A Comparison of Eight Country Plans for the Invasive Indo-Pacific Lionfish in the Wider Caribbean

By:

Roxanne E. Graham

Submitted in partial fulfillment of the requirements for the degree of Master of Marine Management

at

Dalhousie University
Halifax, Nova Scotia

November 2016

TABLE OF CONTENT

List of Tables, Figures and Boxes

Tables

Figures

Boxes

Abbreviations and Acronyms

AIMS	Atlantic, Indian Ocean and South China Sea
AIS	Aquatic Invasive Species
ANST FORCE	Aquatic Nuisance Species Task Force
CARICOM	Caribbean Community and Common Market
CBD	Convention on Biological Diversity
DFO	Department of Fisheries and Oceans (Canada)
DPSIR	Driving Forces-Pressures-State-Impacts-Responses
EDRR	Early Detection and Rapid Response
IAS	Invasive Alien Species
IPCC	Intergovernmental Panel on Climate Change
JNCC	Joint Nature Conservation Committee
MIS	Marine Invasive Species
NGO	Nongovernmental Organisation
NISC	National Invasive Species Council (United States)
SPAW	Specially Protected Areas and Wildlife
UN-OHRLLS	United Nations- Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States
USEPA	US Environmental Protection Agency
USVI	United States Virgin Islands
WCR	Wider Caribbean Region

Abstract

The coastal Caribbean region is generally characterized by the following ecosystems: coral reefs, mangroves and seagrasses, also including other environments, such as sandy beaches and rocky shores. These tropical ecosystems incorporate a high diversity of associated flora and fauna and have significant ecological, aesthetic, economic and amenity value to the countries and territories of the region. Moreover, the islands collectively encompass a major global marine biodiversity hot spot. Over the years, the multitude effects of climate change and marine invasive species (MIS) have posed a major threat to the island biodiversity and combined, the complexity of the interaction of these two global drivers has increasingly been showing devastating effects. Today, the Caribbean Sea is plagued with the invasive lionfish *(Pterois volitans* and *P. miles).* As the range of the lionfish throughout the Caribbean has grown and their abundance has increased, recognition that the lionfish poses a grave threat to the native marine ecosystems has prompted the development of lionfish management plans across the region. Eight (8) countries' response and management plans for the lionfish were evaluated using the US Environmental Protection Agency (USEPA) Aquatic Invasive Species (AIS) framework and their criteria and scoring assessment for state management plan and assessment consideration of climate change and/or changing conditions. The countries include Anguilla, Bahamas, Cayman Islands, Grenada, St. Eustatius, St. Lucia, St. Vincent and the US Virgin Islands. Although specific strategies differ amongst the islands depending upon needs, culture, and individual circumstances, most of the plans include three main components: education and outreach, control and monitoring protocols, and research and information management. The research also provided a comprehensive perspective of the opportunities and obstacles to enhancing both individual country and regional management of lionfish species through the use of a Comparison Matrix. This ultimately led to suggestions for intra- and inter-country cooperation and the transfer and development of interventions which could thereby make a major contribution to the conservation of significant island biodiversity.

Keywords: Wider Caribbean Region, lionfish, marine invasive species, biodiversity, climate change, management plans, adaptive capacity

Dedication

You never know when one kind act or one word of encouragement will change a life forever.

To my dear friend, Ezra A. Campbell, this is dedicated to you.

Acknowledgements

This graduate project is the result of all the work and help from a number of people who have supported me over the past year and half. In particular, there would have been no research without the award given by the Canadian Queen Elizabeth II Diamond Jubilee Scholarship. I express my appreciation for their interest and support.

I specifically acknowledge the invaluable support and guidance provided by my supervisor, Dr. Lucia Fanning, whose encouragement and friendship has sustained me throughout my work. Ms. Becky Fields, the administrative assistance for her help, advice and care of my wellbeing. Additionally, I would also like to express gratitude to the Marine Affairs Program faculty and review committee members for arming me with all the necessary tools and knowledge to shape this body of work, and Dr. David Gill, Luc Hoffman Institute Post-doctoral Fellow, National Socio-Environmental Synthesis Center, my external examiner for my graduate project.

I thank the Fisheries Division, Grenada for their travel grant and for hosting me for my internship and project field work. Also I wish to express my appreciation to the list of informants in Appendix A for providing me the management plans and supporting documents needed for this research. Lastly, thanks to my family and friends for their continuous encouragement and support.

CHAPTER 1 – INTRODUCTION

The Wider Caribbean Region (WCR) is defined in Article 2:1 of the Cartagena Convention as the marine environment of the Gulf of Mexico, the Caribbean Sea and the areas of the Atlantic Ocean adjacent thereto, south of 30° north latitude and within 200 nautical miles of the Atlantic coasts of the United States of America (USA) (Polar and Krauss 2015). The WCR comprises the 36 UN member states. It includes Mexico, Central America, and many small island nations and territories of the insular Caribbean (Polar and Krauss 2015). The WCR encompasses two biodiversity hotspots including the Caribbean hotspot and the Mesoamerica hotspot, where exceptional concentrations of endemic species are undergoing exceptional loss of habitat. Loss of habitat is the process in which natural habitat is rendered unable to support the species present. In this process, the organisms that previously used the site are displaced or destroyed, reducing biodiversity (Holbrook et al., 2015). One such event that results in displaced biodiversity is invasive species.

Invasive species are generally defined as nonindigenous flora and fauna whose presence in a newly introduced ecosystem poses, or is likely to pose, an ecological threat to the native habitat, the economy, or harm human health (U.S. Fish and Wildlife Service, 2013). These nonindigenous organisms, which have an evolutionary advantage over local biota, often devastate their new ecosystems (Kannan, 2015). Environmental degradation and movement of biota by humans across the planet have contributed to numerous introductions of alien plant, animal, and microbial species. As nations are more interdependent and trade continues to flourish, the problem of invasions is only becoming more difficult to handle (Kannan, 2015). Some of the most notorious are invasions by marine species, which have had severe impacts on ecosystems where they have proliferated (LaJeunesse, Forsman and Wham, 2016). Despite an increased awareness of invasion problems in the scientific community, national governments continue to fall short on implementing preventative measures (Kannan, 2015). According to Early et al. (2016), reactive national policies aimed at managing Invasive Alien Species (IAS) that are already established and problematic in a given country tend to be more common than proactive policies to detect or counteract the emergence of potential IAS.

One such invasion and need for improved response management has recently unfolded in the Wider Caribbean and according to Côté, Green and Hixon (2013), it is at a rate and

magnitude never before documented in any marine system. It involves two species of Indo-Pacific lionfish *(Pterois volitans and P. miles)*, which represent the first non-native marine finfish to become established in Atlantic waters of the United States, including the Gulf of Mexico and Caribbean (ANST Force, 2015). Caribbean coral reef ecosystems are already at the forefront of a global decline and are now facing a new threat - elimination of native vulnerable species by the invasive lionfish (Rocha et al., 2015). According to Albins and Hixon (2013), lionfish possess a broad suite of traits that makes them particularly successful invaders and strong negative interactors with native fauna. These include defensive venomous spines, cryptic form, color and behavior, habitat generality, high competitive ability, low parasite load, efficient predation, rapid growth, and high reproductive rates.

The lionfish is established along the Atlantic coast of the USA (from the Florida Keys to Cape Hatteras), the Caribbean coasts of Central and South America, the Gulf of Mexico, and throughout the Greater Antilles, Leeward and Windward Islands. (Schofield, 2010). According to Gómez Lozano et al. (2013), climatic conditions and change, including oceanic currents, elevated sea surface temperature, and increased frequency, duration, and magnitude of storms and hurricanes are responsible for the extensive range. Given the abundance and widespread range of the lionfish invasion, eradication of the species will be extremely difficult and costly, if not pragmatically impossible (ANST Force, 2015). Added to these circumstances, invasions are less likely to be accurately recorded and monitored in marine, as opposed to terrestrial, environments (Reiss et al., 2014).

Management and control actions of lionfish has been challenging at best. Efforts have been localized and not well coordinated across agencies or with other stakeholders (ANST Force, 2015). Today, various incentive and alternative-use programs utilizing lionfish have risen in popularity and serve as a means to raise awareness and encourage the harvest, use and consumption of invasive lionfish on local and regional scales. Development of markets for lionfish jewelry, aquarium specimens, and as a food fish, among others, provides incentives encouraging removals (ANST Force, 2015). Research demonstrates that lionfish are edible and have higher levels of healthy omega-3 fatty acids than some frequently consumed native marine fish species (Morris et. al., 2011).

It is critical to continue learning as much as possible from this invasion to determine the best ways to control and manage lionfish numbers to reduce ecological and socioeconomic

impacts, as well as harm to human health. By researching the invasion ecology of lionfish, one can gain a better understanding of the highest risk vectors for marine finfish introductions, the potential impacts, and possible ways to control and manage a marine invasive finfish. Additionally, it is necessary to document the current status in the WCR and thereby identify what is needed in terms of experiences and capacities for managing MIS such as the lionfish. This research is being undertaken in response to these issues. The study can therefore form the baseline against which future projects and actions can be proposed as well as assessed. The aims and objectives of this research were guided by this premise.

1.1 Aims and Objectives of the Project

The aim of this research is to provide a comprehensive review on localized and regional lionfish management practices and challenges in the Caribbean and to determine adaptive capacity i.e. ability to adjust in response to climate change. This research will then report on each of the eight case study country's research and management needs. The goal is to inform relevant managers of these countries of effective approaches to lionfish management and possibly other future finfish invasion in a changing climate. It will also determine the similarities and differences in existing management protocols for the lionfish species with the intention of providing useful recommendations.

This research also relates to, but is not influenced by the Regional Strategy for the Control of Invasive Lionfish in the Wider Caribbean (Gómez Lozano et al., 2013). The regional strategy was developed by the Regional Lionfish Committee, also known as *Ad Hoc* Committee, and was published in 2013. The Wider Caribbean's strategy rationale is intended to facilitate collaboration by providing a framework to i) facilitate on-the-ground implementation of actions through regular exchanges of experiences, protocols, and tools; ii) help reduce costs and avoid duplicative efforts by designing regional programs with pooled resources; iii) enunciate roles and potential actions among different actors and sectors; iv) guide researchers and donors by identifying projects that require action as top priority; and v) ensure actions are consistent and complementary at all levels and across all sectors. This framework however lacks an assessment and evaluation tool to guide and report on collaboration. Given the situation, the objectives of this research are as follow:

- Assess the management activities for lionfish control in the Wider Caribbean
- Assess each of the selected country plans for adaptive capacity for changing conditions (i.e. adjusting in response to climate change)
- Identify the opportunities and obstacles to enhancing the Caribbean's approach to managing the lionfish in this changing climate.

The results of this research study could be used by relevant managers of the Wider Caribbean region as the baseline for proposing future goals and actions in management planning of future lionfish plans and projects as well as potentially new invasions. The next section describes the WCR and includes some of key contexts pertinent to regional strategizing.

1.2 Regional Profile: the Wider Caribbean

Mahon, Fanning and McConney (2014) summarized that the WCR (see Figure 1) extends from French Guinana in the south, through the insular Caribbean, Central America, the Gulf of Mexico and north along the east coast of North America to Cape Hatteras. The authors further state that the WCR is one of the most geopolitically complex regions in the world and this has considerable implications for ocean governance. The WCR includes twenty-nine (29) countries and fifteen (15) territories (together referred to as states) that are dependencies of France, the United Kingdom, the United States and the Netherlands. This results in an extremely wide range in their capacities for governance.

Figure 1. Map of the Wider Caribbean Region (Mahon et al., 2014)

The countries of the region also have a diversity of language, culture and administrative arrangements as part of their colonial heritage. These all lead to differences in perspectives on ocean governance within the WCR. Additionally, the states of Wider Caribbean also share a number of socio-economic challenges. Among which are: a heavy dependence upon the natural resource base (agriculture, forestry, fishing, tourism, mining and light manufacturing); susceptibility to the vagaries of international trade; lack of economies of scale; high transportation and communication costs; extreme vulnerability to natural disasters; scarce land resources; and ever increasing pressures on coastal and marine environments (Bizikova, Bizikova, Metternicht and Yarde, 2015).

The services which the marine and coastal environment provides to the Caribbean states are all interconnected. Over the years, ocean related issues across the region prompted relevant managers and organisations to work on a regional scale. Examples include programmes such as International Coral Reef Initiative (ICRI) and Caribbean Coastal Marine Productivity (CARICOMP) Programme; projects such as the Caribbean Planning for Adaptation to Global Climate Change project and Caribbean Large Marine Ecosystem project; and networks or organisations such as Caribbean Marine Protected Area Management (CaMPAM) Network or Gulf and Caribbean Fisheries Institute.

The marine environment of the WCR is also very diverse. It encompasses both tropical and sub-tropical ecosystems, from coral reefs to mangrove forests to sea-grass beds, each with its unique wildlife (UNEP, 2008). The states of the WCR have a high degree of dependence on marine ecosystems for fisheries and tourism livelihoods. Fisheries and tourism are the two important drivers of the region's economies (Debels, Fanning, Mahon and McConney, 2016). The fisheries of the Caribbean region exploit a diversity of resources. Offshore pelagic fishes, reef fishes, lobster, conch, shrimps, continental shelf demersal fishes, deep slope and bank fishes, and coastal pelagic fishes are among the most important. Most fisheries are artisanal or small scale, contributing predominantly to local livelihoods and food security. Additionally, marine-based tourism is a major contributor to the economy in many Caribbean states (Mahon et al., 2014).

1.3 Report Layout

Following this introductory chapter which sets out the aims, objectives and geographic scope of the research, the remainder of this graduate research report is organized into seven chapters. Chapter two reviews important and recent literature as it relates to climate change in the Caribbean, marine invasive species in the Caribbean, climate change and invasive species interactions, lionfish historic range and impacts of the indo-pacific invasive lionfish. Chapter three describes the current lionfish management approaches by highlighting the regional framework and national management plan governing implementation of management activities for the invasive indo-pacific lionfish. It also uses the DPSIR framework to define the information about the state of the environment and the human uses of it, as it relates to the lionfish and potentially other marine finfish invasions. This chapter represents one of the core components of the report, and forms the foundation of the assessments and discussion elucidated in chapters five and six. Chapter four describes the methodology used to analyze the results of this research which will be found in chapter five. Chapter six discusses the significant findings of the research project. It also recommends best management measures to ensure future enhanced lionfish and other MIS management planning and implementation. Chapter seven is the conclusion. It summarizes the findings of this research and shares final thoughts on the future of management of lionfish and potentially new introductions of finfish invasive species.

CHAPTER 2 - LITERATURE REVIEW

Given that the focus of this research is based on marine invasive species with a focus on the lionfish, its impacts on the WCR, and current management this chapter explores relevant as well as current literature surrounding these issues. Since this research is also about MIS planning in the context of climate change and changing environmental conditions this chapter also provides relevant information from primary source materials and secondary literature.

2.1 Overview of Climate Change in the Caribbean

According to USEPA (2008), there is no mandate that directs states (or countries in this case) to consider climate change in MIS management plans. However, managers can consider predicted effects of climate change on prevention, control, and eradication in order to manage natural resources effectively under changing climatic conditions. Many managers and decision-makers are cognizant of the potential impacts of climate change on invasive species and the effect this driver may have on the goals and objectives associated with existing activities and decisions. USEPA (2008) reported concerns that emphasize how climate change will exacerbate existing problems, and how it may enhance conditions suitable for invasive species not previously established. Furthermore, the interactions between stressors and invasive species, although not well understood, may exacerbate the impacts of climate change on ecosystems, and likewise, climate change may enable further invasion (USEPA, 2008)

Altered conditions such as increased atmospheric carbon dioxide, modified precipitation regimes, warming ocean and coastal currents, increased ambient temperature and altered nitrogen distribution can increase invasive species success in some contexts. USEPA (2008) also acknowledges that long-term studies are necessary to understand more fully the interaction between climate change and invasive species and more species-specific information are needed for improved resource management. The level of uncertainty about specific effects of climate change is high. However, a necessary first step to address these effects is the development of management strategies that incorporate existing climate-change information and facilitate the addition of new information (USEPA, 2008).

In the case of the lionfish, research by Morris and Whitfield (2009) has exemplified a strong correlatfion between invasion ranges and ocean warming. Thus increasing temperature is a critical characteristic to be considered. The Caribbean Sea has warmed by 1.5ºC over the last century (UNEP 2008). Additionally, according to Simpson, Scott, and Trotz (2011), over the past 50 years, increases in mean air temperature across the Caribbean have been consistent with the observed global warming trend, and they are expected to generally parallel global trends in the twenty-first century. The authors also stated that changes in sea surface temperatures are projected to be similar to those for at least the minimum air temperatures over coastal regions and islands (Simpson et al., 2011). Moreover, most climate models project total annual rainfall to decrease throughout all CARICOM countries by an average of 5–10 percent (MacLean, Breeze, Walmsley and Corkum, 2015), with decreases amplifying with increased temperatures. An analysis of data from the late 1950s to 2000 has shown that the number of very warm days and nights in the Caribbean is increasing dramatically and very cool days and nights are decreasing (Sauter, ten Brink, Withana, Mazza & Pondichie, 2013).

Across the Small Island Developing States, the abundance of coral species is rapidly declining, particularly across the Pacific as well as the Caribbean where it has decreased by over eighty percent (80%) (UN-OHRLLS, 2015). The Intergovernmental Panel on Climate Change (IPCC) estimates that one third of global coral reefs will experience degradation over the coming decades (UN-OHRLLS, 2015). This is evident in Caribbean countries Haiti and Grenada, which were among the 4 islands of the Caribbean, Pacific, and the Atlantic, Indian Ocean and South China Sea (AIMS), stated to be most vulnerable to the effects of coral reef degradation (Burke, Reytar, Spalding and Perry, 2011).

2.2 Overview of Marine Invasive Species in the Caribbean

Marine invasive species is an issue rapidly increasing in importance and relevance in the Caribbean but thus far little has been done to address the problem of invasive species in marine planning and management (Kling and Sanchirico 2014). The Global Invasive Database reports several species in the region including, fish such as tilapia (*Oreochromis niloticus, Oreochromis mossambicus* and other species and hybrids), corals (*Tubastraea coccinea*), algae (*Kappaphycys spp.*), and bacteria (*Vibrio cholera*). Today, there are two major and different types of invasive

species affecting the entire region including the two (2) lionfish species and the invasive Indo-Pacific green mussel (Ziska and Dukes, 2014).

Marine invasive species has been a major threat to the vulnerable marine and coastal biodiversity of Caribbean islands and to the people depending on this biodiversity for their livelihoods. Caribbean states have recognized the need for a regional strategy and expressed strong interest in linking their national efforts in implementing Article 8 (h) of the Convention on Biological Diversity (CBD) to mitigate the threats of MIS in the Caribbean. They are also contracting parties to other international instruments addressing issues related to MIS threats such as the Specially Protected Areas and Wildlife Protocol of the WCR (Cartagena Convention), and the International Maritime Organization's Ballast Water Management Convention (Cox, 2015).

The issue of MIS and their potential impact on the marine ecosystems and coastal economies is a relatively new topic, particularly in the Caribbean. The impacts of invasive species can be ecologically complex. MIS invasions can result in a number of severe changes in the availability of resources (nutrients, light, oxygen), the dynamics of competition for resources, and ecosystem structure and function (Gioria and Osborne, 2014).

In terms of response management, Lopez and Krauss (2006) state that marine environments present exceptionally challenging conditions for the control of marine invasions. They note that the absence of clear borders in the marine environment severely limits management options and that detection, particularly at low densities, is difficult. Species spread in a three-dimensional fluid system, where monitoring is a difficult and costly task. Furthermore, many eradication and control options (e.g., shooting, species specific pesticides) used on the terrestrial biota are harder to apply in the aquatic systems. Thus, while management options and mechanisms for MIS have been relatively well-studied and understood for terrestrial systems, particularly for species impacting human activity, much more research and capacity building activities are necessary before the management of MIS can be successfully undertaken (Lopez and Krauss, 2006).

2.3 Climate Change and Invasive Species Interactions

Once a non-native MIS have been introduced into foreign waters, it becomes problematic if the conditions are right. There are few studies that have illustrated how climate change influences invasive species. For instance, Burgiel and Muir (2010) stated that a shift in environmental variables, such as temperature and water availability, will have implications for species (native and non-native), particularly if variables shift outside the range of the species' bioclimatic envelope for survival. This may prompt species to migrate to new areas where conditions may be a better match or to simply go into decline if such movements are not biologically or physically possible. Relationships with symbiotic hosts, presence/absence of predators and other ecological dynamics will also play a significant role in regulating population size.

Climate change also increases the severity of extreme weather events (Konisky, Hughes and Kaylor 2016). Strong winds, currents and wave action can facilitate the movement of invasive species at regional and global scales. Thus climate change has significant amount of influence on marine invasive species which ultimately results in species competition and range shifts etc.

As it relates to the lionfish, research has attempted to illustrate the possible correlation between temperature rise and the spread of lionfish. For example, in the study by Morris and Whitfield (2009), lionfish were not initially thought to survive winter temperatures in the northern Atlantic Ocean, but warming ocean temperatures have enabled the lionfish to establish and impact parts of this area. Small changes of 1°C in winter bottom water temperatures have already shifted the species balance in some marine ecosystems from tropical towards temperate communities (Burgiel and Muir, 2010).

2.4 Lionfish Historic Range

The lionfish is native to coral reefs in the sub-tropical and tropical regions of the South Pacific, Indian Ocean and the Red Sea (see Figure 2). As it relates to the native range: *P. volitans* is native to most of Oceania (including the Marshall Islands, New Caledonia and Fiji) east to French Polynesia. *P. miles* is from the Indian Ocean and Red Sea, although its range extends to Sumatra (Morris and Whitfield 2009).

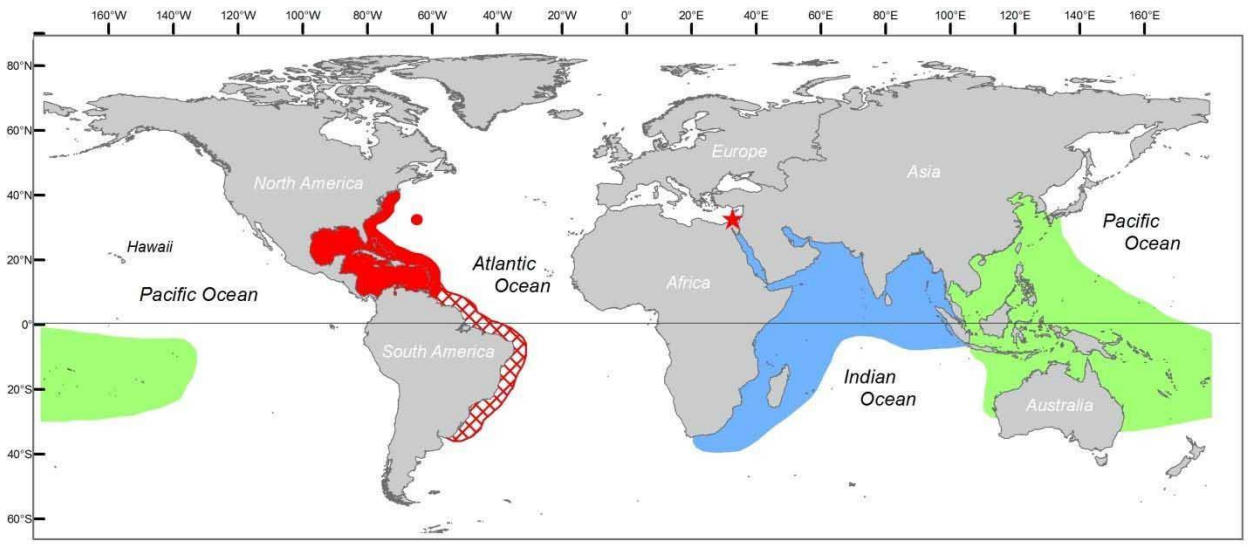

Figure 2. Map of native range of *Pterois volitans* (green) and *P. miles* (blue). Star in Mediterranean Sea denotes Lessepsian migration of *P. miles* via the Suez Canal. Non-native range of *P. volitans* and *P. miles* in the Americas is shown in red. Predicted future distribution of lionfish along coastal South America is shown in red hatching. (ANST Force, 2015)

The establishment of invasive marine fish populations can begin via several pathways, including introduction into non-native environments to improve fisheries resources, range expansion through canals and channels, transport in ballast water, and unintentional (or intentional) aquarium or aquaculture releases (Morris and Whitfield, 2009). Although some of the most prevalent U.S. policy regulations aimed at preventing invasive species introductions focus almost exclusively on ballast water releases, lionfish were most likely first introduced into the Atlantic through both intentional and unintentional aquarium releases.

Lionfish are popular ornamental fish that are heavily imported into the U.S.A. for the aquarium trade (Morris and Whitfield, 2009). The first confirmed sighting of lionfish occurred in 1985 off Dania Beach, Florida (Morris and Akins, 2009). Although lionfish are the first invasive marine finfish to become established in this region, Florida is a known hotspot for marine fish introductions, as nearly 40 species of nonnative fishes have been seen in Florida waters in the last two decades (Schofield, 2010). The exact cause of the lionfish introduction has not been determined. However, researchers speculate that lionfish were introduced to the Atlantic during Hurricane Andrew in 1992, when several were accidentally released from hotel aquaria in Florida during inundations (Estrella et al., 2010).

Current sightings and collection reports indicate that lionfish are established in the offshore waters of the southeast U.S. throughout the majority of the Caribbean, and most recently the Gulf of Mexico (Schofield, 2010) (see Figure 2). Burgiel and Muir (2010) state that lionfish inhabit marine environments from the coast out to depths of 300+ meters within a temperature range of ~10-35° C. They may continue their southward expansion along the coast of South America (see Figure 2) until they reach areas where water temperatures fall below their thermal tolerance (Morris and Whitfield, 2009). In 2015, there were reports of sightings of lionfish along Brazil's coastline, indicating that predictions are correct. One mechanism helping to fuel the continued spread of lionfish throughout the region is larval dispersal by ocean currents (ANST Force, 2015). Lionfish are also achieving high population densities, reaching well over 400 lionfish per hectare and becoming one of the most abundant species on some reefs (ANST Force, 2015).

2.5 Biology of Lionfish

Lionfish, as other Scorpaenids, are venomous and possess highly developed venom apparatus comprised of 13 dorsal spines, 2 anal spines, and 2 pelvic spines. The toxin in lionfish venom contains acetylcholine which affects neuromuscular transmission and causes cardiovascular and neuromuscular effects in animals and humans (Morris, 2012). Moreover, lionfish are prolific breeders, with one female being able to eject up to 15,000 eggs during a single mating event, of which she can have at least three per month (Ali, Collins and Peachey, 2013). The eggs are bound in an adhesive mucus that disintegrates a few days later, allowing the embryo and/or larvae to become free-floating (Morris et al. 2009). The juveniles develop rapidly and begin to actively hunt at approximately 7 cm length. Lionfish are also known to consume marine creatures that are as large as their size (Ali et al., 2013). As it relates to their diet, lionfish employ a diverse range of feeding strategies making them well suited for feeding on benthic and cryptic prey (Morris, 2009). Prey species in the Caribbean region are naïve to lionfish's novel predation strategies, resulting in lionfish having higher predation efficiencies in the invaded range compared to its native range (Albins and Hixon, 2013). Moreover, lionfish are opportunistic predators consuming a wide variety of ecologically and economically important fish and invertebrates. Studies in Anguilla for example revealed that the preferred fish families

consumed were Scaridae (parrotfish), Acanthuridae (doctor and surgeonfish), Labridae (wrasses), Carangidae (jacks), Haemulidae (grunts), Gobiidae (gobies), Apogonidae (cardinalfish), Pomacentridae (damselfish and chromis), Grammatidae (Basslets), Serranidae (groupers, hinds and basses), Holocentridae (squirrelfish) and Monocanthidae (filefish) (Ali and Bertuol, 2014).

2.6 Impacts of the Invasive Indo-pacific Lionfish

Generally, the introduction of invasive alien species is a major threat to ecosystem biodiversity, structure and function. They may displace native species, reduce community biodiversity, change species composition and abundance across habitats, modify habitat structure and produce cascading effects or trophic web shifts that could result in major negative impacts on the ecosystem (Eby, Roach, Crowder & Stanford, 2006). In terms of the lionfish, as the population increases, so does the effects associated with them. Unfortunately, as an invasive species to the Caribbean, the lionfish, with no known predator, voracious appetites, and high rates of reproduction, has the competitive advantage (Simmons, 2014). Lionfish abundance increased rapidly between 2004 and 2010 in the Atlantic Ocean and Caribbean Sea. By 2010, lionfish comprised nearly 40% of the total predator biomass in the system (Green et al., 2012). The increase in lionfish abundance coincided with a 65% decline in the biomass of the lionfish's 42 Atlantic prey fishes in just two years (Green et al., 2012). Additionally, lionfish have been found to have reduced the abundance of small native reef fishes by up to 95% at some invaded sites (Côté et al., 2013). The presence of the lionfish and the related impacts on the ecosystem ultimately has a number of ecological, economic and social implications.

2.6.1 Ecological Impacts

There are many publications that have also shown that lionfish impacts are highly negative on native populations and the entire Caribbean ecosystem (Albins, 2013; Green et al., 2012; Lesser and Slattery, 2011; Rocha et al., 2015). Because lionfish are highly piscivorous, they may have the capacity to reduce the recruitment of juvenile fishes to reef areas. According to Kulbicki et al. (2012), this has been experimentally confirmed by short-term studies on a few small Bahamian patch reefs. Such impacts could lead to declines in Caribbean reef biodiversity,

disruption of normal ecological processes, and possibly the local extinction of select species. Lionfish could contribute to the decline of other predators, by competing for food and shelter, which could lead to an imbalance in the ecosystem. The reduction of native prey fish suggests a high competitive ability. Indeed, lionfish seem to monopolize the majority of food resources. Côté et al. (2013) highlighted that the competition between lionfish and native predators is not clearly defined. However, Layman and Allgeier (2012) showed an important overlap between lionfish diet and other native predators' diet.

2.6.2 Economic Impacts

Lionfish may damage the economies of island communities dependent upon fishing (Ballew et al., 2016; Côté et al., 2013), by reducing populations of native species at varying stages from juveniles to adults and through consumption and competition for food and shelter, resulting in negative economic impacts. Such is the case with some commercially valuable species such as jacks, snappers and groupers, which many fishing communities depend on to earn a living (Côté et al., 2013). Destinations relying on dive tourism are also affected, since attractive, game and reef cleaning species are all included in the lionfish's diet, which could result in declining populations. Thus, lionfish may also impact the recreational sector and local tourism, an economic mainstay of many Caribbean island nations (Morris and Whitfield, 2009).

2.6.3 Social implications

There are two major social implications including effects on human health and social practices. As it relates to human health, the lionfish are highly venomous, with the capacity to inject neurotoxins dangerous to humans (and other animals) from stout spines on several of the main fins. As lionfish populations continue to increase, so does the likelihood of human injuries (Haddad et al., 2015). Lionfish envenomation is considered a serious injury requiring immediate professional medical evaluation and treatment (Haddad et al., 2015).

The lionfish invasion has also caused changes in some fishing practices and systems in certain islands for example the Cayman Islands. For instance, spearfishing is a common method for lionfish removal in the WCR (Dahl, Patterson and Snyder, 2016), given that it is a highly selective method of fishing. However according to Hart, Frank and Platt (2015), spearfishing restrictions for locals anywhere in the Cayman Islands presented a serious problem as lionfish

populations rapidly increased since its first sighting in 2008. However, recently, tourists and locals alike can now obtain a PADI Cayman Islands Lionfish Culler diving certification offered by local dive shops (McCoy, 2016). This certification allows the use of Department of Environment (DoE) approved spears while hunting lionfish in the Cayman Islands. Given the amendments and changes to spearfishing, there is now a fear that these changes could result in greater risks for improper usage, human endangerment and unregulated usage (Hart et al., 2015).

CHAPTER 3- CURRENT LIONFISH MANAGEMENT APPROACHES

Currently, eradication is unlikely given the ability of the lionfish to quickly spread and establish within the warming waters of the Caribbean and Atlantic Ocean. Population models predict that culling can reduce lionfish abundance substantially, but removal rates must be high (Côté et al., 2013). Robust empirical estimates of the cost-effectiveness and effects of removal strategies are urgently needed because lionfish management will require a long-term, labor-intensive effort that may be possible only at local scales (Côté et al., 2013). For the most part, control methods for lionfish currently consist of only mechanical harvest by divers (Burgiel and Muir, 2010). This chapter explains the current management frameworks and activities involved in lionfish management in the Caribbean region and it compares the Caribbean strategy with the EPA's framework.

3.1 The Caribbean Regional Strategy

In an effort to raise the understanding concerning the invasive lionfish and to regularize the response to this ever-increasing threat across all Caribbean states, as part of the International Coral Reef Initiative, Gómez Lozano et al. in 2013, published the Regional Strategy for the Control of Invasive Lionfish in the Wider Caribbean. The strategy aims to establish a framework for action to prevent, minimize and mitigate the adverse impacts of the lionfish on biodiversity and ecosystem services, as well as limiting social and economic damage. It also provides a framework to address the invasion with a concerted approach across political and geographical boundaries. It further states that this will be achieved through measures to ensure coordinated action in accordance with the approach taken under the Convention on Biological Diversity (CBD) (CBD, 2005) and with a focus on using resources on priority activities (Gómez Lozano et al., 2013). Cooperation is promoted among governments, reef-reliant industries, civil society and academia. It also proposes trans-boundary research and a monitoring agenda is coupled with local action plans, information campaigns and the adaptation of policy guidelines.

Gómez Lozano et al. (2013) urged decision-makers, marine managers, researchers, fishers, divers and educators to use the regional strategy as a guide to develop national strategies and local management plans. Each of the objectives is supported by strategies and actions with

specific stakeholders identified as possible implementers. It is expected that this Strategy will be used by governments and other stakeholders to create plans to implement many of the actions identified in it. The strategy is distributed in three languages used throughout the Caribbean: English, French and Spanish.

Although the strategy provides a management framework, it lacks an assessment and evaluation tool to determine the consistencies and collaboration in specific management activities.

3.2 Management Activities- Definitions and Lessons Learnt from USEPA

The current state-of-practice of management of marine invasive species such as the lionfish in the WCR demands clearer definitions and guidance in determining collaboration. The last section of the previous chapter describes the lack of a strategic assessment and evaluation tool to ensure consistencies in planning. Despite the geopolitical differences of the countries within the WCR (as described in section 1.2), most effective regional plans associated with coastal and marine management uses a strategic management framework (DFO, 2004) and offer specific guidance and assessment tools to ensure countries are addressing key aspects of management (Halpern, Gaines, Gelcich, Gleason, Jennings, and Napoli, 2012). The US Environmental Protection Agency (USEPA) Aquatic Invasive Species (AIS) Management Framework's assessment of state plans is a standard and leading example in US states and territories (Premo et al., 2014). In response to the issues of invasive species in the US, the federal government coordinates research and other activities through the National Invasive Species Council (NISC) and the Aquatic Nuisance Species Task (ANST) Force (ANST Force, 2015). In 2001, NISC wrote and revised a national management plan that describes strategies for the following categories: leadership and coordination, prevention, early detection/rapid response (EDRR), control and management, research, and research for federal agencies (USEPA, 2008). These categories were further used by the United States Environmental Protection Agency (USEPA) framework for state-level assessment of MIS management planning. It is important to note that that while there are similarities, there are also some significant differences between the Caribbean Regional Strategy and the USEPA Aquatic Invasive Species Management

Framework, particularly in the area of leadership, restoration, EDRR and prevention (see Table 1).

Table 1. List of management activities of Regional Strategy for the Control of Invasive Lionfish in the Wider Caribbean for the Lionfish and the USEPA Aquatic Invasive Species Management Framework.

Regional Strategy Activities for Control of Lionfish in the Wider Caribbean	**USEPA Aquatic Invasive Species Management Framework: Categories**
Collaboration	Leadership and Coordination
Research and monitoring	Prevention
Legislation (amendments), New regulations and policies (if necessary)	Early Detection/Rapid Response
Control	Control and Management
Education, information, and outreach	Restoration
	Research
	Information management
	Education and Public Awareness

3.2.1 Leadership and Coordination

Both the regional strategy for lionfish and the USEPA framework for AIS addresses coordination of various stakeholders such as government bodies, agencies with responsibility for managing MIS and fishers playing a key role in the management of marine invasive species within their borders. They've also indicated the need to build capacity and capability at state or regional and local levels to coordinate, detect, and respond to invasive species (National Invasive Species Council, 2001; USEPA, 2008; Gómez Lozano et al., 2013). Additional steps are also needed to ensure a unified, effective, and coordinated federal (governmental) response (USEPA, 2008). Such steps can be found in Box 1. Meanwhile, the regional strategy of the WCR describes prerequisite for success as managers having a good understanding of the lionfish issue across sectors, the existence of coordination and collaboration among affected communities, research institutions, government bodies, and technicians.

Box 1. Steps in response to ensuring unified, effective, and coordinated Federal response (NISC, 2001)

- Establish a transparent oversight mechanism for use by Federal agencies in complying with the Order and reporting on implementation.
- Ensure that a clearly defined process will be developed and procedures will be in place to resolve jurisdictional and other disputes regarding invasive species issues.
- Conduct an evaluation of current legal and regulatory authorities relevant to invasive species.
- Prepare an analysis of legal and policy barriers to coordinated and joint actions among Federal agencies.
- Identify at least two major invasive species issues, regulations, or policies where coordination is inadequate and take action that fixes the problem.
- Coordinate and provide to the Office of Management and Budget (OMB) a proposed cross-cut budget for Federal agency expenditures concerning invasive species.
- Convene a working group of agency leads on international agreements relevant to invasive species.
- Prepare a 2-year work plan identifying specific initiatives to work with state, local, and regional organizations.
- Prepare and issue guidance on invasive species for Federal agencies to use in
    - Implementing the National Environmental Policy Act (NEPA)

3.2.2 Prevention

The first line of defense is prevention. Often, the most cost-effective approach to combating invasive species is to keep them from becoming established in the first place. According to the NISC (2001), diverse tools and methods are needed to prevent invasive species from becoming established in ecosystems where they are not native. According to UNEP (2008), warming waters, altered hydrology, and nutrient level changes may affect the ability of certain aquarium species or bait fish to survive and become established in Wisconsin's waters. Incorporating these climate change considerations into prevention strategies may improve their success.

3.2.3 Early Detection/Rapid Response (EDRR)

EDRR refers to efforts that identify and control or eradicate new infestation before they reach severe levels (NISC, 2001; USEPA, 2008). Because even the most effective barriers to entry will at some point be breached, EDRR is an important element in preventing and controlling invasive species problems (USEPA, 2008). Comprehensive EDRR plans identify participating and lead agencies, potential regulatory requirements for control, and other EDRR protocols.

3.2.4 Control and Management

When invasive species appear to be permanently established, the most effective action may be to prevent their spread or lessen their impacts through control measures. Control and management of invasive species encompass diverse objectives such as eradication within an area, population suppression, limiting spread, and reducing effects (NISC, 2001). Complete eradication is not generally feasible for widespread invasive species (NISC, 2001; Gómez et. al., 2013). According to USEPA (2008), because control actions have local effects and cross jurisdictional borders, they are often carried out by or in cooperation with other countries and local and regional agencies. Adequate funding and public awareness are critical to success.

It is also essential to note that changing conditions, such as warmer waters, extreme weather events, salt water intrusion and/or changes in water chemistry may affect the success of "tried and true" control measures (USEPA, 2008). Henceforth it is critical to consider changing environmental factors.

3.2.5 Restoration

Plans should provide for restoration of native species and habitat conditions in ecosystems that have been invaded (USEPA, 2008). Without restoration, areas may become re-infested by the same or new invasive species (NISC. 2001; USEPA 2008). USEPA (2008) also mentions that restoration projects should include analyses of which native species may thrive in, or at least tolerate future climate-change conditions and avoid those species that may not be as well suited to future conditions.

3.2.6 Research

Research supports each aspect of the plan. Complementary research projects ranging from basic investigations with broad application to highly targeted applied efforts are required. Federal (or regional in the case of the Caribbean) research outcomes, where appropriate, should be transferred to states or, in the case of the WCR, to individual countries, local, tribal, and private sector stakeholders for their utilization. While the topic of monitoring is dealt as a separate section in the USEPA (2008) report, monitoring efforts will need to be adapted to ensure effective identification of potential new MIS. USEPA (2008) recommends collaborating with neighboring states to share monitoring data.

3.2.7 Information Management

The NISC (2001) and the USEPA (2008) describe Information Management (IM) as establishing a coordinated, up-to-date information-sharing system. Although there are many sources of information concerning invasive species, incompatible database formats and other factors impede information sharing. The long-term goal is to provide accessible, accurate, referenced, up-to-date, comprehensive, and comprehensible information on invasive species that will be useful at multiple jurisdictional levels, tribal, and governmental managers, scientists, policy-makers, teachers, students, and others (NISC, 2001). This statement goal can in fact be used to sum the current goal of the US framework and the Caribbean's strategy with regard to information management. In addition to data on species movement and establishment, information on ecosystem conditions for example water temperatures, chemical composition, and salinity levels, where applicable, should also be monitored and evaluated to fully assess invasive-species threats in the context of a changing climate (USEPA, 2008).

3.2.8 Education and Public Awareness

Many states conduct public awareness campaigns to inform the public, decision-makers, and other stakeholders about ways to prevent the introduction and spread of invasive species (USEPA, 2008). A wide variety of education, outreach, and training programs are needed. As noted by the NISC, the views of invasive species issues are molded by human values, decisions, and behaviors. Furthermore, the prevention and control of invasive species will require modifying behaviors, values, and beliefs and changing the way decisions are made regarding actions needed to address invasive species. USEPA also states that modifying outreach and education efforts to incorporate information about climate change effects on MIS and their management is another possible management response.

CHAPTER 4: DATA COLLECTION AND METHODS

The following chapter describes the methodology used to achieve the objectives of this research study. First the Drivers–Pressures–State–Impacts–Responses (DPSIR) framework was used for the WCR to connect the concepts and understand the interactions between issues surrounding the lionfish invasion and the management approaches. Second, the data collection method and analysis used for evaluating the management activities in individual countries of the WCR would also be captured in this chapter. A desk research and communication with relevant national informants were used throughout.

4.1 DPSIR Framework

DPSIR is a general framework for organizing and defining information about the state of the environment and the human uses of it. It guides the assessment from general concepts towards details and helps establish cause–effect relationships between interacting components of social, economic, and ecological systems based on data and indicators (Cranford et al., 2012; Benoît et al., 2013; MacLean et al., 2013). The framework also provides a communication tool for engaging a diverse group of participants in the management response process (Benoît et al., 2013). The DPSIR framework was tailored to the issue of the lionfish invasion in the WCR using primary source documents and secondary literature.

4.2 Country Management Plan Assessment

4.2.1 Data Collection Methods

The countries in this study were selected on the basis of the accessibility and availability of country plans during the first two weeks of the study period. It includes both those provided by relevant national informants (see Appendix A) and those available on the internet. Legitimacy of the plans available on the internet were either confirmed by national informants attached to the relevant institution or government department, or were assumed to be legitimate since they were found under established non-governmental organization including the Joint Nature Conservation Committee and the Gulf and Caribbean Fisheries Institute. National informants

also shared detailed information on some of the management practices that were lacking in the plan.

In total, eight (8) country plans (approved and working draft plans) (See Table 3 for names of plans) were studied including those of Anguilla, the Bahamas, Cayman Islands, Grenada, St. Eustatius, St. Lucia, St. Vincent and the US Virgin Islands (Figure 3). Several other Caribbean countries are currently developing a plan for lionfish, some for marine invasive species, and some general invasive species.

Figure 3: The Eight (8) Study Countries

4.2.2 Data Analysis

The analysis framework chosen to achieve the objectives of the study was the US Environmental Protection Agency (USEPA) Aquatic Invasive Species (AIS) Management Framework's assessment of state plans, which is a standard tool used in US states and territories (Premo et al., 2014).

First the management activities (also referred to as categories) for MIS as proposed by the US National Invasive Species council in 2001, were assessed in these plans. The categories included leadership and coordination, prevention, EDRR, restoration, research, information management, and education and public awareness. A Comparison Matrix was also used to

represent the results and illustrate the similarities and differences among management strategies as objectively and rigorously as possible.

The plan's rank in relation to others and their adaptive capacity for changing conditions were also assessed by determining the:

i. Potential impacts resulting from climate change

ii. Capacity to adapt goals and activities to changing conditions

iii. Provision of monitoring strategies

iv. Plans for periodic revision and update of the plan

v. Description of funding sources/strategies for plan implementation.

For each category a score from 0 to 3 was assigned. Table 2 shows the general scoring of each assessment.

Table 2. Scoring System (Information from USEPA, 2008)

Assessment in terms of plans accounting for a management activity	
Score	**Analysis**
0	no mention or evidence of the activity in question
1	implicitly mentioned
2	explicitly in passing
3	explicitly and specifies associated goals and/or action items
In terms of the plans considering climate change and/or changing environmental conditions	
0	Plan has no evidence of capacity to address a particular question or set of activities
1 – 3	There is some level (implicit, explicit in passing, explicit with goals) of capacity or potential for that state to incorporate and address information on and impacts from changing conditions, including climate change

4.3 Limitations

There are four main limitations which could affect the information and result of this report. First, although eight (8) countries from various parts of the Caribbean could give an appropriate representation of the region, the selected eight countries may not be representative of the management of lionfish of individual nations. Second, language considerations were also a factor in selecting countries, due to a lack of access to resources for translation. The final list notably excludes any countries that did not have its information in English. The final list also did not incorporate any continental Caribbean countries, which given their particular political and civil society cultures is important to consider in framing any generalizations that might be drawn

from the findings. Third, the appropriateness of the USEPA assessment can perhaps also be called to question as the geography and management cultures of the US and Caribbean region are different. Lastly, it is difficult to state whether these plans were influenced, developed or updated on the basis of the Regional Strategy for the Control of Invasive Lionfish in the Wider Caribbean. None of the plans acknowledged this. Moreover some plans were prepared prior to the regional strategy and some have not been updated since (see Table 3).

Table 3. Lionfish management plan status, year published and update information

Management Plan Name	**Status**	**Year Published**
Lionfish Response Plan, Anguilla BWI	Approved	N.D, Updated*
National Lionfish Response Plan, Bahamas	Approved	2009
Cayman Islands National Biodiversity Action Plan 2009 3.M.2.4 Marine Species - Fish Invasive Red Lionfish	Draft	2009, Updated*
Grenada Lionfish Action Plan: Implementation of a Lionfish Management and Control Program in Grenada	Approved	2015
St. Eustatius National Marine Park Lionfish Response Plan	Approved	2009
Saint Lucia Lionfish Response and Action Plan-First Working Draft	Draft	2016
St. Vincent and the Grenadines Lionfish Response Plan	Approved	N.D
Lionfish Response Management Plan, US Virgin Islands	Approved	2009, Updated in 2014

*Country produced a lionfish response strategy workshop report published under Joint Nature Conservation Committee (JNCC) in 2013

CHAPTER 5 - RESULTS & SUMMARY OF FINDINGS

This chapter explains the results of the DPSIR framework with relation to the lionfish invasion as well as the results for the assessment of country management plans for the lionfish.

5.1 DPSIR framework: Connecting the Concepts

The DPSIR system (framework) states that economic and social development, which are driving forces (D), exert pressure (P) on the environment, and as a result, the state (S) of the environment changes, such as depletion of natural resources, a decrease in biodiversity and degradation of environmental quality (Mateus and Campuzano, 2008). These changes then have impacts (I) on the ecosystems or human health for example and due to these impacts, society responds (R) to the driving forces, or directly to the pressure, state or impacts through preventive, adaptive or curative measures. In Figure 4, the framework for understanding MIS management in the context of the lionfish is summarized.

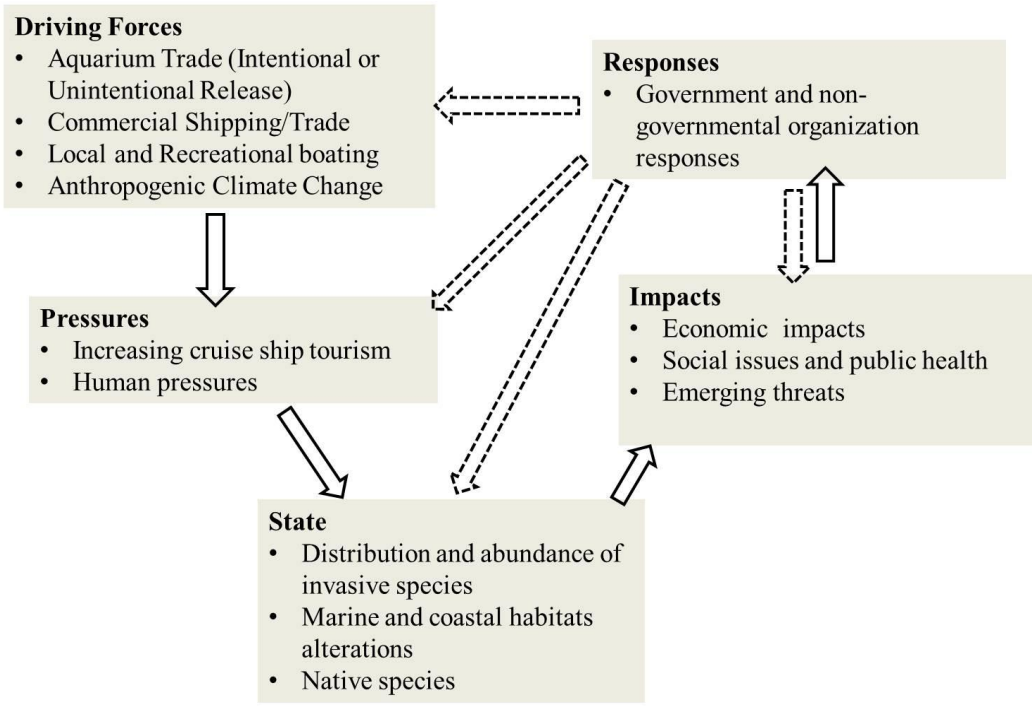

Figure 4. Driving forces, pressures, state, impacts and responses (DPSIR) framework for indo-pacific lionfish in the WCR.

5.1.1 *Driving Forces and Pressures*

Based on the above analysis, aquarium trade, trade and commercial shipping, recreational boating and climate change are driving forces. As previously discussed, the exact cause of the lionfish introduction has not been determined, but researchers speculated that lionfish were introduced to the Atlantic during Hurricane Andrew in 1992, when several were accidentally released from hotel aquaria in Florida during inundations (Estrella et al., 2010). Ship based vectors such as commercial shipping is considered to be one of the most significant vectors of introductions and spread for marine invasive species through ballast water (MacLean et al., 2013). Within the Caribbean, more than ninety percent (90%) of the goods traded at the international level are transported by sea. This growing intensity of trade has brought about changes both in maritime transport and port infrastructure; and as the shipping industry changes, so too must the region's response to it. The WCR is also one of the world's leading cruise destinations (Hilaire, 2007). This mode of transport and its supply chain plays a key role in the participation of the countries of the Caribbean in an increasingly global economy (Gallegos, 2009). Local shipping and recreational boating are also considered drivers. The pressures in this scenario would include the increases in cruise ship tourism and general human pressures.

Other drivers include anthropogenic climate change and oceanographic conditions. Oceanographic transport of non-indigenous species is more likely to occur and spread easily at the regional than at the global scale. Ocean currents and storms helped lionfish spread from Florida's Atlantic coast to the Bahamas, throughout the Caribbean Sea and into the Gulf of Mexico. For example Johnston (2015) showed that hurricanes accelerated the Florida–Bahamas lionfish invasion spanning the years 2000-2007. The previously mentioned driving forces and pressures influence the status, trend, distribution and abundance of species, as well as the cost incurred in control and management of the lionfish, in this instance. At the same time, global warming may reduce or eliminate oceanic temperature barriers to dispersal or alter relative competitive abilities of native species (Moe et al., 2013).

5.1.2 State, Impacts and Responses

The DPSIR framework also illustrates how the changing state of the environment can lead to impact on human health, ecosystems, and materials. This may elicit societal or government responses that feedback on all other elements of the DPSIR framework. One major

response activity planned involved education and awareness raising programs. The status and impacts of the lionfish were discussed in detail in Sections 2.4 and 2.5. To summarize, the lionfish populations continue to increase in abundance and range and some of the major impacts include negative consequences on the tourism and fisheries industries, risks of reef health declines and societal implications from law amendments for spearfishing and health related issues like lionfish envenomation.

Using the DPSIR framework (Figure 4), the responses generally target the impacts, pressures, states and/or driving forces. For example the creation of a regional strategy for the control of lionfish and local management planning are responses in particular to the states and impacts of the lionfish. In the management plans, most educational program goals have common themes including to increase public awareness on identifying the lionfish, how to properly capture, understanding its negative impacts, what to do if stung and promoting lionfish consumption (to help reduce population, lift pressures of valuable native marine species competing with the lionfish). Indirectly, these plans also increase community awareness as to the value of the ocean and build community support and aids development of a network of partners, in working with community groups, nongovernmental organizations (NGOs), and other stakeholders.

Moreover, several NGOs and nonprofits, such as Toledo Institute for Development and Environment, are now taking a market-based approach to battle the poverty in Belize, and also help with the coral reef conservation efforts. In addition to encouraging people to target the lionfish for food, a new social movement is teaching women how to use the tails of the lionfish to create jewelry. The tail of the lionfish is considered waste among fishermen, as it is not edible. By using the tails of the lionfish for jewelry, each lionfish caught then gains 40 percent more monetary value (Voncannon, 2015).

The indicator summary found in Table 4 identifies indicators relevant to the theme of this research and exemplifies existing management issues. The main goal of establishing indicators is to measure, monitor and report on progress towards sustainability (MacLean et al., 2013). A set of indicators should be broad enough to present a comprehensive picture of the environmental quality, yet be few enough to be easily understood by managers, decision makers, and the public (MacLean et al., 2013). Adapting the approach of MacLean et al. (2013), the table identifies the category of each indicator (driving force, pressure, state, impact or response) and provides an

assessment or status of the indicator in terms of current impacts on the environment (good, fair, poor or unknown). The general trend of the indicator, in terms of future implications for the state of the environment, is also shown. Categories are improving, worsening, no trend or unknown. According to the authors, improving meant that the general trend should result in improvements in the state of the environment. This means that the assessment in the future is likely to improve, such as from poor to fair or from fair to good. Worsening meant that the general trend is towards a further decline in the state of the environment, such as from fair to poor. No trend meant that there is not a positive or negative trend. Unknown meant that it is not clear if the trend will result in a decline or improvement in the state of the environment, or there is not enough data to see a clear trend.

Table 4. Indicators and information linking DPSIR elements for lionfish invasion in the Caribbean

Management Issue	Indicator	DPSIR	Assessment	Trend
Increase in regional vectors and habitat pressures (i.e., aquarium trade, ballast, habitat modification, climate change)	Distribution and spread of lionfish	Driving force, pressure	Good	-
Change in availability of fisheries resources	Effects of lionfish invasion on Ecosystems, Habitats and Biota: Shifts in species distribution	Impact	Fair	-
Public health, environmental protection and regulation	Increase in likelihood of human injuries due to increasing population	Impact	Good	?
Investment in lionfish management programs and education	Costs incurred or spent on invasive species awareness	State	Good	/
Investment in promotion of lionfish use and consumption	Use of lionfish: diet & jewelry	Response	Fair	+
The development of response and management plans	The lionfish plans and projects	Response	Good	+

Box 2: Key to Table 4: Trend	
Description	Symbol
Negative trend	-
Positive trend	+
Unclear or neutral trend	/
No assessment due to lack of data	?

5.2 Results using USEPA AIS Assessment Framework

The results of the analysis are presented in Table 5 and Figure 5. It highlights the assessment results from the scoring of the management plans for each of the eight countries and the identification of similarities and differences among the plans respectively. First, it was important to determine if each management plan accounted for the management categories (or activities) as stated by the NISC and USEPA AIS management plan assessment. Common grounds and objectives for strengthening cooperation and collaboration among the countries were then derived.

Most plans with the exception of USVI do not specify any form of prevention. There are two other types of prevention since preventing more lionfish from entering into territorial waters is not an option. First, there is the option of preventing increased growth. The second option is preventing the negative effects which include significant decreases in native species that are economically and ecologically viable or endangerment to public health and safety. Though both types of prevention could be related, the second type was the general aim of each plan. However, these forms of prevention fall within the context of control and restoration, thus there is some discrepancies. Only the USVI plan clearly acknowledged the prevention of increasing populations in specific monitoring sites.

Early detection and rapid response (EDRR) seems to be non-existent or hardly acknowledged in the eight (8) country plans. The plans that implicitly mentioned EDRR include Grenada, St. Vincent, St. Eustatius and USVI. While Grenada, St. Eustatius and USVI mainly addressed rapid response and removal as it relates to the lionfish, only St. Vincent additionally included the need for EDRR for potentially new introductions of like invasive species.

The results table revealed that each country plan did not account for restoration. This is not a surprise as most Caribbean countries do not know the status of their marine ecosystem, nor do they know what fraction or direct negative impacts upon marine biodiversity is due solely to the lionfish (Miloslavich et al. 2010). According to these authors, despite a long history of scientific research in the region, the present knowledge about Caribbean marine biodiversity and species distribution does not satisfy the needs for objectively defining geographic conservation priorities and designing management plans at a regional scale. This is one of the reasons why conservation planners often make use of surrogates of species diversity (e.g., presence of habitats, bottom topography and wave exposure) to offset uncertainty and lack of detailed

information. This has been the case in various recent attempts to determine the relative importance of sites for conservation in the Caribbean (Miloslavich et al., 2010). Overall, each plan had some level of activities as it relates to management and control, and education and awareness. Each plan also had some evidence of organization with regards to leadership and coordination.

Table 5: Plan accounts for the following management activities as stated in the USEPA Guidelines for AIS.									
COUNTRY	**Leadership & Coordination**	**Prevention**	**EDRR**	**Control & Management**	**Restoration**	**Research**	**Information Management**	**Education & Awareness**	**Total**
Anguilla	1	0	0	1	0	1	1	2	**5**
Bahamas	2	0	0	2	0	2	3	3	**12**
Cayman Islands	3	0	0	3	0	3	1	3	**13**
Grenada	3	0	1	2	0	0	1	3	**10**
St. Eustatius	2	0	1	2	0	2	2	3	**12**
St. Lucia	2	0	0	1	0	1	1	3	**8**
St. Vincent	1	0	1	2	0	3	1	2	**10**
USVI	3	3	1	2	0	3	2	3	**17**
Scoring: 0= no; 1=implicitly (i.e. includes goals and strategies that can be used to account for the activities); 2= yes, explicitly in passing; 3= yes, explicitly and specifies associated goals and/or action items									

The data included in Table 5 was used to create a visual illustration of the similarities and differences in the level of management planning activities (see Figure 5). In Figure 5, the red boxes mean that one of the plans has no mention of activities versus the other having some level of the activity planned. Blue boxes mean that activities are at similar stages (whether they received a score of one, two or three), thus they are a complete match in terms of commonalties in activities planned. Green boxes indicate that plans have some level of the activity in subject mentioned, however are at various stages; and yellow boxes mean there is no action and plans are at that similar stage of non-activity. There are comparatively more green boxes than the other colors. This indicates that across the countries planning and expected outcomes for management of the lionfish were not consistent. However it also suggests that there is some level of that activity included and that improvements can be adapted easily, compared to countries that completely lack the activity in planning. Therefore, despite the lack of similarities in some areas, there are some that prove to have potential for strengthening their goals, activities, and expected outcomes.

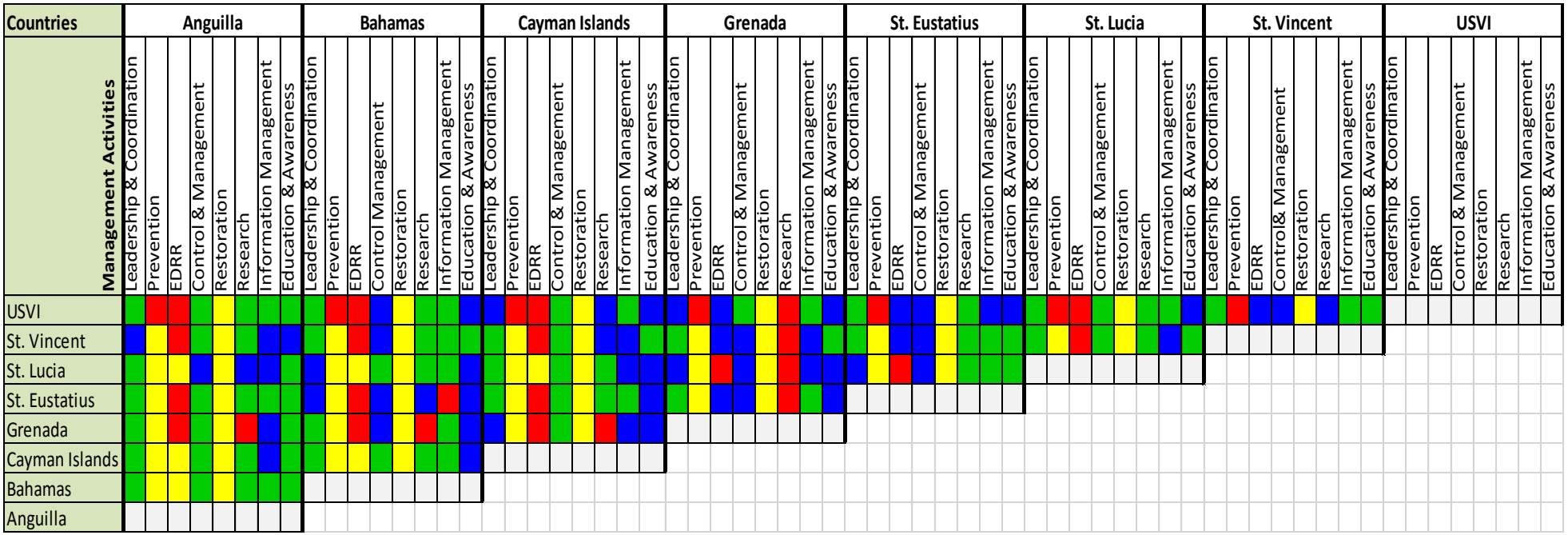

Figure 5: Comparison Matrix: illustrating the level of each country's commonality related to the management activities set for the invasive lionfish. **Red boxes- No Match (no activity vs. brief and upward); blue boxes-Complete Match (at similar stage); green boxes- At different stages; yellow boxes- No Action- Similar "0" Stage; gray boxes- Not applicable**

The results provided in Tables 6 to 10 illustrate each country's plan with respect to how well it: (1) demonstrates capacity to adapt goals and activities to changing conditions, (2) addresses potential impacts resulting from climate change, (3) provides monitoring strategies, (4) includes plans for periodic revision and update of the plan, and (5) describes funding sources/strategies for plan implementation.

While most country plans do not mention climate change or changing conditions, the assessment reveals that countries have some capacity to adapt their program or activities (Table 6). An assessment of the capacity of each country's plan to adapt its goals and activities related to management activities to changing conditions is shown in Table 6. Each category has some level of changing conditions to consider. For example, leaders and coordinating bodies in MIS related projects should be aware of changing conditions as it relates to sensitive reef ecosystems, species of conservation concerns to name a few. According to USEPA (2008), this enables managers and decision-makers to experience less difficulty in addressing potential program vulnerabilities to climate change. The results illustrate that countries that scored high in their planned management activities for lionfish such as the USVI (Table 5), scored considerably lower in this assessment moving from a score of 17 to 8, and Cayman Islands, moved from 13 to 3. Evidently there is a clear need to consider changing conditions within these activities.

Table 6. Country assessment relating to capacity of planned activities to adapt to changing conditions									
	Plan accounts for changing conditions in its goals and strategies for…								
COUNTRY	**Leadership & Coordination**	**Prevention**	**EDRR**	**Control & Management**	**Restoration**	**Research**	**Information Management**	**Education & Awareness**	**Total**
Anguilla	0	0	0	1	0	1	0	1	**3**
Bahamas	1	0	0	3	0	1	1	1	**7**
Cayman Islands	0	0	0	1	0	0	1	1	**3**
Grenada	1	0	1	1	0	0	0	1	**4**
St. Eustatius	1	1	1	2	0	1	1	1	**8**
St. Lucia	0	0	0	0	0	1	1	1	**3**
St. Vincent	0	0	1	2	0	1	1	1	**6**
USVI	1	1	1	1	0	1	1	2	**8**
Scoring: 0= no; 1=implicitly (i.e. includes goals and strategies that can be used to account for changing conditions but does not specify changing conditions as part of their purpose); 2= yes, explicitly in passing; 3= yes, explicitly and specifies associated goals and/or action items									

The results of Table 7 illustrate the level in which each plan incorporates potential impacts resulting from climate change. Out of a possible score of 12, only one of the eight countries scored half- Anguilla. According to the USEPA (2008), this indicates that the majority of country plans have management actions that if conducted under different environmental conditions, may prove less relevant, less efficient, or less successful than they are under current conditions. It is important to build in considerations of changing conditions into a country's management actions. Furthermore, there is a clear need for some countries more than others to acknowledge climate change data in their plans. Cayman Islands and St. Lucia for example are two countries which scored nil in three out of the four categories in this assessment.

Table 7. Country assessment relating to the incorporation of potential impacts resulting from climate change.

COUNTRY	Plan specifically mentions climate change	Plan acknowledges climatic boundaries of species (zones)	Plan demonstrates understanding of species and/or ecosystem sensitivity to changing conditions	Plan identifies research on the potential effects of species responding to changing conditions	Total
Anguilla	1	2	2	1	6
Bahamas	0	2	1	1	5
Cayman Islands	0	2	0	0	2
Grenada	1	2	2	0	5
St. Lucia	0	1	0	0	1
St. Eustatius	0	2	1	2	5
St. Vincent	0	1	1	1	4
USVI	0	2	2	0	4

Scoring: 0= no; 1= briefly mentions; 2= includes general discussion; 3= includes quantitative into and/or specific examples

Note: The USEPA AIS plan assessment also has a column for 'acknowledgment of regional differences in expected climate change,' however it was removed for this assessment because of the similarities of conditions in the insular Caribbean.

As it relates to monitoring strategies (Table 8), seven of the eight countries with the exception of Anguilla have clear strategies for using the data. Six of the eight countries, excepting Anguilla and Grenada cater for managing and updating monitoring data. Thus overall, 81% of the country plans included brief statements for using, managing and updating information. Monitoring objectives were largely proposed for number of caught lionfish and key native fish species populations. The USVI plan received the highest ranking with a score of five of a total of nine potential points. The objectives of the USVI updated plan involved a collaboration of research and monitoring, data gathering and analysis to improve understanding of lionfish impacts, effectiveness of removal and examining the local and regional scientific research with observational data and by concentrating the collection of removal and sighting data into one shared database (Kilgo, 2014). According to the USEPA (2008), these results indicate a high capacity to modify activities associated with monitoring to include information on climate change effects. As seen in the same table, climate change incorporation into monitoring is lacking in seven out of the eight countries excepting USVI.

Table 8. Country assessment relating to monitoring strategies

COUNTRY	Plan includes strategy for changing conditions	Plan includes strategy to utilize monitoring data	Plan includes strategy for managing/updating monitoring data	Total
Anguilla	0	0	0	**0**
Bahamas	0	1	1	**2**
Cayman Islands	0	1	3	**4**
Grenada	0	1	0	**1**
St. Eustatius	0	1	1	**2**
St. Lucia	0	1	1	**2**
St. Vincent	0	1	1	**3**
USVI	1	1	3	**5**

Scoring: 0= no; 1=yes, briefly mentions; 2= yes, but unclear how information will be used; 3= yes, and specifies associated goals and/or action items

Seven of the eight country plans excepting Grenada implicitly included periodic revisions and updating information (Table 9). Thus, these countries recognize the need to include new information and update goals and activities.

According to USEPA (2008), the identification of funding indicates an overall high capacity for states to accomplish tasks in management plans. Six of the eight country plans have some level of funding stated or a strategy to acquire funding, excluding St. Eustatius and St. Vincent (Table 10). Perhaps at the time of developing the plans, neither funding nor a plan for funding was established, or it was not a requirement for these two countries.

Table 9. Country assessment relating to periodic revision and update

COUNTRY	Plan includes strategy for updating and incorporating new information
Anguilla	1
Bahamas	1
Cayman Islands	1
Grenada	0
St. Eustatius	1
St. Lucia	1
St. Vincent	1
USVI	1

Scoring: 0= no; 1=yes, in passing; 2= yes, and includes qualitative description;; 3= yes, and includes timeline and/or benchmarks for doing so

Table 10. Country assessment relating to funding sources/strategies for plan implementation

COUNTRY	Score
Anguilla	3
Bahamas	2
Cayman Islands	1
Grenada	3
St. Eustatius	0
St. Lucia	3
St. Vincent	0
USVI	2

Scoring: 0= no; 1= a source is specified for a partition of the required funding; 2= a source is specified for a portion of the required funding along with strategies for obtaining remaining funding; 3= a source is specified for 100%

The scores from table six to ten are accumulated in Table 11. The best possible score is 54 and none of the countries scored half. This is an indication that there is a need for improving the plans by revisiting weak areas and incorporating climate and/or changing conditions. Nonetheless, USVI, score is the highest, likely because it is a US territory and is being guided by the NISC.

Table 11. Total score and ranking for 8 countries' management plan with consideration of climate change. Possible total score is 51

COUNTRY	Capacity to adapt to changing conditions	Understanding and incorporating potential impacts resulting from climate change	Monitoring Strategies	Strategy for updating an incorporating new information	Dedicated funding source or strategies for implementation	Score	Rank among 8 countries
Anguilla	2	6	0	1	3	12	6th
Bahamas	7	5	4	1	2	19	2nd
Cayman Islands	3	2	4	1	1	11	7th
Grenada	4	5	1	0	3	13	5th
St. Eustatius	8	5	4	1	0	18	3rd
St. Lucia	3	1	2	1	3	10	8th
St. Vincent	6	4	3	1	0	14	4th
USVI	8	4	5	1	2	20	1st

CHAPTER 6 - DISCUSSION AND RECOMMENDATIONS

Chapter six discusses three crucial outcomes derived from the results including a discussion on the overall management of MIS in WCR, gaps and opportunities in state plan activities for lionfish and other suggestions for future planning and orientation.

6.1 Management of Marine Invasive Species in the WCR and in this Changing Climate

Marine invasive species (MIS) and their potential damage to WCR coastal and marine ecosystems pose a multi-faceted problem and the solutions are not simple. Globally, there are no quick fixes for the environmental, economic and social damage done by MIS (DFO, 2004). Importantly, many of the strategies required to deal with the threat of MIS, call for action within a specific pathway or with respect to a single species (DFO, 2004). This is encouraging to managers since the lionfish plans are specific to its species. Furthermore, invasive species can be characterized as a "wicked problem" meaning there is not a definitive solution for eradicating all invasive species, each problem (invasive species) is unique, and there is no single formulation or set mechanism to combat all species (Jentoft and Chuenpagdee, 2009). The authors describe "wicked problems" as ones that are often difficult or impossible to solve.

The situation is complex and in the case of the lionfish, the scope of the problem, combined with the fact that it will continue to grow if left unchecked in certain areas leaves no doubt that immediate steps must be taken. The consequences of the lionfish are often wide-spread and can negatively affect the environment, trade, shipping, recreational use of waterways, fishing, resource management, and human health, and in some cases, some of these consequences have already been reported. Thus, the task of resolving lionfish problems are complicated and the solutions would involve trade-offs. For example, allowing the species to spread may irreversibly alter the ecosystem, thereby threatening fishing, recreation, and hospitality industries. However, efforts to control the population via increased culling may pose increased human injuries, placing increased pressure on health services for lionfish stings and envenomation. Management strategies must provide a thorough analysis of the potential risks and benefits of specific actions in order to balance environmental and socio-economic interests.

Focused efforts on the management of MIS are a relatively recent phenomenon in the WCR. In contrast with terrestrial invasions, government and other agents have been slow to recognize marine introductions as an issue, primarily due to a lack of information and demonstrable impacts to human health, ecosystems, and economies (Hewitt, Everett and Parker, 2009). Also, where coastal areas and oceans are shared between countries, maritime boundary disputers and management remain a major challenge to the conservation of marine ecosystems (DFO, 2004). Lack of collaboration between states often produces harmful consequences to coastal water biodiversity and thus to human activities, vital human needs, and livelihoods (Brels, Coates and Loures 2008). It is evident that marine biodiversity conservation has become a growing concern with the introduction of the lionfish. Its importance for preservation of healthy ecosystems has been increasingly recognized as crucial for the future (McKinnon et al., 2014).

The DPSIR framework identified the main drivers of the issues resulting in the spread of the lionfish One driver, the aquarium trade via unintentional or intentional release is challenged by unsustainable practices and lack of monitoring, effective regulation and legislation to govern the trade (Dee, Horii and Thornhill, 2014). Marine transportation and associated ballast water management relies heavily on enforcement activities (e.g., budgets for enforcement of saltwater flushing), which is a challenge for most countries. Under the current enforcement regime, the risk of MIS introductions via ballast water is likely low, and enforcement actions are subject to political commitment and capacity. As it relates to climate change and MIS, interactions are complex, however climate change is known to drive or dramatically increase invasive species (Burgiel and Muir, 2010). Climate change impacts, such as warming atmospheric temperatures, ocean warming and sea level rise are likely to increase opportunities for invasive species because of their adaptability to disturbance and to a broader range of biogeographic conditions and environmental controls. The impacts of those invasive species may be more severe as they increase both in numbers and extent, and as they compete for diminishing resources (Burgiel and Muir, 2010). In terms of the lionfish, changes in water temperature for example, can make conditions more favorable for lionfish and potentially future marine finfish introductions while at the same time suppressing native species or causing them to move into temperate oceans (Figueira and Booth, 2010).

Few plans in the WCR incorporate climate change or the resultant change of environmental conditions and this is a cause for concern. Because species' abilities to spread are affected in part by climate, action plans particularly the regional strategy, should incorporate projected changes in ocean temperatures for instance. In recent years, both environment and fisheries sectors are becoming increasingly aware that climate change consideration is crucial for long-term sustainability of ecosystem services. According to the USEPA (2008), incorporating climate-change information when planning and implementing prevention, control, and eradication activities will also help to maintain the manager's ability to successfully carry out these activities. Adopting an adaptive management framework for MIS management practices will allow states to be better equipped to prevent and control MIS invasions under changing conditions and will also maximize the effectiveness and efficiency of each dollar spent by the country on such activities (USEPA, 2008).

According to NISC (2001), plans should reflect the need to build capacity and capability at regional (in the context of the Caribbean) and local levels to coordinate, detect, and respond to invasive species. It is important to note that some conflicts may arise in the process of plan implementation at the local level even for plans whose objectives are synergistic with other countries. Regional plans generally serve to coordinate activities among states and their MIS management plans, while state plans outline more specific activities. Existing MIS related plans in the Caribbean are actually in various stages of both development and implementation, and some countries operate a multitude of MIS management activities and programs in the absence of a plan as well. The existing plans discussed in this research however, can provide a guideline as to the gaps and opportunities when it comes to evaluating the management activities for marine invasive species like the lionfish.

6.2 Gaps and Opportunities

One of the objectives of this project was to identify gaps and opportunities for improving country management activities as well as coordination of activities by stakeholders in WCR who are working to manage the threats of the lionfish. This section will elaborate further on the chief gaps and opportunities identified within the management activities of localized planning for the lionfish.

6.2.1 Leadership and Coordination

The results indicated that each plan had some evidence of organization with regards to leadership and coordination however some countries were better than others (Table 5). Country plans which scored low (see Table 5) including Anguilla's and St. Vincent's in leadership and coordination lacked a responsible entity and coordinated system for management actions. As MIS response approach in the WCR is largely inter-governmental (Gómez Lozano, 2013), inter-sectoral commitment from numerous departments and agencies across all levels of government as well as other stakeholders is required (DFO, 2004). The participation of all Caribbean people is necessary to deal with the threats to the Caribbean's marine biodiversity and economy from invasive species. Governments and relevant regional bodies need to be committed to providing the necessary leadership and formulate or enhance solutions to the lionfish threat and potential future threats. This plan cannot succeed without the full participation of the private sector and other affected actors such as those involved in tourism, NGOs, the general public and tribal groups. All stakeholders can contribute valuable resources that will help control MIS. In researching the plans, some of the chief stakeholders mentioned included government, tourism authorities, dive companies, environmental related NGOs, food fish retailers, scientists and academics. However there is a larger group of people that can be acknowledged or integrated into the plans such as the shipping industry, harbour and port authorities.

A major constraint for actions to improve is a reporting entity. The reality of Caribbean ocean governance is a diversity of networks of actors serving various purposes that seldom intersect effectively, but with the potential to do so if greater attention is paid to networking (Fanning, Mahon and McConney, 2011). Furthermore, according to Mahon et al. (2014), there is no functioning body providing the overarching policy integrating and coordinating role for oceans affairs in the WCR. The authors further state that in developing an operational response to these identified needs for effective ocean governance in the WCR, it is therefore critical to identify an organization that has the potential to play this role in the region and to determine what must be done in order for it to take up the role. This should be remembered in management of lionfish and overall MIS.

6.2.2 Prevention

According to Olson and Roy (2005), prevention is extraordinarily expensive to implement. In addition, a preventative approach typically places constraints on the import and/or transport of commodities and services that are beneficial, thereby making it a politically contentious solution (Olson and Roy, 2005). Prevention is also very complex for the WCR as in some cases the introduction of new species could be originating from Florida, which is a known hotspot for marine fish introductions. Schofield (2010) stated that nearly 40 species of nonnative fishes have been seen in Florida waters in the last two decades. Florida needs to improve its regulations surrounding marine introductions. Since it has been established that prevention cannot be a goal in the case of the lionfish, alternative goals have been set including the preventing of lionfish population growth as well as the prevention of loss of native species, which are key expected outcomes of control activities. Thus control goals need to abate harmful ecological, economic, social, and public health impacts resulting from the lionfish invasion.

6.2.3 EDRR

Fifty percent (50%) of the country plans (Anguilla, Bahamas, Cayman Islands and St. Lucia) did not include any activities for EDRR nor did they mention a need for it. An integrated approach involving research and development, technical assistance, and operations is needed to facilitate and implement effective action. Unfortunately, inadequate planning, jurisdictional issues, insufficient resources and authorities, limited technology, and other factors often hamper early detection and rapid response in many locations (Waugh, 2009). There was also no mention in the regional strategy that a comprehensive regional system was in place for detecting and responding to incipient invasions. Moreover, given the enormous number of known MIS and the unknown number of MIS yet to emerge, rapid evaluation schemes to prioritize responses are crucial (Early et al., 2016).

6.2.4 Control and Management

Control implies that populations of the lionfish are at levels where they can be managed. Anguilla's and St. Lucia's management plans lacked information on the needs and goals for

controlling and managing the lionfish. According to Tahoe Regional Planning Agency (TRPA) (2014), which is guided by the NISC, factors to consider when evaluating the feasibility of control include size of infestation, demonstrated history of successful control elsewhere, knowledge of species life history, potential environmental impact, financial support for initial and follow-up management, likelihood of reintroduction, public comment, current policy restriction, well-coordinated efforts and the availability of approved control tools. These all serve to increase the likelihood of a successful eradication. However, this likelihood decreases substantially as the population spreads and becomes more abundant. Some of these factors, particularly knowledge of species life history, potential environmental impact, control tools, related policy restrictions, have been mentioned in the plans or are already being practiced in the WCR.

The WCR control techniques such as culling are proposed to be effective, economical, safe, and targeted to an individual MIS-the lionfish. Control in this case implies that populations of various MIS are declining or are at levels where they can be managed. However lionfish populations are currently increasing. According to ANST Force (2015), lionfish are also achieving high population densities, reaching well over 400 lionfish per hectare and becoming one of the most abundant species on some reefs. This can be a result of some countries lacking management. Other ways to improve the control status include using existing resources and coming up with new ideas to expand the opportunities to share information, technologies, and technical capacity with other countries.

6.2.5 Restoration

Both Canada and the US frameworks for addressing MIS advocate restoration. Any management activities intended to eliminate invasive species must include a restoration component (DFO, 2004). A damaged ecosystem will not always be able to regenerate itself to its previous state and is more susceptible to subsequent invasion (DFO, 2004). This may involve taking an active approach in terms of encouraging native species to thrive, perhaps by targeting the fishing communities to have less pressure on the commonly fished stocks that are in decline, for example the parrot fish (a reef fish of ecological importance) (Perry et al., 2013), which is a favorite of the WCR. The healthier an ecosystem is, the more capable it is of resisting invasions.

6.2.6 Research

The scores for research in management plans for the lionfish within the WCR fluctuated among the countries and this is due to little recognition that research and monitoring needs to be continued during the management phase. Research is usually included in the creation of management and response plans. Frequent research and scientific information utilized by these plans include lionfish life history, environmental thresholds, and interactions with native species, all of which are critical components to MIS management framework according to ANST Force (2015). This information allows for more effective and efficient management and results in reduced impacts to desirable species, but only if it influences decision making. Current research efforts in the Cayman Island and USVI include evaluating the effectiveness of physical removal methods such as diver-assisted sanction and monitoring lionfish distribution. Additionally, departments in the US engaged in invasive species prevention and control activities have developed a variety of databases and decision support tools to increase predictive capacity for preventing introduction of new invasive species and to improve control efforts (NISC, 2001). Caribbean countries should consider adopting a similar approach. Each plan should support research, applied research projects and research that includes social sciences.

6.2.7 Information Management

Only the Bahamas scored high for the category of information management. The Bahamas for instance gives in length their arrangements for managing and use of information and the details of stakeholders involved. While the USVI and St. Eustatius were also detailed in the information management component, a lower ranking was assigned as their plans were not as thorough as the plan for the Bahamas. However, mention must be given to the USVI's Caribbean Oceanic Restoration and Education Foundation (CORE) monitoring system or as they call it, the "lionfish response hotlines." CORE is a universal removal and sightings reporting form and website for communication and should be used by associated partners. CORE developed an online lionfish sighting and removals reporting form and map that can be used to help track control efforts (Kilgo, 2014). The data can be used to guide control activities to prevent duplication of effort and ensure that popular dives sites or priority areas are targeted every few months for removal. It also serves as a way to monitor lionfish populations and the data collected can be used by researchers and managers to guide more directed and strategic actions (Kilgo,

2014). For managers that are considering introducing or developing information management systems as stated in some of the country plans, it is not too late to consider the USEPA (2008) suggestion for countries in the WCR to develop an information management system that will support rapid and accurate discovery of data, correlate and synthesize data from many sources, and present results of data synthesis that meets the needs of users. This can be a possible role for the Caribbean Large Marine Ecosystem (CLME) Project. The CLME Project assists participating countries from the Wider Caribbean Region to improve the management of their shared living marine resources, and in recent development of the CLME integrated Information Management System (IMS) tool, project managers and coordinators should consider these important topics.

6.2.8 Education and Public Awareness

The results for education and public awareness revealed that 75% of the Caribbean countries analyzed in this study have strong educational and awareness strategies. Most educational program goals have common themes which are to increase public awareness on identifying the lionfish, how to properly capture, understanding its negative impacts, what to do if stung and promoting lionfish consumption. The management plans also captured similar campaign slogans including but not limited to "Save our reefs, eat lionfish," "Eat it to Beat it," "Feast on the Beast" and many more. Programs to educate the public about the impacts of MIS, methods to prevent introduction and further spread in the region, and control efforts are actively underway by several organizations as well. Most plans though, (87.5%) lack the capacity to adapt their goals and activities to changing climatic conditions within their educational and awareness programs.

It was observed as well, that although plans addressed regional coordination in general, there were no common goals or specific collaborative activities identified. For example, according to Carballo-Cárdenas (2015), some countries managers are beginning to advocate for commercializing lionfish which would require a sustainable population of lionfish. While others countries are still striving for a declining population. If the goal of the WCR remains to control or reduce lionfish population, this encourages fishers for instance to overfish them and one suggestion to ensuring that countries are working together is to start collaborating on activities, such as hosting an inter-regional (country against country) derbies. Having a common goal is a

key point which managers and policy makers should be aware off. Countries' responses can undermine another, if not consistent with each other.

Overall, country managers and relevant governmental bodies need to be consistent with their educational awareness goals. If country managers, relevant government bodies and other stakeholders work along and cooperate with neighboring countries, this can prove to have positive consequences. They can pool together resources, share and access ideas and establish new and mutual collaborations and networks.

Another opportunity is the incorporation of climate-change information into education and awareness activities, which is important for every country program with MIS responsibility (USEPA, 2008). This is especially needed so that government and society at large can be aware of potential future impacts if proper management is not made a priority.

Related to the broader scope of the study, another suggestion could be conducting public surveys of attitudes and understanding, as it relates to invasive species issues and host a series of regional or maybe international workshops on MIS in different regions specifically for policy makers.

6.3 Suggestions for Future Planning and Orientation

This section addresses recommendations as it relates to plan adaptation by looking into adaptive management, monitoring strategies, discussing potential in periodic revisions and updates and the importance of funding sources and strategies for implementing management plans. Within each of these subjects, it also suggests possible ways of implementation, by whom and describes foreseen challenges. While fisheries or resource managers are likely to be charged with implementing plans and subsequent projects and activities related to lionfish control, there are other resources to capitalize on. According to Morris (2012), working in partnership with resource users, stakeholders, nongovernmental organizations, and neighboring countries, managers can add significant capacity to control efforts. He also stated that many partners are eager to assist and can enhance and broaden government-led programs. Thus by collaborating, programs not only increase removal efforts, but valuable partnerships that could benefit other programs and issues can be formed. Effective partnership requires dedicated coordination and communication (DFO, 2004). The following suggestions could be established soon and achieved with an ongoing timeline.

6.3.1 Adaptive Management

Plans are not necessarily meant to be static or prescriptive. It should provide a framework to adapt to rapidly changing conditions (USEPA, 2008). MIS management is a relatively new field in marine resource management, and new experiences and developing research will need to be incorporated to prevent and manage the presence of MIS. For the WCR, it will be a journey of continuous improvement, building upon gained knowledge to reduce uncertainty, maximize the efficient use of resources, and seek more effective results.

The examination of eight state plans' capacities to adapt to changing conditions shows that few states and regions have developed strategies and associated tasks that specifically address climate change or consider potential changes in environmental conditions in general. While this is not a surprising finding, since states and regions currently are not mandated to consider climate-change effects and have limited resources for MIS management activities, management plans could incorporate more strategies to increase a state's or region's capacity to adapt to changing conditions. The analysis highlights that some capacity exists to deal with the additional stressor of climate change, particularly through existing and/or establishing monitoring strategies, revisions of management plans, and the ability to fund specific activities. The results provide managers and decision-makers with information on what aspects of management plans can be readily revised to incorporate climate-change information and where adaptive management approaches may be most beneficial.

McOmber et al. (2013) states that the adaptation process requires the capacity to learn from previous experiences to cope with current climate, and to apply these lessons to cope with future climate, including surprises. The authors also stated that adaptive capacity can be undermined by a refusal to accept the risks associated with climate change, or by a refusal of key actors to accept responsibility for adaptation. Therefore key actors such as governments, institutions and planning bodies might want to undertake a combination of proactive and reactive adaptation, in which lessons learned from past management experiences are incorporated into adaptation strategies. Foreseen challenges to adaptive management might be a lack of willingness of key actors and resources necessary to adapt.

6.3.2 Monitoring Strategies

The results revealed that 81% of the country plans included brief statement for using, managing and updating information. Of this 81%, the chief purpose of monitoring was for keeping track of lionfish and key native species populations. Monitoring for follow-up activities to improve or adapt management strategies is critical (USEPA, 2008; Williams and Brown, 2014). Although the plans stated usage of the information gathered from monitoring, they did not specifically state that it would be used to determine follow-up activities. Despite that, countries need to have monitoring strategies in place before making improved management decisions. One suggestion for countries is to consider adapting a similar vision illustrated by the USVI. As mentioned in Chapter 5, the objectives of the USVI updated plan involved a collaboration of research and monitoring, data gathering and analysis to improve understanding of lionfish impacts, effectiveness of removal and examining the local and regional scientific research with observational data and by concentrating the collection of removal and sighting data into one shared database (Kilgo, 2014). Using the USVI's Caribbean Oceanic Restoration and Education Foundation (CORE) monitoring system is a start, or adapting the concept. Usage of their system is free, however adapting and promoting the concept at state or regional levels, will require dedicated funding. Another recommendation is to incorporate the need for monitoring systems for the purpose of early detection of new MIS populations.

Morris (2012), in his book titled The Invasive Lionfish, a Guide to Control and Management, discusses other suggestions for appropriate monitoring protocols for monitoring lionfish populations and their effects and ultimately the success of control in mitigating them. He highlights four key thematic areas including monitoring local lionfish populations, monitoring ecological impacts by multiple surveying methods, organismal monitoring through dissection and monitoring socioeconomic impacts: fishing, tourism, and human health. In the case of the lionfish, monitoring can begin with marine and coastal areas of high priority.

6.3.3 Periodic Revisions and Updates

Most plans, excepting Grenada's, implicitly mentioned the need for periodic revisions but did not set specific goals and actions items. Periodic review if incorporated in an adaptive management plan implementation also includes an analysis of progress and areas where adaptations are warranted (Reed and Egunyu, 2013).

6.3.4 Importance of Funding Sources and Strategies

Financial resources are critical to the successful implementation of plans (USEPA, 2008). Adequate funding is necessary to accomplish the objectives and goals of the plan. Moreover, the plan is an important first step in this process of MIS Management (SPREP, 2009). It is likely that most of the funding and associated human capacities are dedicated to educational and awareness programs through derbies and promotional campaigns via billboards and accessories to name a few. Hosting lionfish derbies for example play a valuable role in increasing public awareness and engagement in marine conservation (Malpica-Cruz, Chaves and Côté, 2016). The dominant discourse frames lionfish as a threat and control efforts as a war to keep the enemy out, and promotes lionfish hunting and consumption by humans as the ultimate predators (Carballo-Cárdenas, 2015). As it relates to the other management activities not receiving much comprehensive actions in planning as compared to education, this can be a result of the lack of available staff and funding necessary to take full advantage of relevant existing laws, regulations, management frameworks et cetera.

In regards to changing conditions, according to USEPA (2008), funding combine with periodic revisions demonstrate that many of the countries could accomplish activities that may ameliorate climate change effects on their lionfish management programs.

CHAPTER 7 - CONCLUSION

Given the overall results and discussion, islands should be able to be better prepared in future for controlling the lionfish and for possible new introductions of finfish invasive species. According to Schofield (2010), lionfish are the first marine fishes to invade the western Atlantic Ocean and Caribbean Sea, and have potential to add additional stress to an environment already compromised by overfishing, pollution and global climate change. Managers of draft plans as well as existing plans (that are in various stages of both development and implementation), and states that operate a multitude of MIS management activities and programs in the absence of a plan, need to be aware of the gaps and opportunities available to them to mitigate the negative consequences of lionfish in the region.

Strong plans on paper do not necessarily result in effective implementation. However, evidence indicates that plans and policies having specific goals, activities and/or outcomes is one of the criteria for reactive capacities (Early et al., 2016). Despite the shortcomings of this approach, CBD reports that contain policies or planning on many elements of IAS response capacities do suggest a higher level of awareness, expertize, legal structure and financial allocation than reports with little such information. (Early et al., 2016). Overall, this study forms a baseline against which future projects and actions related to MIS can be proposed as well as assessed.

Despite the range of programs designed to control the lionfish, the number of lionfish and their impacts in the Caribbean region are accelerating at an alarming rate. Management planning with common goals is an important first step for a unified and cooperative approach to addressing invasive species issues (NISC, 2001). The Wider Caribbean Regional Strategy for the Control of Invasive Lionfish should upgrade to present an ambitious yet doable management scheme inspired by the U.S. NISC's framework. It is acknowledged that the next and most challenging step is the implementation of plans, which should be considered the highest and most immediate priority (Malphurs, 2013). Additionally, both planning and implementing require local and regional regulatory and legislative instruments and authority, partnership building, a clear framework for cooperation among partners and sustainable funding sources for long-term implementation of strategies needed to be addressed by each plan (NISC, 2001). In

general, collaboration and coordination are themes that flow throughout the MIS management plans discussed in this report.

The research discusses the planned MIS management activities and highlights some of the work being done by the countries, identifies gaps in current plans, programs and activities, and outlines future actions necessary to address priority activities consistent with the current goals of national plans and the response strategy for the WCR. Since the creation of original responses (plans made 2009 and prior), the severity of the lionfish invasion has worsened, local circumstances have changed, and researchers, managers and citizen groups are more organized and knowledgeable about what is working and what is not (Kilgo, 2014). This accounts for the plans that are being updated and plans that are focused on a specific category such as education and public awareness, for the majority of countries. The analysis also revealed that most countries depend upon having an informed and involved public as the greatest asset in meeting the invasive species challenge.

It is evident that increased coordination between government, organizations, non-profits, businesses, and other stakeholders are needed, but where and how? Some ideas have been examined in this report and are feasible. This research illustrated how the status and trends of climate change in lionfish management or future MIS management underscores the need to consider climate-change effects in every part of MIS management plans and programs in order to address MIS effectively (USEPA, 2008). A relevant DFO (2004) suggestion includes having effective legislative frameworks take into account the varying needs and priorities of different jurisdictions and sectors.

To sum, the areas for action include the use of existing reviews, such as this research, to apply to the lionfish management strategies and perhaps other MIS strategies, to identify gaps, overlap, and inconsistencies. With increasing demand for foreign products (Walters and Jones, 2012), increased shipping and cruise tourism, former methods of dealing with invasive species are clearly no longer adequate. By adopting a comprehensive plan such as the NISC's and coordinating efforts, as well as considering climate change as is proposed in the USEPA framework, managers can help minimize the spread of the lionfish and potentially like invasions.

In future the governments for instance can compare plan implementation experiences, seek answers to common problems, identify good practices and work to co-ordinate domestic plans and update regional frameworks. It is highly recommended that a re-evaluation and update

is done to the regional framework and local management plans, to include similar guidelines as the USEPA AIS Management Plan Assessment. In combination with adaptive management, revised plans can be used also as a guide in future management of MIS.

REFERENCES

Albins, M. A. (2013). Effects of Invasive Pacific Red Lionfish Pterois Volitans versus a Native Predator on Bahamian Coral-Reef Fish Communities. *Biological Invasions* 15 (1): 29–43

Albins, M. A., & Hixon, M. A. (2013). Worst case scenario: potential long-term effects of invasive predatory lionfish (Pterois volitans) on Atlantic and Caribbean coral-reef communities. *Environmental Biology of Fishes*, *96*(10-11), 1151-1157

Aquatic Nuisance Species Task (ANST) Force. (2015). National Invasive Lionfish Prevention and Management Plan. Retrieved from http://www.anstaskforce.gov/Meetings/2015_May/18-NILPMP-Final_Draft-4.pdf

Ali F., & Bertual P. (2014). An Ecological Analysis of the Lionfish Invasion in Anguilla. government of the UK Report. Retrieved from http://jncc.defra.gov.uk/pdf/An%20ecological%20analysis%20of%20the%20lionfish%20invasion%20in%20Anguilla_FINAL[1].pdf

Ali, F., Collins, K., & Peachey, R. (2013). The role of volunteer divers in lionfish research and control in the Caribbean.

Ballew, N. G., Bacheler, N. M., Kellison, G. T., & Schueller, A. M. (2016). Invasive lionfish reduce native fish abundance on a regional scale. *Scientific Reports*, *6*.

Benoît, H. P., Gagné, J. A., Savenkoff, C., Ouellet, P., and Bourassa M.-N. (eds.). (2012). State-ofthe-Ocean Report for the Gulf of St. Lawrence Integrated Management (GOSLIM) Area. *Can. Manuscr. Rep. Fish. Aquat. Sci*. 2986: viii + 73 pp

Bizikova, L., Metternicht, G., & Yarde, T. (2015). Advancing Environmental Mainstreaming in the Caribbean Region: The Role of Regional Institutions for Overcoming Barriers and Capacity Gaps. *Sustainability*, *7*(10), 13836-13855.

Brels, S., Coates, D., and Loures, F. (2008). Transboundary water resources management: the role of international watercourse agreements in implementation of the CBD. CBD Technical Series no. 40, 48 pages. Secretariat of the Convention on Biological Diversity, Montreal, Canada.

Burgiel, S. W., & Muir, A. A. (2010). Addressing multiple drivers of global change. Global Invasive Species Programme.

Burke, L., Reytar, K., Spalding, M., & Perry, A. (2011). Reefs at risk revisited. 2011. *World Resources Institute, The Nature Conservancy, WorldFish Center, International Coral Reef Action Network, UNEP World Conservation Monitoring Centre and Global Coral Reef Monitoring Network: Washington, DC*, 114.

Carballo-Cárdenas, E. (2015). Controversies and consensus on the lionfish invasion in the Western Atlantic Ocean. *Ecology and Society*, *20*(3).

Convention on Biological Diversity (CBD). (2005). Handbook of the Convention on Biological Diversity Including its Cartagena Protocol on Biosafety, 3rd edition, (Montreal, Canada)

Côté, I. M., Green, S. J., & Hixon, M. A. (2013). Predatory fish invaders: insights from Indo-Pacific lionfish in the western Atlantic and Caribbean.*Biological Conservation*, *164*, 50-61.

Cox, K. (2015). Alien Invasion: An Ocean Picture Coming to a Sea Near You: An Analysis of International Frameworks for Aquatic Invasive Species Control. *U. Miami Inter-Am. L. Rev.*, *47*, 53.

Cranford, P. J., Kamermans, P., Krause, G., Mazurié, J., Buck, B. H., Dolmer, P., ... & Thorarinsdottir, G. G. (2012). An ecosystem-based approach and management framework for the integrated evaluation of bivalve aquaculture impacts. *Aquaculture Environment Interactions*, *2*(3), 193-213.

Dahl, K. A., Patterson III, W. F., & Snyder, R. A. (2016). Experimental assessment of lionfish removals to mitigate reef fish community shifts on northern Gulf of Mexico artificial reefs. *Marine Ecology Progress Series*, *558*, 207-221

Debels, P., Fanning, L., Mahon, R., McConney, P., Walker, L., Bahri, T., & Toro, C. (2016). The CLME+ Strategic Action Programme: An ecosystems approach for assessing and managing the Caribbean sea and North Brazil Shelf Large Marine Ecosystems. *Environmental Development*.

Dee, L. E., Horii, S. S., & Thornhill, D. J. (2014). Conservation and management of ornamental coral reef wildlife: successes, shortcomings, and future directions. *Biological Conservation*, *169*, 225-237.

Department of Fisheries and Oceans Canada (DFO). (2004). A Canadian Action Plan to Address the Threat of Aquatic Invasive Species Canadian Council of Fisheries and Aquaculture Ministers Aquatic Invasive Species Task Group. Modified September, 2016.

Early, R., Bradley, B. A., Dukes, J. S., Lawler, J. J., Olden, J. D., Blumenthal, D. M. & Sorte, C. J. (2016). Global threats from invasive alien species in the twenty-first century and national response capacities. *Nature Communications*, *7*.

Eby, L. A., Roach, W. J., Crowder, L. B., & Stanford, J. A. (2006). Effects of stocking-up freshwater food webs. *Trends in Ecology & Evolution*, *21*(10), 576-584.

Estrella, M., Peduzzi, P., Chatenoux, B., Velegrakis, A., Kluser, S., Orlyk, E., & Thakur, R. (2010). Risk and Vulnerability Assessment Methodology Development Project (RiVAMP): Linking Ecosystems to Risk and Vulnerability Reduction; The Case of Jamaica, Results of the Pilot Assessment Retrieved from http://www.preventionweb.net/files/13205_RiVAMPexsummary.pdf.

Fanning, L., Mahon, R. and McConney, P. (eds). (2011). Towards Marine Ecosystem-based Management in the Wider Caribbean. Amsterdam University Press, Amsterdam

Figueira, W. F., & Booth, D. J. (2010). Increasing ocean temperatures allow tropical fishes to survive overwinter in temperate waters. *Global Change Biology*, *16*(2), 506-516.

Gallegos, C. M. (2009). Trends in Maritime Transport and Port Development in the Context of World Trade. Retrieved from http://scholar.googleusercontent.com/scholar?q=cache:-ujP7OxLz8QJ:scholar.google.com/&hl=en&as_sdt=0,5

Gioria, M., & Osborne, B. A. (2014). Resource competition in plant invasions: emerging patterns and research needs. *Frontiers in Plant Science*, *5*, 501.

Gómez Lozano, R., Anderson, L., Akins, J. L., Buddo, D. S. A., García-Moliner, G., Gourdin, F., & Torres, R. (2013). Regional strategy for the control of invasive lionfish in the wider Caribbean. *International Coral Reef Initiative*. , 31 pp..

Green, S. J., Akins, J. L., Maljković, A., & Côté, I. M. (2012). Invasive lionfish drive Atlantic coral reef fish declines. *PloS one*, *7*(3), e32596.

Haddad, V., Stolf, H. O., Risk, J. Y., França, F. O., & Cardoso, J. L. C. (2015). Report of 15 injuries caused by lionfish (pterois volitans) in aquarists in Brazil: a critical assessment of the severity of envenomations. *Journal of Venomous Animals And Toxins Including Tropical Diseases*, *21*(1), 1.

Halpern, B. S., Diamond, J., Gaines, S., Gelcich, S., Gleason, M., Jennings, S., & Napoli, N. (2012). Near-term priorities for the science, policy and practice of Coastal and Marine Spatial Planning (CMSP). *Marine Policy*, *36*(1), 198-205.

Hart, J., Frank, S., & Platt C. (2015). OpEd: Cayman's Lionfisher Kings Caribbean Journal Retrieved from http://www.caribjournal.com/2012/08/30/op-ed-caymans-lionfisher-kings/#

Hewitt C.L., Everett R. A. & Parker N. (2009). Examples of current international, regional, and national regulatory frameworks for preventing and managing marine bioinvasions. In: Rilov G, Crooks JA (Editors). Biological Invasions in Marine Ecosystems Ecological, Management, and Geographic Perspectives. Berlin, Heidelberg: Springer-Verlag. pp. 335-349

Hilaire, A. (2007). *An analysis of cruise tourism in the Caribbean and its impact on regional destination ports* (Doctoral dissertation). World Maritime University.

Holbrook, S. J., Schmitt, R. J., Messmer, V., Brooks, A. J., Srinivasan, M., Munday, P. L., & Jones, G. P. (2015). Reef fishes in biodiversity hotspots are at greatest risk from loss of coral species. *PloS one*, *10*(5), e0124054.

Jentoft, S., & Chuenpagdee, R. (2009). Fisheries and coastal governance as a wicked problem. *Marine Policy*, *33*(4), 553-560.

Johnston, M. W., & Purkis, S. J. (2015). Hurricanes accelerated the Florida–Bahamas lionfish invasion. *Global change biology*, *21*(6), 2249-2260.

Kannan, V. (2015). Globalization and Government Regulations: Invasive Species Management in an Era of Interdependence. *Critical Writing Program*, *19104-6221*, *27*(4), 8.

Kilgo, J.M. (2014). Lionfish Response Management Plan U.S. Virgin Islands. Update February 2014. Retrieved from: http://lionfish.gcfi.org/sites/default/files/documents/lionfishplan_usvi_update_feb2014_sm.pdf

Kling, D. M., & Sanchirico, J. N. (2014). Controlling marine invasive species: The case of the Indo-Pacific Lionfish Invasion in the Southeast US and Caribbean. Retrieved from https://escholarship.org/uc/item/7zz429tm

Konisky, D. M., Hughes, L., & Kaylor, C. H. (2016). Extreme weather events and climate change concern. *Climatic Change*, *134*(4), 533-547.

Kulbicki, M., Beets, J., Chabanet, P., Cure, K., Darling, E., Floeter, S. R., & Letourneur, Y. (2012). Distributions of Indo-Pacific lionfishes Pterois spp. in their native ranges: implications for the Atlantic invasion. *Marine Ecology Progress Series*, *446*, 189-205.

LaJeunesse, T. C., Forsman, Z. H., & Wham, D. C. (2016). An Indo-West Pacific 'zooxanthella'invasive to the western Atlantic finds its way to the Eastern Pacific via an introduced Caribbean coral. *Coral Reefs*, *35*(2), 577-582.

Layman, C. A., & Allgeier, J. E. (2012). Characterizing trophic ecology of generalist consumers: a case study of the invasive lionfish in The Bahamas. *Marine Ecology Progress Series*, *448*, 131-141.

Lesser, Michael P., and Marc Slattery. (2011). Phase Shift to Algal Dominated Communities at Mesophotic Depths Associated with Lionfish (Pterois Volitans) Invasion on a Bahamian Coral Reef. *Biological Invasions* 13 (8): 1855–68.

Lopez, V., & Krauss, U. (2006). National and regional capacities and experiences on marine invasive species, including ballast waters, management programmes in the wider Caribbean region-a compilation of current information. *CABI, Trinidad & Tobago, UNEP*.

MacLean, M., Breeze, H., Walmsley, J. & Corkum, J. eds. (2013). State of the Scotian Shelf Report. *Can. Tech. Rep. Fish. Aquat. Sci.* 3074: xvi + 352 p.

Mahon, R., Fanning, L., & McConney, P. (2014). Assessing and facilitating emerging regional ocean governance arrangements in the Wider Caribbean Region. *Ocean Yearbook Online*, *28*(1), 631-671.

Malphurs, A. (2013). *Advanced Strategic Planning: A 21st-century Model for Church and Ministry Leaders*. 3rd Edition. Grand Rapids, MI: Baker, 2013

Malpica-Cruz, L., Chaves, L. C., & Côté, I. M. (2016). Managing marine invasive species through public participation: Lionfish derbies as a case study. *Marine Policy*, *74*, 158-164.

Mateus, M., & Campuzano, F. J. (2008). The DPSIR framework applied to the integrated management of coastal areas. *Perspectives on Integrated Coastal Zone Management in South America*, 29-42.

McCoy C. (2016). *Biomass and a Biomass and abundance of coral reef fish in the Cayman Islands; an assessment of fish assemblages after 29 years of monitoring and protection*. Paper presented at the 69th Annual Gulf and Caribbean Fisheries Institute (GCFI) Grand Cayman, Cayman Islands Government Department of the Environment. Technical Session.

McKinnon, A. D., Williams, A., Young, J., Ceccarelli, D., Dunstan, P., Brewin, R. J., ... & Kelley, R. (2014). Tropical marginal seas: priority regions for managing marine biodiversity and ecosystem function. *Annual Review of Marine Science*, *6*, 415-437.

Bartels, W., McKune, S., McOmber, C., Panikowski, A., & Russo, S. (2013). Investigating climate information services through a gendered lens. CCAFS Working Paper No. 42..

Miloslavich, P., Díaz, J. M., Klein, E., Alvarado, J. J., Díaz, C., Gobin, J., & Bastidas, A. C. (2010). Marine biodiversity in the Caribbean: regional estimates and distribution patterns. *PloS one*, *5*(8), e11916.

Moe, S. J., De Schamphelaere, K., Clements, W. H., Sorensen, M. T., Van den Brink, P. J., & Liess, M. (2013). Combined and interactive effects of global climate change and toxicants on populations and communities. *Environmental Toxicology and Chemistry*, *32*(1), 49-61.

Morris Jr, J. A. (2012). *Invasive Lionfish: A Guide to Control and Management*. GCFI. 113pp.

Morris JA, Jr., Whitfield PE (2009) Biology, ecology, control and management of the invasive Indo-Pacific lionfish: an updated integrated assessment. NOAA Tech. Memo. NOS NCCOS 99: 1-57.

Morris Jr., J.A., Thomas, A., Rhyne, A.L., Breen, N., Akins, L., & Nash, B., (2011). Nutritional properties of the invasive lionfish: a delicious and nutritious approach for controlling the invasion. AACL Bioflux 4, 21–26.

Morris Jr., J.A. and J.L. Akins. (2009). Feeding ecology of invasive lionfish (Pterois volitans) in the Bahamian archipelago. *Environmental Biology of Fishes* 86:389-398.

National Invasive Species Council (NISC). (2001). *Meeting the Invasive Species Challenge: National Invasive Species Management Plan*. US Government Printing Office, Washington, DC.

Olson, L. J., & Roy, S. (2005). On prevention and control of an uncertain biological invasion. *Applied Economic Perspectives and Policy*, *27*(3), 491-497.

Perry, C. T., Murphy, G. N., Kench, P. S., Smithers, S. G., Edinger, E. N., Steneck, R. S., & Mumby, P. J. (2013). Caribbean-wide decline in carbonate production threatens coral reef growth. *Nature Communications*, *4*, 1402.

Polar, P., & Krauss, U. (2015) Status of International Legislative Framework for the Management of Invasive Alien Species in the Wider Caribbean Region. Accessed from https://www.researchgate.net/publication/276090084

Premo, D., Clarke, C., Stine, A., & Hindelang, M. (2014). Keweenaw Bay Indian Community Aquatic Invasive Species Adaptive Management Plan. *White Water Associates Inc.*, 1-41

Reed, M. G., & Egunyu, F. (2013). Management effectiveness in UNESCO Biosphere Reserves: Learning from Canadian periodic reviews. *Environmental Science & Policy*, *25*, 107-117.

Reiss, H., S. Birchenough, A. Borja, L. Buhl-Mortensen, J. Craeymeersch, J. Dannheim, A. Darr, I. Galparsoro, M. Gogina, H. Neumann, J. Populus, A. M. Rengstorf, M. Valle, G. van Hoey, M. L. Zettler, S. Degraer, 2014. Benthos distribution modelling and its relevance for marine ecosystem management. ICES Journal of Marine Science. 10.1093/icesjms/fsu107

Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*(2), 155-169.

Rocha, L. A., Rocha, C. R., Baldwin, C. C., Weigt, L. A., & McField, M. (2015). Invasive lionfish preying on critically endangered reef fish. *Coral Reefs*, *34*(3), 803-806.

Sauter, R., ten Brink, P., Withana, S., Mazza, L., & Pondichie, F. with contributions from Clinton, J., Lopes, A, Bego, K. (2013) Impacts of climate change on all European islands, *A report by the Institute for European Environmental Policy (IEE)*

Schofield, P. J. (2010). Update on geographic spread of invasive lionfishes (Pterois volitans [Linnaeus, 1758] and P. miles [Bennett, 1828]) in the Western North Atlantic Ocean, Caribbean Sea and Gulf of Mexico. *Aquatic Invasions*, *5*(Supplement 1), S117-S122.

Secretariat of the Pacific Regional Environment Programme (SPREP). (2009) .Guidelines for invasive species management in the Pacific : a Pacific strategy for managing pests, weeds and other invasive species / compiled by Alan Tye. - Apia, Samoa. Retreived from http://especes-envahissantes-outremer.fr/pdf/guidelines_invasive_pacific.pdf

Simmons, K.R., (2014). *Evidence of the enemy release hypothesis: parasites of the lionfish complex (Pterios volitans and P. miles) in the Western North Atlantic, Gulf of Mexico, and Caribbean Sea* (Master's thesis). Nova Southeastern University, Davie, Florida.

Simpson, M., Scott, D., & Trotz, U. (2011). Climate Change's Impact on the Caribbean's Ability to Sustain Tourism, Natural Assests and Livelihoods. Inter-American Development Bank.

Tahoe Regional Planning Agency (TRPA). (2014). Lake Tahoe Region Aquatic Invasive Species Management Plan, California - Nevada. 35 pp

U.S. Environmental Protection Agency (EPA). (2008) Effects of climate change for aquatic invasive species and implications for management and research. National Center for Environmental Assessment, Washington, DC; EPA/600/R-08/014. Available from the National Technical Information Service, Springfield, VA, and online at http://www.epa.gov/ncea.

U.S. Fish and Wildlife Service (2012). Species Listed as Injurious Wildlife under the Lacey Act (50 CFR 16). U.S. Fish and Wildlife Service,

United Nation Environment Programme (UNEP), 2008. Climate Change in the Caribbean and the Challenge of Adaptation. UNEP Regional Office for Latin America and the Caribbean, Panama City, Panama. Printed in Panama City, in October 2008

United Nations- Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States (UN-OHRLLS). (2015). Small Island Developing States in Numbers Climate Change Edition. Retrieved from https://sustainabledevelopment.un.org/content/documents/2189SIDS-IN-NUMBERS-CLIMATE-CHANGE-EDITION_2015.pdf

Voncannon, S. (2015), Lionfish Jewelry: A Market Solution to an Invasive Species. Belize News. Retrieved from http://www.triplepundit.com/2015/04/lionfish-jewelry-market-based-solution-ecological-problem/

Walters, L. M., & Jones, K. G. (2012). *Caribbean Food Import Demand: Influence of the Changing Dynamics of the Caribbean Economy*. In Presentation at the Southern Agricultural Economics Association Annual Meetings.

Waugh, J. D. (2009). Neighborhood watch: early detection and rapid response to biological invasion along US Trade Pathways. IUCN.

Williams, B. K., & Brown, E. D. (2014). Adaptive management: from more talk to real action. *Environmental Management*, *53*(2), 465-479.

Ziska, L. H., & Dukes, J. S. (Eds.). (2014). Invasive Species and Global Climate Change (Vol. 4). CABI.

APPENDIX A

Management Plans and Supplementary Documents Provided by:

- Roland Baldeo, National MPA Coordinator, Fisheries Division, Ministry of Agriculture, Lands, Forestry, Fisheries and the Environment Grenada
- Julio M. Santiago Ríos, Wildlife Biologist, Endangered Species Coordinator, USVI and Alan 'Shane' McKinley, Biologist National Park Service at Saint John, USVI
- Bradley Johnson, Research Officer, Department of Environment, Grand Cayman
- Allena A. Joseph MSc, BSc Fisheries Biologist Ministry of Agriculture, Food Production, Fisheries, Co-operatives and Rural Development, St. Lucia
- Jennifer Cruickshank- Howard, Chief Fisheries Officer, Fisheries Division, Ministry of Agriculture, Rural Transformation, Forestry, Fisheries and Industry, St. Vincent