Cape Cod to see how climate change is having an impact.[104]

The Maine lobster case collides with the potentiality of a lionfish takeover in that, as noted before, lionfish may target crustaceans as they seek to satiate their capacious appetite within novel ranges. Lionfish, therefore, will likely compound stress on this crucial fishery by the end of this century, the expected time that the lionfish isotherm will meet the Maine waters.

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[102]Jesica D. Waller et al., "Linking rising pCO2 and temperature to the larval development and physiology of the American lobster (Homarus americanus)," *ICES Journal of Marine Science: Journal du Conseil* fsw154 (2016).

[103] University of Maine, "Rising ocean temperatures threaten baby lobsters," ScienceDaily, September 26, 2016, https://www.sciencedaily.com/releases/2016/09/160926115343.htm (accessed March 14, 2017).

[104] *Ibid*.

In an era of climate change, the risk of potential invasions by non–native species is only going to expand as isotherms grow, thermal barriers dissolve, and habitats become increasingly vulnerable. Ultimately, policy measures will need to be rethought so that they may adequately address the rapidly changing conception of established non–native species, and improved frameworks for collaborative management efforts will be essential to the sustainability of global economies.

B. America's Broken Standard: Non–Native Species Are Innocent Until Proven Guilty

In February 1999, President William J. Clinton signed Executive Order 13112, an order that "called upon executive departments and agencies to take steps to prevent the introduction and spread of invasive species and to support efforts to eradicate and control invasive species that are established."[105] Additionally, the order sought to minimize the economic, ecological, and human health impacts that invasive species cause. Building upon a number of existing laws,[106] Section 3 of the Order established a coordinating body: the National Invasive Species Council. As per Section 4, the NISC would provide national leadership regarding the response to invasive species by overseeing the implementation of the order, developing a coordinated network of Federal agencies to monitor and to respond to invasives, proposing recommendations for international cooperation, and encouraging proactive planning and action. In many ways, Executive Order 13112 reflected an understanding that collaboration across "Federal, State, local, tribal, and

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[105] USDA, "Executive Order 13112," United States Department of Agriculture, National Agriculture Library, Laws and Regulations, Federal Laws and Regulations, https://www.invasivespeciesinfo.gov/laws/execorder.shtml (accessed January 8, 2017).

[106] Executive Order 13112 (1999) rests upon federal statutes including but not limited to: National Environmental Policy Act of 1969, as amended (42 U.S.C. 4321 *et seq*.), Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, as amended (16 U.S.C. 4701 *et seq*.), Lacey Act, as amended (18 U.S.C. 42), Federal Plant Pest Act (7 U.S.C. 150aa *et seq*.), Federal Noxious Weed Act of 1974, as amended (7 U.S.C. 2801 *et seq*.), and Endangered Species Act of 1973, as amended (16 U.S.C. 1531 *et seq*.).

territorial government; stakeholders; and the private sector is critical to minimizing the spread of invasive species and that coordinated action is necessary to protect the assets and security of the United States."[107]

Importantly, Executive Order 13112 established within the federal register a definition of the term "invasive species" that would apply to any executive agency investigating such organisms. According to this definition, "invasive" applies to "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health."[108] Here, also, the order defines introduction: "the intentional or unintentional escape, release, dissemination, or placement of a species into an ecosystem as a result of human activity."[109] In this way, Executive Order 13112 establishes a three–prong test for determining whether or not a species is indeed "invasive" (and thereby governed by the NISC). For a species to be invasive, it must:

1) Be non–native (or alien) to the ecosystem being considered,
2) be otherwise absent from that ecosystem were it not for human–related activity, and
3) cause or be likely to cause economic or environmental harm or harm to human health.

While a well–intentioned piece of legislation, the narrow prescription of the definition limits its breadth in that — as evidenced by the narrative in Chapter One — it can be remarkably difficult to pinpoint the introduction vector to a specific human activity. Moreover, as noted in the section on isotherms, as thermal barriers dissolve in accordance with climate change, indigenous species will move beyond their historical geographic ranges and into novel territories. Here, the Order's policy conception of invasive species is stretched thin: directly linking expanded range to climate

[107] USDA.
[108] Clinton (2009).
[109] *Ibid*.

change as a "human–related activity" may be difficult to establish given differing environmental ethics amongst policy–makers.[110] Moreover, expert analyses of the risk of "economic or environmental harm or harm to human health" posed by invasives may differ according to those experts' values, "in particular their beliefs about the levels of risk to which the public ought to be exposed."[111] Similarly, the harm that is caused by a non–native species may be refuted by members of the scientific community, at least until more conclusive studies can be completed, which may take several years (and meanwhile create skepticism amongst policy–makers and members of the public). By that time, the invasive species may have established itself so intensely that removal or mitigation strategies may become ineffectual or cost prohibitive. As made clear by lionfish, invaders can exhibit a "lag time" before establishment that can sometimes consist of years to decades[112] — therefore rendering the "harm prong" mute. In light of this, the most efficacious strategy to prevent establishment (or at least dense populations) of an invasive is to prevent its very introduction to a novel range.

Here, we must pause and recognize the absolute paradox upon which the United States' federal invasive species mandates rest. There are currently no screening processes for non–native marine species based on invasiveness and the likelihood of establishment that are required before importing non–natives into the U.S. This is a massive policy oversight that effectively allowed the lionfish to be imported into the U.S. as an ornamental fish for aquaria without thorough risk assessment.

[110] Davenport (2017).

[111] Judith A. Layzer, *The Environmental Case: Translating Values Into Policy, 4th Ed.* (Thousand Oaks, CA: CQ Press, 2016), 63.

[112] J.A. Crooks, "Lag times and exotic species: the ecology and management of biological invasions in slow–motion," *Écoscience* 12 (2005) : 316–329.

This policy gap is not due to scientific ignorance on the matter. In fact, a great amount of scholarship has been completed in attempts to understand and "even predict the likelihood for a species to become established outside of its native range."[113] Approaches such as "species profiling"[114] and quantitative analysis[115] provide frameworks for risk assessment of a fish species' invasivity.[116] While the scientific community has not identified any individual component of the lionfish life history that has contributed more than others toward its present invasiveness, lionfish exhibit many of the life history traits that are known to be main predictors of invasivity for aquatic species (Figure II.2).[117] Despite the stipulation of the "harm prong" that "likely" harm be considered, the case of the lionfish suggests that likely harm is insignificant or outright ignored by the NISC when evaluating non–native species. This great lapse in environmental policy has left commercial fishing and tourism industries highly vulnerable to the effects of unchecked, highly invasive non–native species. As Simberloff (2009) established, prevention, early detection (ED), and rapid response (RR) are the least expensive and most effective means of managing invasive species.[118] The failure of U.S. public policy to proactively prevent and detect the introduction of invasive species has hindered response efforts that could have prevented the ecological catastrophe now underway in the Caribbean–Atlantic waters.

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[113] Morris and Whitfield (2009), 29.

[114] C. S. Kolar and D. M. Lodge, "Ecological predictions and risk assessment for alien fishes in North America," *Science* 298 (2002) : 1233–1235; A. Ricciardi and J. B. Rasmussen, "Predicting the identity and impact of future biological invaders: a priority for aquatic management," *Canadian Journal of Fisheries and Aquatic Sciences* 55 (1998) : 1759–1765; P.B. Moyle and T. Light, "Biological invasions of fresh water: empirical rules and assembly theory," *Biological Conservation* 78 (1996) : 149–161.

[115] M. P. Marchetti, P. B. Moyle, and R. Levine, "Invasive species profiling? Exploring the characteristics of non–native fishes across invasion stages in California," *Freshwater Biology* 49 (2004) : 646–661; M. P. Marchetti, T. Light, P. B. Moyle, and J. H. Viers, "Fish invasions in California watersheds: testing hypotheses using landscape patterns," *Ecological Applications* 14 (2004) : 1507–1525; C. S. Kolar and D. M. Lodge, "Progress in invasion biology: predicting invaders," *Trends in Ecology and Evolution* 16 (2001) : 199–204.

[116] Kolar and Lodge (2002); Ricciardi and Rasmussen (1998).

[117] *Id.* at 30.

[118] Daniel Simberloff, "We can eliminate invasions or live with them. Successful management projects," *Biological Invasions* 11 (2009) : 149–157.

A ray of hope came in January 2009, when Congresswoman Madeleine Bordallo, D-Guam, introduced H.R. 669 to the 111th Congress. The bill, the Nonnative Wildlife Invasion Prevention Act, was designed to "prevent the introduction and establishment of nonnative wildlife species that negatively impact the economy, environment, or other animal species' or human health."[119] The Act would build upon Executive Order 13112 as well as the National Invasive Species Act of 1996 (P.L. 104-332) and the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (16 USC 4701-4751) by adding additional evaluative criteria for the Secretary of the Interior to review before permitting the proposed importation of non–native species into the United States.[120] Specifically, H.R. 669 would mandate rigorous screening processes for prospective imported species that assessed both the likelihood of their establishment within that locale and their capacity to become invasive within the recipient ecosystem ("invasivity"). "This new legislation is different in that it takes a 'guilty until proven innocent' rather than an 'innocent until proven guilty' approach. In the present state, a species must be declared 'injurious' under the Lacey Act of 1998 (18 USC §42), a classification that can take years to achieve before importation and interstate commerce is banned."[121] This standard was reinforced in Executive Order 13112 with its "harm prong." Again, however, by the time that the injury is fully recognized, it may be too late to adequately respond to and prevent establishment of the species in question.

H.R. 669 died in Congress in 2009, and no such legislation has been passed since. Had such a law been in effect in the U.S. and — importantly — other countries within the Caribbean–Atlantic before the lionfish's 1980's introduction, it is likely that the lionfish would have never

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119 GovTrack, "H.R. 669 (111th): Nonnative Wildlife Invasion Prevention Act," GovTrack, Congress, Bills, https://www.govtrack.us/congress/bills/111/hr669 (accessed March 15, 2017).

120 Congressional Research Service, "Summary: H.R.669 — 111th Congress (2009–2010)," Congress, Home, Legislation, 111th Congress, H.R.699, https://www.congress.gov/bill/111th-congress/house-bill/669 (accessed March 15, 2017).

121 Morris and Whitfield (2009), 33.

been permitted to enter the region and that the current epidemic would have never occurred. Even a brief assessment of the lionfish life history and ecological traits would have presented an overwhelming number of red flags to the Secretary of the Interior, barring the import of the lionfish into the U.S. even for the aquarium trade. Indeed, as established in Chapter One, the U.S. aquarium industry is to blame for the introduction of lionfish to the Caribbean–Atlantic.

C. The Culprit Revisited: Lionfish Case Implicates Global Aquarium Trade

Lionfish are highly sought–after for saltwater aquaria. Known for their dramatic striping, "seemingly fragile beauty," and "gracefully flowing fins,"[122] they are considered a staple for saltwater aquarium enthusiasts and are commonly found at local U.S. fish stores for roughly US$30 each, with larger specimens fetching upwards of US$60.[123] They can also be purchased online for delivery anywhere in the U.S.[124] A 2008 study indicated that the import of lionfish generated revenues in excess of US$3 million per month in 2006 alone.[125] The high sales of lionfish support the estimated 700,000 saltwater aquariums within the U.S.[126] and are just part of the "multibillion–dollar global industry trading in live tropical reef organisms,"[127] an industry growing at a shocking pace of 14% annually.[128] The reasons for this explosive growth are simple:

> [O]n a per–pound basis, the value of ornamental fish collected for the aquarium trade far outstrips the value of fish harvested for food. … Year after year, millions of marine organisms are captured from

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[122] Bratspies (2014), 833.

[123] Petco, "Black Volitan Lionfish," Petco, Store, Product, SKU 1033280, http://www.petco.com/shop/en/petcostore/product/black-volitan-lionfish (accessed March 18, 2017).

[124] *Ibid*.

[125] Cristina Balboa, "The Consumption of Marine Ornamental Fish in the United States: A Description from the U.S. Import Data," in *Marine Ornamental Species*, eds. James Cato and Christopher Brown (Ames, Iowa: Iowa State Press, 2008), 65–76.

[126] Henry Fountain, "Are Aquariums Getting Too Lifelike?" *New York Times*, Science, March 22, 2010, http://www.nytimes.com/2010/03/23/science/23aquarium.html?pagewanted=all?src=tp (accessed March 15, 2017).

[127] Bratspies (2014), 834.

[128] Dianna Padilla and Susan Williams, "Beyond Ballast Water: Aquarium and Ornamental Trades as Sources of Invasive Species in Aquatic Ecosystems," *Frontiers in Ecology & The Environment* 2, no. 3 (2004) : 131.

> coral reef ecosystems and [are] 'inserted into a pipeline that empties into more than two million homes and public aquariums worldwide.' The overwhelming majority of the organisms sold through the global aquarium trade (98%) are captured from their [respective] natural habitats — primarily coral reefs. More than half of these organisms find their way to the United States. … In 2005 alone, more than eleven million fish were imported into the United States, along with an untold number of marine invertebrates and corals. While forty–five countries participate in the global aquarium trade, 85% of the marine organisms traded globally for ornamental purposes come from Indonesia and the Philippines. The aquarium fish trade is clearly an economic boon for these countries, providing employment for thousands of people with few livelihood alternatives.[129]

As noted before, stress placed on coral reef systems is already at a critical level, with a plethora of unsustainable anthropogenic forces (*e.g.,* overfishing and the use of cyanide in some harvesting practices) leading the onslaught on these threatened ecosystems. That half of the ornamental marine organisms harvested globally are imported into the U.S. speaks not only to the United States' culpability in this unsustainable trade, but also to the nation's potential efficacy in limiting the global movement of non–native marine species in the future. Legislation restricting such trade would minimize the United States' ecological impact overseas.

While there is great cause for concern of ecological damage within source countries when ornamental species are collected from their reefs, the importing countries face danger just as well. At least one third of the aquatic species listed by the International Union for the Conservation of Nature (IUCN) Invasive Species Specialist Group as the "one hundred worst invasive species entered their new environments through aquarium or ornamental releases."[130] While some aquarium releases are accidental, many pet owners intentionally release unwanted animals into the wild, believing that it is the "humane" choice. This "unregulated introduction of non–native

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[129] Bratspies (2014), 835; For the Fishes, "Home," For the Fishes: Protecting Coral Reef Wildlife, 2017, http://forthefishes.org (accessed March 19, 2017).

[130] Bratspies (2014), 836–837.

species into importing country ecosystems raises the possibility that, under appropriate conditions, the introduced animals can become invasive."[131] The warming waters of the Caribbean–Atlantic and the vulnerability of its damaged reef ecosystems constitute those "appropriate conditions" to support the lionfish takeover.

The massive U.S. policy gap within Executive Order 13112 and the failure to enact a remedy à la H.R. 669 have unquestionably allowed for the unburdened introduction of the lionfish into the domestic ornamental fish market and — through it — the Caribbean–Atlantic. Only through thorough analyses of species' respective life histories and ecological traits that conclusively determine low invasivity should transfer of non–native species be approved. Species profiling must become a key component of green–listing non–native organisms for import. The economics driving the U.S. aquarium trade must be reconsidered and be balanced against the startling US$137 billion spent mitigating invasive species in the U.S. alone.[132] Clean–up and removal efforts are simply too expensive when weighed against the revenue generated by the aquarium trade. The U.S. must stop treating non–native species as innocent until proven guilty — the risk is just too great. When it comes to the demonstrated invasivity of individual species and their capacity to wreak havoc within particular novel ranges, some modicum of xenophobia is more than justified. Perhaps *this* is the situation that warrants the equivalent of extreme vetting or a travel ban.

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[131] Bratspies (2014), 836; Pamela J. Scholfield, "Update on Geographic Spread of Invasive Lionfish (*Pterois volitans* [Linnaeus, 1758] and *P. miles* [Bennett, 1828]) in the Western North Atlantic Ocean, Caribbean Sea and Gulf of Mexico," *Aquatic Invasions*, 5, sup. 1 (2010) : S117–S122; Burke et al. (2011).

[132] Morris and Whitfield (2009), 1.

D. Slippery When Wet: International Treaties Fail to Grasp Invasive Marine Species

"There are few global or international legal tools available for confronting the lionfish invasion. The dominant multilateral regime is the Convention on International Trade in Endangered Species (CITES) — a treaty regime focused on protecting wild species and their habitats."[133] Unfortunately, CITES is predominantly a foreign trade agreement limiting the exchange of endangered species — not endanger*ing* species. CITES does not seek to control invasive species. Instead, rather, it provides trade regulation frameworks to signatory countries that restrict the harvest, export, and import of threatened species. "While grouper (one of the fish species … jeopardized by the lionfish invasion) are listed as 'critically endangered' on the International Union for the Conservation of Nature (IUCN) Red List, lionfish, the source of the problem, are not on any kind of CITES list."[134] In fact, CITES is rather limited in that it does not ban or otherwise regulate the traffic of species which do or are likely to cause harm to a protected Red List species.

Because CITES maintains purview solely over the international trade of particular threatened species, it has no bearing over the current lionfish situation. Even if it could ban continued traffic of lionfish within the aquarium trade, "this remedy would be of the 'too little too late' variety."[135] Additionally, because lionfish are living, breathing organisms capable of reproduction that have already established themselves across the Caribbean–Atlantic, a trade agreement has no teeth in responding to the current invasion. A successful trade–based agreement aimed at mitigating the potential impact of non–native species (through a thorough species

[133] Bratspies (2014), 843.

[134] *Id.* at 844. From the same: "The IUCN Red List is generally considered the most comprehensive evaluation of the status of individual plant and animal species. Species are listed in a range of categories ranging from 'least concern' through various levels of endangerment up to extinction."

[135] *Ibid*.

profiling process complete with rigid ecological impact assessments or similar) could have been effective before lionfish were introduced to the region (as noted in the previous section). Regardless, a scheme that seeks to prevent issues before they occur is of no use when the problem has already become manifest (and is capable of continued reproduction). Moreover, a trade ban on lionfish before "an actual problem existed … would [have] likely [been] deemed a violation of other international obligations, most notably the General Agreement on Tariffs and Trade (GATT)."[136] While trade–based remedies may "conceivably allow a state to prohibit lionfish imports on environmental grounds,"[137] a trade ban will not "undo the effects of past trade or eliminate the invasive species problem."[138]

While a trade–based schema would be ineffectual given the current prevalence of the lionfish throughout the Caribbean–Atlantic, international law may still maintain some efficacy in addressing the current situation. In particular, as noted in Bratspies (2014), international law could "alter the background conditions that made the lionfish invasion possible, specifically climate change and the attendant changes in ocean conditions."[139] The Caribbean–Atlantic lionfish epidemic has illustrated that the fish itself is not the sole culprit, but rather so too are the global climate change–induced factors that enabled the invasion's speed. While unsustainable anthropogenic activities (*i.e.,* overfishing) have decimated the biomass on Caribbean–Atlantic reef systems, rising ocean water temperatures have exacerbated the lionfish problem by extending their

[136] Bratspies (2014), 844.

[137] Bratspies (2014), 844–845. See also: General Agreement on Tariffs and Trade, *opened for signature* Oct. 30, 1947, 61 Stat. A–11, 55 U.N.T.S. 187 (entered into force Jan. 1, 1948), art. XX ("Subject to the requirement that such measures are not applied in a manner which would constitute a means of arbitrary or unjustifiable discrimination between countries where the same conditions prevail, or a disguised restriction on international trade, nothing in this Agreement shall be construed to prevent the adoption or enforcement by any Member of measures … (b) necessary to protect human, animal, or plant life or health; … [or] (g) relating to the conservation of exhaustible natural resources if such measures are made effective in conjunction with restrictions on domestic production or consumption … .").

[138] Bratspies (2014), 845.

[139] Bratspies (2014), 845.

range (and thereby increasing the total area in need of management structures and responses). Moreover, the effects of climate change, particularly ocean acidification, have directly impacted the resilience of native ecosystems that otherwise could have likely withstood encroachment by the non–native lionfish.[140] This case has made clear that non–native species can — and are likely to — exploit the weaknesses of damaged ecosystems and has illuminated the necessity of minimizing enabling factors (*i.e.,* the effects of climate change).

Within the sphere of international protocols that seek to mitigate global climate change by limiting carbon emissions, the U.N. Framework Convention on Climate Change (UNFCCC) offers the most promise in accomplishing its stated goal.[141] If the UNFCCC is able to minimize global carbon emissions, it might slow the process of ocean acidification — an important goal in its own right given that a 2017 study investigating ocean acidificaition concluded that only "immediate global action" can curb "future warming [and] is essential to secur[ing] a future for coral reefs."[142] Efforts to stop the coral bleaching through any other method will not be sufficient, according to the study. Regardless, limiting carbon emissions will not quell the lionfish invasion, as climate change has merely enabled and intensified the lionfish problem rather than directly causing it in the first place.

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[140] Stanley W. Burgiel and Adrianna A. Muir, "Invasive Species, Climate Change and Ecosystem-Based Adaptation: Addressing Multiple Drivers of Global Change," Global Invasive Species Programme, September (2010), *available at* http://data.iucn.org/dbtw-wpd/edocs/2010-054.pdf (accessed February 13, 2017); Burke et al. (2011), 2–3.

[141] U.N. Framework Convention on Climate Change (UNFCCC), *opened for signature* June 4, 1992, S. Treaty Doc. No. 102–38, 1771 U.N.T.S. 107 (entered into force March 21 1994).

[142] Terry Hughes et al., "Global warming and recurrent mass bleaching of corals," *Nature: International Weekly Journal of Science*, 543 (2017) : 373–377. Ironically, the worst case on record of coral bleaching due to climate change has occurred in the lionfish's native range along the Great Barrier Reef. *See* BBC Australia, "Great Barrier Reef survival relies on halting warming, study warns," BBC News, World, Australia, March 16, 2017, http://www.bbc.com/news/world-australia-39226494 (accessed March 17, 2017).

The final established piece of international law that may serve as abeacon of hope to the lionfish problem is the U.N. Convention on the Law of the Sea (UNCLOS).[143] Under UNCLOS, signatory states "have the obligation to protect and preserve the marine environment."[144] Some have argued that UNCLOS compels states to take affirmative measures to mitigate the effects of deleterious non–natives under the pollution control directorate of Article 194(1).[145] Even if invasive species could be construed as pollution, UNCLOS would provide little direction as the framework's expectation that states "cooperate" and "harmonize policies" provides "little guidance for what states might do and the kinds of policies that might be needed."[146]

What UNCLOS lacked with regard to fisheries management when the framework activated in 1994 became a substantial amendment just a decade later. The 2005 Supplemental Agreement, the Straddling Fish Stocks Agreement,[147] mandated that states establish and participate in cooperative regional fishery management organizations.[148] Specifically, the Agreement considers

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[143] U.N. Convention of the Law of the Sea (UNCLOS), *opened for signature* December 10, 1982, 1833 U.N.T.S. 397 (entered into force November 16, 1994).

[144] *Id*, at Part XII, Art. 194.

[145] Bratspies (2014), 846, *citing* UNCLOS, Part XII, Art. 194(1) ("States shall take, individually or jointly as appropriate, all measures consistent with [UNCLOS] that are necessary to prevent, reduce and control pollution of the marine environment from any source, using for this purpose the best practicable means at their disposal and in accordance with their capabilities, and they shall endeavour to harmonize their policies in this connection.").

[146] Bratspies (2014), 846.

[147] U.N. Agreement for the Implementation of the Provisions of the U.N. Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, *opened for signature* December 4, 1995, T.I.A.S. 13115, 2167 U.N.T.S. 3 (entered into force December 11, 2001).

[148] *Ibid*, Part IV. *See also:* United Nations, "The United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (in force as from 11 December 2001) Overview," Division for Ocean Affairs and the Law of the Sea, September 2, 2016, http://www.un.org/depts/los/convention_agreements/convention_overview_fish_stocks.htm (accessed April 2, 2017) ("[The agreement] promotes good order in the oceans through the effective management and conservation of high seas resources by establishing, among other things, detailed minimum international standards for the conservation and management of straddling fish stocks and highly migratory fish stocks; ensuring that measures taken for the conservation and management of those stocks in areas under national jurisdiction and in the adjacent high seas are compatible and coherent; ensuring that there are effective mechanisms for compliance and enforcement of those measures on the high seas; and recognizing the special requirements of developing States in relation to conservation and management as well as the development and participation in fisheries for the two types of stocks mentioned above.").

the special requirements of developing countries weighed against regionally compatible and coherent fishery conservation and management priorities. Given its adaptability and scope, the Agreement's framework has been widely embraced as states address the lionfish problem.[149] While the Agreement has provided a template for groups of states to develop their regional fishery management organizations, the Agreement has done little to directly inform regional policies that specifically address invasive species. Additionally, because the effects of a non–native species are intrinsically locale–specific (that is, concomitant on specific interactions with native organisms, as tempered by particular environmental conditions), regional governance remains as the most efficacious means of responding to the lionfish invasion.

E. Coordinating Entropy: Regional Frameworks Can Guide Successful Local Responses

In the absence of proactive policy within the U.S. that directly combats the import of species with considerable "invasivity" and with international legal regimes utterly mute in addressing the lionfish epidemic, regional management programs persist as the most effective agents in responding to the crisis. If the initial assessment of the lionfish invasion vis–à–vis climate change has revealed anything within the sphere of public policy, it is that unified, coordinated responses across multiple levels will be fundamental. Lionfish present a multijurisdictional problem since many large reef systems — including the Mesoamerican Barrier Reef — do not comport to national borders. "As a consequence, no single state is in a position to fully protect its coral reef through its own unitary actions. Instead, protecting and restoring coral reefs demands collaboration on multiple scales — within states, between states, and with nonstate entities,

[149] Bratspies (2014), 846.

including private actors."[150] This animates a need for regional, national, and local response efforts that align in vision, execution, and standards.

The Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region[151] (the "Cartagena Convention") is the predominant agreement that binds signatory states within the Caribbean to affirmatively address environmental concerns. Negotiated in the mid–1980's, the Cartagena Convention developed under the auspices of the U.N. Environment Programme's Regional Seas Programme, an organization guided by the mission of "[p]romoting regional co–operation for the protection and [sustainable] development of the marine environment of the Wider Caribbean Region,"[152] known in the context of the Convention as the Convention Area. This area is defined as:

> The marine environment of the Gulf of Mexico, the Caribbean Sea and the areas of the Atlantic Ocean adjacent thereto, south of the 30 degree north latitude and within 200 nautical miles of the Atlantic coasts of the States referred to in article 25 of the Convention.[153]

The Cartagena Convention typifies a traditional multilateral agreement by presenting a legal structure under which members are required by international law to take action aimed at "preventing, controlling and reducing pollution of the Convention [A]rea"[154] from sources including ships, dumping, and sea–bed exploration or exploitation. The Cartagena Convention also "requires that all parties take measures to protect and preserve rare or fragile ecosystems … and

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[150] Bratspies (2014), 840.

[151] Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region, *opened for signature* March 24, 1983, T.I.A.S. 11085, 1506 U.N.S. 159 (entered into force October 11, 1986).

[152] U.N. Environment, "Home," The Caribbean Environment Programme, 2017, http://www.cep.unep.org (accessed April 3, 2017).

[153] EPA, "Cartagena Convention and Land-Based Sources Protocol," United States Environmental Protection Agency, International Cooperation, https://www.epa.gov/international-cooperation/cartagena-convention-and-land-based-sources-protocol (accessed April 3, 2017). The three states remaining outside of the Convention are Haiti, Honduras, and Suriname.

[154] *Ibid*.

the [habitat] of endangered species" within the Convention Area.[155] Given the scope and geographic application of the Convention, it "has the potential to be a primary transnational governance tool for responding to the lionfish invasion:"[156]

> In particular, the Cartagena Convention's associated Protocol Concerning Specially Protected Areas and Wildlife (the "SPAW Protocol") offers some interesting possibilities for authoritative decisionmaking. Adopted in 1990, and entered into force a decade later, the SPAW Protocol represents an early embrace of the ecosystem approach to conservation and resource management. To that end, the SPAW Protocol commits states to "progressively take such measures as are necessary and practicable to achieve the objectives for which the protected area was established." These measures include "the regulation or prohibition of the introduction of non–indigenous species [and] … any other measure aimed at conserving, protecting or restoring natural processes, ecosystems or populations." There is also an independent obligation for member states to take measures to prevent the introduction of nonindigenous species with the potential to become invasive species. Most importantly, the SPAW Protocol created an infrastructure for cooperation, and established a Scientific and Technical Advisory Committee. Thus, when the scale of the lionfish problem became clear in the mid–2000s, there was already an infrastructure for facilitating a regional response. … Scientists were already collaborating under the SPAW Protocol as part of the International Coral Reef Initiative. Working under the auspices of these preexisting regional cooperative arrangements, scientists were able to produce a "Guide to Control and Management" of lionfish in relatively short order. The Guide details best practices for lionfish control and management, emphasizing eradication measures, outreach, education, research, monitoring, legal considerations, and ideas for securing resources and partnerships. The Guide is meant to help managers coordinate on a regional basis while taking action to reduce the local impacts associated with lionfish.[157]

[155] *Ibid.*
[156] Bratspies (2014), 847.
[157] *Id.* at 847–848, *citing* Protocol Concerning Specially Protected Areas and Wildlife to the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region, *opened for signature* January 18, 1990, S. Treaty Doc. No. 103-5 (entered into force June 18, 2000) [hereinafter SPAW protocol] (*esp*. arts. 5, 12, 17–18, and 20) *and* Morris (2012).

Given the SPAW Protocol's efficacy in coordinating standards and guidelines for adherent regional management organizations, it has become a central conduit through which the lionfish response has mobilized (*e.g.,* the Guide). In large part, the SPAW Protocol was the enabling framework that led to the establishment of the Caribbean Regional Fisheries Mechanism in 2003.[158] CRFM is an intergovernmental organization partnering with seventeen Caribbean states, and it leads these nations to "promote and facilitate the responsible utilization of the region's fisheries and other aquatic resources for the economic and social benefits of the current and future population of the region."[159] Given CRFM's scope and general cognizance of the threats lionfish pose to Caribbean fishing economies, it prioritizes regional strategies for controlling lionfish.[160]

CRFM demonstrated the efficacy of regional response systems, and its reliance on the SPAW Protocol attracted the attention of the International Coral Reef Initiative:

> In January 2010, the [ICRI] established an ad hoc committee (now known as the Regional Lionfish Committee) charged with developing a strategic plan for controlling lionfish in the Western Caribbean. Although ICRI bills itself as "an informal partnership," it functions largely as an international organization. What makes ICRI unique is that it goes well beyond the traditional intergovernmental activities normally associated with international organizations — its membership is not limited to states but also includes intergovernmental organizations and nongovernmental organizations. ICRI's mandate is to preserve coral reef ecosystems through implementation of Chapter 17 of Agenda 21. ICRI is certainly far from what would traditionally be considered an actor under international law, and its self-adopted mandate is to implement a soft law international agreement. Yet, ICRI draws legitimacy for its Regional Lionfish Committee by directing attention to Article 8(h) of the Convention on Biological Diversity,

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[158] Agreement Establishing the Caribbean Regional Fisheries Mechanism, *opened for signature* February 4, 2002.

[159] Caribbean Regional Fisheries Mechanism, "About CRFM," CRFM, http://www.crfm.net/index.php?option=com_k2&view=item&layout=item&id=1&Itemid=114 (accessed April 14, 2017).

[160] Maren Headley, "A Regional Lionfish Strategy," CRFM News, The Newsletter of the Caribbean Regional Fisheries Mechanism, Management Issue, March 2013, *available at* http://ns1.crfm.net/~uwohxjxf/images/documents/Fishery%20Research%20Documents/CRFM_Newsletter_Management_Issue_Mar_19_2013.pdf , at 2.

> which directs states to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species," and to Article 12 of the SPAW Protocol.[161]

While instrumental to state authorities, guiding frameworks (especially the ecologically conscious ICRI) have established key priorities, these goals have been executed most faithfully by smaller, location–specific programs and initiatives. "These high–level regional responses have been buttressed by actions taken by subnational and non–state actors."[162] Indeed, local actions motivated by location–specific concerns have sought to accomplish the goals outlined in the Cartagena Convention. Eradication of the lionfish has been a central theme of such efforts.

In Belize, "local tour guides have organized themselves through their tour guide associations (quasi–governmental entities) to kill lionfish and feed them to sharks and eels."[163] There and elsewhere, resorts and organizations like REEF organize lionfish hunting events ("derbies") that transform lionfish eradication into a tourist attraction.[164] These derbies are organized team events in which divers compete to kill the most lionfish. Winners are awarded cash prizes (Figure II.3). In 2013, a team of four divers was awarded US$1,500 for spearing 268 lionfish, while event participants collectively killed over 1,200 lionfish.[165] In 2012, REEF operated

[161] Bratspies (2014), 850, *noting*: "Negotiated at the 1992 U.N. Rio Convention on the Environment and Development, Agenda 21 lays out the globally agreed-upon action plan for implementing sustainable development. U.N. Conference on Sustainable Development, Rio de Janeiro, Braz., June 3–14, 1992, *Agenda 21*, ¶¶ 17.1–17.136, *available at* http://sustainabledevelopment.un.org/content/documents/Agenda21.pdf. At the 2012 U.N. Rio Conference on Sustainable Development, the gathered nations reaffirmed their commitment to implement Agenda 21. U.N. Conference on Sustainable Development, Rio de Janeiro, Braz., June 20–22, 2012, *The Future We Want*, ¶ 16, *available at* http://www.uncsd2012.org/futurewewant.html."

[162] Bratspies (2014), 849.

[163] Braspies (2014), 854.

[164] Hatchet Caye, "Hunting Lions at Hatchet Caye Resort, Belize," Hatchet Caye Resort, The Island, Blog, January 15, 2013, https://www.hatchetcaye.com/belize-resort-blog/hunting-lions-at-hatchet-caye-resort-belize (accessed April 15, 2017).

[165] Lionfish Derby & Rodeo, "5th Annual Lionfish Derby (1,204 Fish) June 22nd, 2013 Green Turtle Cay, Bahamas," Lionfish Derby 7 Rodeo, Results, June 22, 2013, http://lionfishderby.com/results.html (accessed April 15, 2017).

a monthly contest that awarded individuals who brought the most lionfish into their Key Largo, Florida office.[166]

Derbies have the added benefit of serving as educational seminars for tourists and locals alike. Trained staff members and volunteers from organizations like REEF are present at these events to educate the public on the proper handling of lionfish. Because lionfish are novel to the Caribbean–Atlantic and exhibit unique defensive characteristics (namely, their venomous spines), education can play a central role in transforming the image of lionfish from a sinister invasive predator that must not be approached to a source of meat and income. Once individuals learn how to clip the spines (a simple procedure using kitchen shears), they can prepare lionfish as they would any other fish. In fact, REEF produces a cookbook that contains 45 recipes for dishes that all contain lionfish — a marketing effort to encourage consumption of the invasive species.[167]

On Eleuthera, Bahamas, the Cape Eleuthera Institute began a "You Slay, We Pay!" campaign in which local fishermen were encouraged to focus their attention on lionfish rather than other species. By purchasing lionfish fillets for BS$11 per–pound (several dollars more than the average per–pound local market value of grouper fillets, for example), CEI not only incentivized local fishermen to ease off of species already under threat (from overfishing and the lionfish newcomers), but the organization also created a market for lionfish.[168] A local resort quickly adopted lionfish onto its restaurant's menu.[169] Through this campaign, CEI taught fishermen to identify the previously unknown lionfish as an edible (and delicious) fish, while simultaneously

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[166] Lad Akins, "February Winners Announced in REEF's Florida Keys Monthly Lionfish Contest," REEF, Reef's Monthly Lionfish Contest, March 6, 2012, http://www.reef.org/node/4722 (accessed April 14, 2017).

[167] Reef Environmental Education Foundation, "Lionfish Cookbook 2nd Edition," REEF, Catalog, Field Supplies and More, Lionfish Collecting Gear, Books, Other Books, New Items, http://www.reef.org/store/lionfishcookbook (accessed April 15, 2017).

[168] Cape Eleuthera Institute, "You Slay, We Pay!" CEI, Blog, April 7, 2014, http://www.ceibahamas.org/news/2014/04/07/you-slay-we-pay (accessed April 15, 2017).

[169] Personal observation by the author.

diverting pressure from other species. An ecological problem was positioned as an economic resource.

NOAA launched a similar campaign with an (almost) equally catchy slogan ("If we can't beat them, let's eat them!") to encourage restaurants to buy and prepare lionfish, as well as to promote knowledge of the fish to consumers as a Monterey Bay Aquarium Seafood Watch "best choice" — the highest available rating from the organization.[170] As a response to the Seafood Watch classification, Whole Foods (which only sells fish that have been highly recommended by Seafood Watch) began procuring lionfish fillets. In response, commercial fisheries have been established, with Norman's Lionfish serving as the United States' primary lionfish wholesale business.[171] NOAA's slogan, "If we can't beat them, let's eat them!" was quickly adopted by "Fish House Encore in Key Largo, Norman's Cay in New York City, and many other restaurants across the Western Atlantic and Caribbean," all of which now incorporate lionfish as a key ingredient in their respective menus.[172]

Other market mechanisms have encouraged lionfish harvesting. In Florida, for example, the state's Fish and Wildlife Conservation Commission exempted lionfish from the state's licensing laws and removed recreational and commercial catch limits.[173] Local shops in areas particularly affected by lionfish will "provide discounts for the rental of [SCUBA] gear in exchange for captured lionfish. Some universities even offer community service credit for students who remove lionfish."[174]

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[170] Sarah Shemkus, "Eat an Invasive Species for Dinner," *The Atlantic*, Science, April 8, 2016, https://www.theatlantic.com/science/archive/2016/04/invasive-lionfish/477570/ (accessed April 14, 2017).

[171] *Ibid*.

[172] Bratspies (2014), 855.

[173] Fla. Admin. Code Ann. r. 68B–5.006 (2013).

[174] Emily Boring, "Intrepid invaders: The lionfish problem and what we can do to help," Yale Scientific Magazine, The Scope, November 9, 2015, http://yalescientific.org/thescope/2015/11/intrepid-invaders-the-lionfish-problem-and-what-we-can-do-to-help/ (accessed April 15, 2017).

While sustained eradication work has proven to be effective in removing lionfish from some locales,[175] it must be noted that an estimated 35% to 65% of lionfish have to be removed from an area in order to have any significant effect in minimizing lionfish recruitment (and therefore future populations).[176] Given this and the general intensity of labor required for removals of all specimens from a given reef, widespread regional eradication presents as a seemingly insurmountable management challenge. As demonstrated in this chapter, lionfish are beyond the scope of international law because 1) wild animals simply do not comport to the mandates of law and national boundaries and 2) international legal mechanisms (*e.g.,* constraints on trade, fishing ground closures, marine protected areas,[177] and adaptive management) lack relevance when dealing with a problem that is already established and is capable of self–replication.

The takeaway message from this chapter is not that efforts at mitigation are futile. Rather, releasing this species' grasp over Caribbean–Atlantic reefs is a prospect pervaded by challenges that are broadly emblematic of the effects we can anticipate in an era of climate change. The SPAW Protocol's ecological approach to reef management was somewhat novel at the time of its development, yet its innovative prioritization of preserving and protecting complex relationships between native species led to an effective management regime that has empowered regional responses. As noted in Chapter One, Section A, the lionfish's biogeographical spread adheres to a distribution model already recognized within the Caribbean.[178] By extrapolating that model and anticipating where lionfish are likely to move (including those regions made accessible by expanding isotherms), it is altogether possible that researchers may defend critical chokepoints

[175] Bratspies (2014), 854, noting that in the "tourist town of San Pedro, Belize, … concerted [eradication] efforts have managed to clean lionfish from the more popular dive sites."

[176] Andrew Barbour et. al., "Evaluating the Potential Efficacy of Invasive Lionfish (*Pterois volitans*) Removals," *PLoS ONE* 6, no. 5 (2011) : e19666, *available at* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3091870/ .

[177] *See generally* Clark (2012).

[178] Morris and Whitfield (2009), 15.

and investigate the efficacy of different intervention methods. In such a scenario, as–of–yet unaffected locations can develop rigorous early detection and rapid response (ED/RR) programs:

> Development of ED/RR programs for coastal marine environments is perhaps more difficult than terrestrial and freshwater systems owing to the challenges of accessibility and expansiveness of marine systems. For marine ornamental fish introductions, ED/RR is a viable option, considering past introductions have been closely correlated with highly developed coastlines. These areas often have intensive recreational dive tourism and recreational fishing activities that are capable of providing early detection. Education and outreach to local coastal resource managers and the public is important in establishing rigorous early detection.[179]

Anticipating the lionfish's next move will be essential in the quest to contain the species within its current range in the Caribbean–Atlantic. Only well–prepared ED/RR programs in likely "next stops" of the lionfish can repel the invasion, especially in an era of expanding isotherms caused by climate change. By continuing research on and responding to the lionfish epidemic, similar situations with other non–native marine species may be averted in the future through proactive policy formulas.

[179] Morris and Whitfield (2009), 31.

Conclusion

While subnational and NGO actors have been most effective in addressing the immediate lionfish crisis, it is clear that current legal tools are rather ineffective in preventing marine infestations. Specifically in the arena of the aquarium trade, greater transnational legal oversight must be enacted, or, in absence of such a regime, nations must determine and establish restrictive import policies for non–native species (*i.e.*, ones similar to the failed H.R. 669). Additionally, reforms must be made within the aquarium industry. Attempts at private certification schemes for a "sustainable" aquarium trade have largely proven ineffectual and present issues common to similar private certification programs across different extractive industries that seek to promote food security, sustainable livelihoods, and poverty alleviation. The problems rest in the fact that participant companies generally pass along the costs of these certifications to consumers who themselves are often dissociated from the externalized costs of the products they buy (*e.g.,* consumer demand for ornamental lionfish specimens is concentrated in wealthy countries far removed from the damaged Indo–Pacific reefs from which the species is predominantly extracted for the aquarium trade). Moreover, the missions of most private certification bodies are impaired by their intrinsic non–political status:

> [They differ] vastly from any traditional exercise of authoritative power by the state — [they have] no political status and weil[d] no power to impose civil or criminal sanctions for failure to comply with [their] precepts. … [Whether they possess] the power of authoritative decision is wholly contingent. [Their] authority is defined and circumscribed by the willingness of consumers and producers to participate in [their] certification scheme — producers by abiding by [approved] practices, and consumers by letting certification guide their purchasing behaviors. … Networked governance of this type leverages the power of consumer choice in order to modify unsustainable production practices.[180]

[180] Bratspies (2014), 852. For a thorough examination of the efficacy of global governance initiatives, specifically private aquarium certification schemes, see Bratspies (2014), 850–854.

The issues presented by lionfish are reflective of larger consequences of the global economy; not only are species transported to places where they should not be, but greater issues of equity are brought to the surface. Gains by wealthy nations often lead to costs incurred by poorer nations (where resources are extracted or where waste is offloaded).[181] The lionfish is a prime example of this: an ornamental fish species imported into the United States and released into the Caribbean–Atlantic now threatens the long–term survival of some Caribbean fishing economies and communities. This is the Tragedy of the Commons of which Garrett Hardin warned in the late–1960's: an individual gain has led to a communal cost.[182] In tackling the effects of climate change, a global concept of community "premised on the interdependence of the entire earth–space arena in which people interact" must be recognized and respected by policy–makers as they seek to create a robust, multidimensional response.[183]

The complex ethics presented by the lionfish case are cause for consideration. Not only does the lionfish epidemic call into question consumer habits, but it also clouds the conception of just what constitutes an invasive species. As noted earlier, the broadening of isotherms will dissolve thermal barriers, allowing organisms to migrate beyond their traditional native range and into ecosystems where they outcompete indigenous species (*e.g.*, the lizardfish moving up through the Suez Canal and into the Mediterranean because water temperature increases dissolved the previous thermal barrier).[184] Damage to the recipient ecosystem (and therefore its resilience) caused by the effects of climate change is effectively what enabled the lionfish to be so swift in its

[181] *This Changes Everything*, directed by Avi Lewis (2015; FilmBuff), iTunes, *available at* https://itunes.apple.com/us/movie/this-changes-everything/id1035054045 .

[182] Garrett Hardin, "The Tragedy of the Commons," *Science* 162 (December 1968) : 1243–1248.

[183] W. Michael Reisman, "Myers S. McDougal: Architect of a Jurisprudence for a Free Society," *Miss. L.J.* 66 (1997) : 19–20.

[184] Côté and Green (2012), 6.

takeover of the Caribbean–Atlantic and a previously–occupied ecological niche within the region.[185]

Perhaps most concerning in Executive Order 13112's policy conception of invasive species is that, per the definition of invasive species, "range extensions of native species or nonindigenous species that exhibit no potential for ecological or economic impacts are not considered invasive species."[186] How, then, are we to make sense of the expanding ranges attributed to widening isotherms? We established in Chapter One, Section C that the continued rise of ocean water temperature will likely actuate the furthered expansion of the lionfish invasion. However, if we use lionfish as but one example (albeit, as the "worst case scenario") or even the comparatively mild case of the habitat expansion of the lizardfish, we recognize the potentiality for harm to come from species venturing into novel ranges.

Here, also, the notion of a "native" species is blurred with that of an "invasive" species. We recognize the absurd subjectivity that is the policy conception of "native" species: "species which have auto colonized an area since a selected time in the past."[187] Moreover, Executive Order 13112's reliance upon its "harm prong" narrows the scope of policy reactions to those species that threaten our health or that of resources we as human consumers deem economically or culturally valuable. "The relativity of time and space really makes the fairly arbitrarily defined 'invasive' species one that simply happens to be in the wrong place at the wrong time."[188]

The threat of increasing temperature due to climate change is not solely the bane of marine–based economies. If this issue is extrapolated to terrestrial industries, the threats may seem more

[185] Morris and Whitfield (2009), 17.
[186] Morris and Whitfield (2009), 1.
[187] C. Warren, "Perspectives on the 'alien' versus 'native' species debate: a critique of concepts, language and practice," *Progress in Human Geography* 31, no. 4 (2007) : 427–446.
[188] Clark (2012), 56.

proximate and may activate a stronger response from policy–makers at all levels. Lumber supplies may dwindle as forests dry out in higher average air temperatures and as freshwater sources are exhausted.[189] Livestock may no longer reproduce at anticipated rates and may fail to meet consumers' demand for protein.[190] Ski resorts may be forced to permanently shut down as average winter temperatures prevent adequate snow coverage of mountainsides.[191] The list goes on.

One of the more ethical approaches in managing lionfish populations is a quite simple one: eat them. Rather than eradicating the species purely for sport or for the sake of "saving" the Caribbean, why not supplement local diets with lionfish meat through widespread culling efforts? Efforts to bring lionfish to market are already underway (Chapter 2, Section E), and they seek to avert the current global fisheries crisis in which 90 percent of the world's large–fish stock has been depleted.[192] "Killing lionfish and simply disposing of them, in light of the chilling decline in global fish stocks, is unethical. Killing lionfish and eating them relieves consumer pressure on other highly in–demand fish."[193]

A sustainable lionfish market would capitalize on the exploitation of a species that regional managers are already seeking to eliminate. Because lionfish are invasive, their removal would not pose any ecological consequences. Additionally, lionfish is not a "fishy fish" in that its white, flaky meat is mild in flavor, which is an important factor at least within American markets where tastes

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[189] Cristina Santiestevan, "Changing Climate, Shifting Forests," American Forests, Winter 2010, http://www.americanforests.org/magazine/article/changing-climate-shifting-forests/ (accessed April 14, 2017).

[190] E.S.E. Hafez, "Effects of High Temperature on Reproduction," *Int J Biometeorol* 7, no. 3 (1964) : 223–230.

[191] Katherine Bagley, "As Climate Change Imperils Winter, the Ski Industry Frets," Insideclimate News, December 25, 2015, https://insideclimatenews.org/news/23122015/climate-change-global-warming-imperils-winter-ski-industry-frets-el-nino (accessed April 14, 2017).

[192] R. Myers and B. Worm, "Rapid Worldwide Depletion of Predatory Fish Communities," *Nature*, 423 (2003) : 280–283.

[193] Clark (2012), 50.

are relatively plain. Therefore, it is likely that lionfish will quickly catch on in much the same way as cod and tilapia have.

Some object to the creation of an established lionfish industry, citing fear that creating consumer demand for lionfish may lead to intentional releases in order to maintain a consistent stock for fishermen. However, such a scenario would only reflect the success of a lionfish industry. Here, "the only reason that more lionfish would have to be introduced into U.S. waters would be to meet consumer demand for them. Therefore, it is safe to conclude that in this scenario, the human population is keeping the lionfish population in check and consequently the destruction of marine life caused by lionfish is minimal."[194] This approach would perhaps mitigate the exigency of the situation and would allow the recipient ecosystems to slowly adjust to the lionfish newcomer.

Lionfish as a food product has been brought to market on the suggestion that ordering it off the menu over other staples — salmon, seabass, trout — is a "responsible" choice. One need only to look at how REEF markets its lionfish cookbook:

> Although it is highly unlikely that lionfish will ever be eradicated from their invaded range, it is very possible that local populations can be controlled and their impacts minimized simply by adding it to the menu. While many traditional native seafood species are under immense fishing pressure and in need of protection, lionfish are a tasty, nutritious and environmentally conscious seafood choice. There is simply no "greener" fish to eat![195]

By presenting consumer choice as a moral obligation, the developing lionfish market seeks to impose new duties upon consumers and to ignite a cultural shift toward 'sustainatarianism' — a means of informed human consumption cognizant of food availability and the effects consumption has on the planet. The moral underpinning of this movement is one that is protective of the

[194] Clark (2012), 51.
[195] REEF, "Lionfish Cookbook 2nd Edition."

livelihood of future generations and their capacity to enjoy a standard of living equal to (or better than) that of current generations. By transporting goods around the world and by expecting that all foods are accessible at all times at all places, modern humanity has transformed the very notion of what it means to be a consumer. Selecting an entrée in a typical restaurant of the developed world is not about what is seasonal or what is fresh or what is local, but instead the decision hinges upon "what sounds good." In the first world's quest to ensure an overabundance of food, fundamental ecological tradeoffs were made in our design of intensive agriculture and industrialized fishing. "Our choices as consumers affect global biodiversity," asserts Professor Yvonne Sadovy of the University of Hong Kong.[196] Indeed, aquarium enthusiasts' interest in importing the non–native lionfish has affected biodiversity throughout the Caribbean–Atlantic (as well as the Indo–Pacific from which the lionfish is extracted). In fact, a 2010 study considered the non–native lionfish to be "one of the top fifteen global threats to conservation biodiversity."[197] The significance of the lionfish case is heightened when we pause and realize the gravity of this point — "even though the lionfish invasion is limited to the coasts of the Western Atlantic and Caribbean, it is considered to be one of the top fifteen threats to *the world's* biodiversity."[198] In an area of a million–plus square miles, the region is rife with a critical problem that threatens biodiversity, management efforts, and the security of human economies.

Finally, we may end on a note that seeks to play the role of the Devil's advocate with respect to conservation efforts. All conservation paradigms identified in this work seek to do

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[196] *The End of the Line*, directed by Rupert Murray (2009; Documurafilms), DVD. Beyond the present case of lionfish, one need only to turn to the case of the complete exhaustion of Newfoundland cod in the early 1990's. It was said that waters there contained so many cod "that a man could walk across the waters on their backs" (Murray). Due to technology that increased yields compounded by a growing global appetite for fish and chips, the "cod rush" lead to a near extinction of the species in 1992. 40,000 people lost their jobs.

[197] Sutherland, William J. et al., "A horizon scan of global conservation issues for 2010," *Trends in Ecology and Evolution,* 30, no. 10 (2010) : 4–5.

[198] Clark (2012), 45.

exactly as the word implies: conserve an ecosystem in its steady state. However, like the definition of "native" being determined at a specific time and place, so too is the conception of an ecosystem by its appointed managers. "The treatment of the wild as a pristine exterior, the touchstone of an original nature, sets the parameters of contemporary environmental politics."[199] In this "pristine exterior," organisms, their interrelationships, and surrounding abiotic factors are viewed as unchangeable, absolute, and "as intended." Catastrophic sudden changes (like those presented by invasive species) are deemed unacceptable and they attract human intervention. In the shadow of climate change, however, we may see "correcting" these changes as an insurmountable challenge, as made evident by the lionfish epidemic:

> Indeed, it is not at all clear that even all of [the] actors working in concert can solve this problem, bringing us to another key principle: the possibility that lionfish have irreversibly changed these marine ecosystems. Resilience theory teaches us that ecological systems can exist in multiple steady states rather than a single equilibrium. Thus, in response to a perturbation like the lionfish invasion, these marine ecosystems might shift to an alternative steady state rather than return to the prior equilibrium.[200]

This is not say that lionfish management efforts should be immediately halted. They play an important role in mitigating the invasion's immediate effects, especially those impacting fishing economies. However, it must be recognized that all efforts thus far on a regional scale (*i.e.*, within the Convention Area) have been ineffective in totally thwarting the invasion. Given the difficulty of removing invasive species after they have already become established, the best way of preventing damage is to prevent the introduction of the species in the first place. This is a simple concept, and yet it is not reflected in U.S. policy measures that govern the importation of non–

[199] Sarah Whatmore, *Hybrid Geographies: Natures, Cultures, Spaces* (Thousand Oaks, California: SAGE Publications Ltd., 2002), 9.

[200] Bratspies (2014), 849.

natives. This manifests as a massive policy oversight, the redress of which ought to be a priority for federal legislators.

At some point, regional decision–makers must accept the "new normal" of the lionfish's presence. Over time, native species may adjust to the newcomer: prey may react defensively, and native predators may identify the lionfish as prey rather than as an unknown stranger. Because of this, every effort must be made to ensure the integrity of potential predator populations. For example, evidence suggesting that grouper eat lionfish[201] has garnered public support for ongoing efforts to protect grouper spawning grounds in Belize.[202] In the Cayman Islands, "divers have trained wild Nassau grouper to consume lionfish, without the grouper showing ill effects."[203] More efforts to protect these likely predators from overfishing[204] in this novel range are likely to enhance local ecosystems' capacity to fend off the lionfish and achieve a stable state. In this light, a lionfish–focused fishing industry seems most appropriate.

Lionfish are especially troubling because they have disrupted the *status quo*. Instead of "traditional" adaptation through the "survival of the fittest" paradigm (in which a new predator is introduced to an ecosystem and species within that ecosystem adapt and evolve accordingly over time), the introduction and distribution of lionfish have been alarmingly swift. In large part, this is because lionfish were transported to a novel environment in which native species were totally

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[201] Aleksandra Maljković et al., "Predation on the Invasive Red Lionfish, *Pterois Volitans* (*Pisces: Scorpaenidae*) by Native Groupers in the Bahamas," *Coral Reefs* 27 (2008) : 501.

[202] Spawning Aggregation Working Group, "Belize National Spawning Aggregation Working Group," SPAG, Home, 2017, http://www.spagbelize.org (accessed April 16, 2017).

[203] NOAA Fisheries, "Nassau Grouper Biological Report," NOAA Fisheries, *available at* http://www.fisheries.noaa.gov/pr/species/documents/nassau_bioassessrpt_final.pdf (accessed April 16, 2017).

[204] IUCN Red List, "Epinephelus striatus," IUCN Red List, Epinephelus striatus (Nassau Grouper), Full Account, http://www.iucnredlist.org/details/full/7862/25 (accessed April 14, 2017), *noting* "This species is widely distributed in the Gulf of Mexico and occurs over reef habitat. Due to overexploitation, there has been a more than 80% decline in Cuba, Mexico and the US over the past 30 years (3 generation lengths). Spawning aggregations have been overfished and have disappeared in some regions, with no evidence of recovery. Therefore, it is listed as Critically Endangered under Criterion A2bd."

unaccustomed to the physical and behavioral characteristics exhibited by lionfish. "[T]he unprecedented rate and scale of human–induced invasions has transformed 'what once was a catalyst for evolutionary invention [into] an over–whelming force for ecological destruction.' "[205] By diverting pressure away from threatened species and instead focusing fishing efforts on lionfish, a new equilibrium may be reached in which "more proper" evolution and ecological adaptation can occur.

Even beyond motives stemming from morality and environmental ethics, our earth's resources are worth safeguarding. Precisely *because* we attribute economic value to our fisheries, our waters, our forests, and all our other natural resources, they receive political protection. However, as made clear in this case, greater breadth and adaptability in environmental policy are essential in securing our future. The lionfish story, while an extreme one, illustrates the immense challenges that climate change and unsustainable human activity pose to the continued viability of the resources upon which our economies and lives depend.

[205] Warren (2007), 430.

Appendix

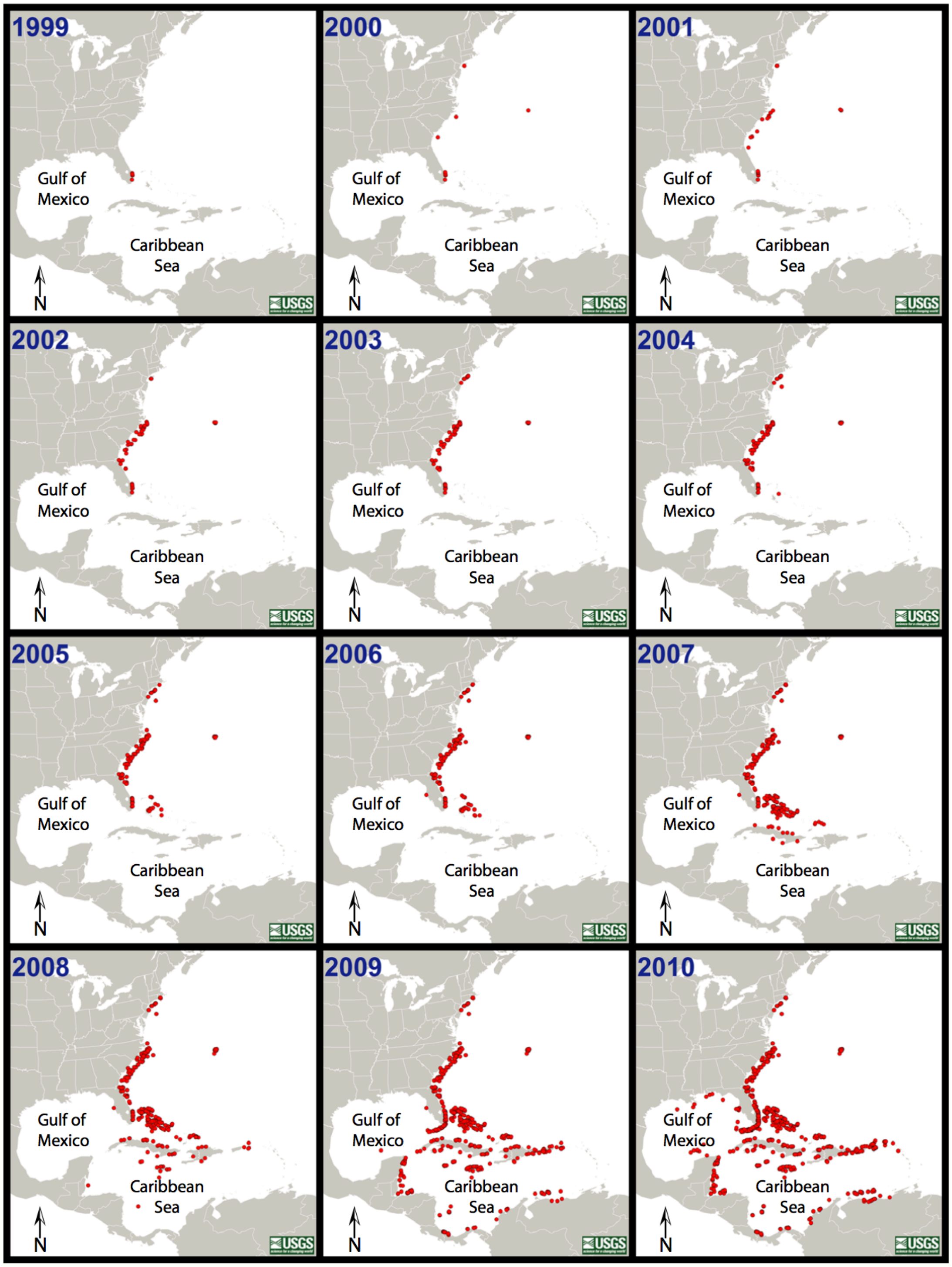
Figure I.1: Native range of lionfish within the Indo–Pacific

Lionfish are native to the warm, tropical waters of the Western Pacific and Indian Oceans (*i.e.,* the Indo–Pacific region), including the Red Sea.

Source: NOAA.

Figure I.2: Reported sightings of lionfish in Caribbean–Atlantic, 1999—2010

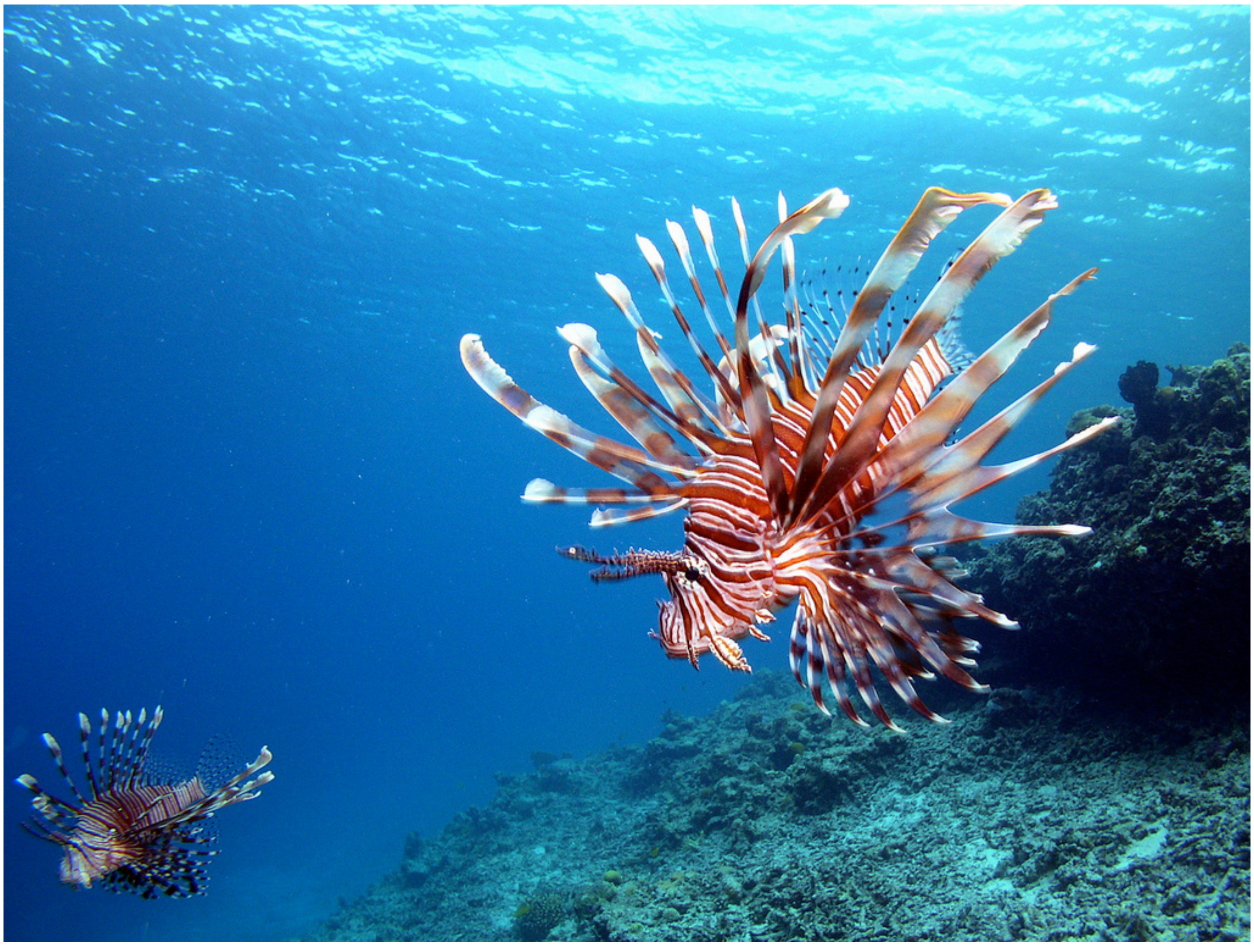
A chronology of lionfish sighting occurrences within the Western Atlantic and Caribbean demonstrating initial novel range of U.S. east coast with subsequent populations spreading throughout the region.



Source: NOAA.

Figure I.3: Image of lionfish

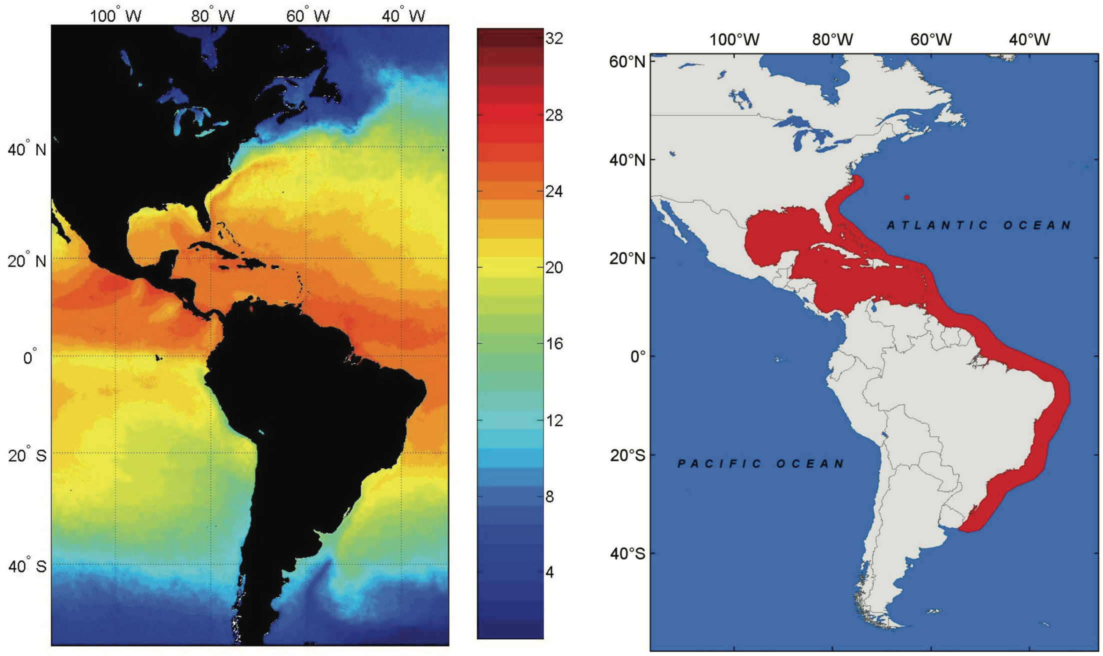
Maroon–brown in color with white stripes or bands, the lionfish exhibits thirteen dorsal spines, ten to eleven dorsal soft rays, three anal spines, six to seven anal soft rays, fan–like pectoral fins, and tentacles above their eyes and under their mouth. Absolutely unique in their appearance (hence their popularity in the aquarium trade), the lionfish's venomous spines are all encompassing, radiating dorsally in nearly all directions, with the large pectoral fins extending laterally and ventrally. Able to grow as large as eighteen inches, lionfish are intimidating creatures.



Source: Kawasak (2014).

Figure I.4: Current regional water temperatures and lionfish isotherm

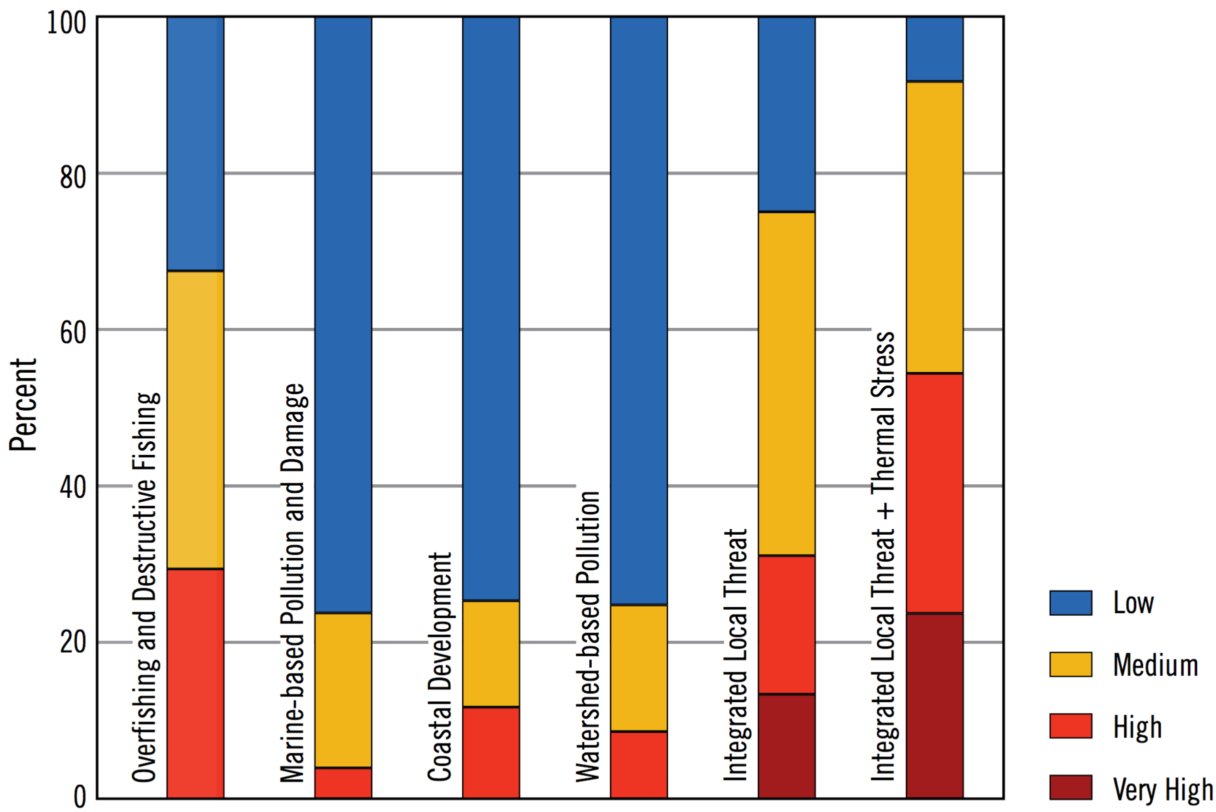
Composite 9 km resolution image of average annual sea surface temperatures (°C) collected by Aqua MODIS in 2008 for North, Central, and South America (left) and potential future range of lionfish based on the lethal minimum of 10°C and current sea surface water temperatures (right).



Source: Morris and Whitfield (2009), 7.

Figure I.5: Relative risks imposed upon Caribbean–Atlantic reef systems

Coral reefs throughout the Caribbean–Atlantic face a broad array of threats. While some threats present regionally and affect multiple reef systems, some location–specific activities (like overfishing) affect only individual reefs/groups of reefs within national waters. Differing laws and policies between nations, including the relative coverage of marine protected areas (MPAs), cause discrepancies between states. Reefs facing thermal stress along with local ecological threats combat significantly more risk than reefs that do not.



Source: Burke et al. (2011), 64.

<u>Figure I.6: Reefs at risk in the Caribbean–Atlantic</u>
Corals throughout the region have been in decline for at least several decades, attributed largely to systematic overfishing, coastal development, and the effects of climate change, particularly ocean acidification.

Source: Burke et al. (2011), 63.

Figure II.1: The Bahamian coat of arms

The national symbol for the Bahamas is a composition of the indigenous life of the archipelago. The crest of the arms, a light pink conch shell, symbolizes the marine life of the Bahamas. The shield of the coat of arms is adorned by the Santa Maria, flagship of Christopher Columbus, and the sun, a reference to the balmy climate and the bright future of the nation. Like many other Caribbean nations, the coat of arms is an exaltation of rich maritime traditions.

Source: Government of the Bahamas.

Figure II.2: Summary of main predictors of invasiveness for established nonindigenous fish species relevant to lionfish

The lionfish exhibit many of the key indicators used to predict fish's capacity to become invasive within recipient non–native ecosystems. The presence (Y) or absence (N) of each predictor exhibited in the lionfish life history or ecological traits is noted. This summative evaluation of "invasivity" was adopted from a comprehensive review by Morris and Whitfield (2009), 30.

Main predictor	Lionfish
Broad diet	Y
High physical tolerance	Y
Prior invader	Y
Fast growth	Y
Large native range	Y
High adult trophic status	Y
High propagule pressure	Y
Long life span	Y
High fecundity	Y
Large egg diameter	Y
Long reproductive season	Y
Young age at maturity	Y
Large body size	Y
Short distance to native source	N
Parental care	N

<u>Figure II.3: Promotional poster for Florida lionfish derby series</u>

Lionfish derbies are important events to educate the public on the deleterious effects of lionfish. Participants (either individually or as teams) compete against each other to spear the most lionfish, and cash prizes are awarded to winners. These events have become tourist attractions in coastal regions where lionfish are prevalent.

Source: Boring (2015).

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