Worcester Polytechnic Institute
Major Qualifying Project
Lionfish Bot 2.0
International Studies Report

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Robot in Service of the Environment (RSE)

1.0 Introduction

The introduction of a species to new areas outside their native habitat often has extensive impacts on the existing ecosystem balance. Lionfish were introduced to the Western Atlantic Basin in the 1980's, where they quickly became a dominant invasive species. Their presence in the Atlantic has caused significant damage to the coral reef of the Caribbean, which in turn has had an impact on the ecology and economy of the island region. As the population of lionfish continues to grow, the waters they inhabit continues to expand, as well. Lionfish are adapting to the colder waters and are spreading up the North American Eastern Seaboard and are soon expected to inhabit the brackish bayou waters of the northern shores of the Gulf of Mexico.

Lionfish currently have no natural predators in the Atlantic and the only efforts to control their population growth are made when human divers hunt them. Lionfish, however, are capable of living at depths up to 1000m, 10 times the depth of recreational divers. Female lionfish can also lay upwards of 2 million eggs each year, which allows the growth of the lionfish population to drastically outpace human hunting efforts. Given the fragility of the coral environment and the local laws regulating fishing, the best method for capturing lionfish is with the use of an elastic sling. This method is slow and divers are limited by the number of lionfish they can store on their person, roughly 6-10 fish.

Robots in Service of the Environment (RSE), a nonprofit entity associated with iRobot, is attempting to develop a new way of controlling the lionfish population without these limitations of human hunters. RSE is developing a platform that will autonomously navigate a reef, identify and capture lionfish and then return to the surface. Their current platform, in the version 1 stage, is a tethered, remote-controlled system that uses an electrode shocking mechanism to stun and then capture lionfish. The RSE team is finalizing the first version of this system and intends to make the second version fully autonomous. The team has tested their platform in the Caribbean and identified components that needed improvement, including electrode optimization, the intake mechanism and the computer vision classification system for the second version.

The components identified by RSE for improvement were assigned to Lionfish Bot 2.0, a Major Qualifying Project (MQP) completed by Alexander Antaya, Katharine Conroy, Eric Peterson and Thomas Ralph during the 2018-2019 school year. This report is an independent extension of that MQP that addresses the international and global context and impact of the RSE project. This report explores the damage caused by lionfish in the Atlantic, the composition of the Caribbean political atmosphere, the legal and regulatory considerations of implementing the platform, the societal concerns surrounding autonomy and animal protections and the application of globally-minded engineering.

2.0 Global Impact

2.1 Global Lionfish Populations

Lionfish (*Pterois volitans & Pterois miles*) are a species of fish native respectively, to the eastern and western waters of Asia. Within their native waters, lionfish have natural predators that include sharks, cornetfish and grouper (Harrell). *P. volitans* and *P. miles* are closely related to each other and are difficult to distinguish from each other outside the laboratory. The only distinguishable feature is the number of dorsal-fin spines and anal-fin spines, with the Red Lionfish (*P. volitans*) having generally 11 dorsal-fin and 7 anal-fin spines and the Devil Firefish (*P. miles*) having typically 10 dorsal-fin and 6 anal-fin spines. This, however, is a generalization of the closely relation species and not a guaranteed way to determining between them (Schofield et al., 2019).

2.1.1 Lionfish Populations in the Western Atlantic

Lionfish are believed to have been first introduced to the Atlantic Ocean in 1985 (US Department of Commerce, & National Oceanic and Atmospheric Administration, 2004). Since then, their population as an invasive species has grown quickly and they have continued to work their way up the eastern seaboard of the United States and down the eastern coast of South America. Today, lionfish have permanently established habitats from North Carolina to Venezuela and eastward to Bermuda, as seen in Figure 1. Intermittent sightings have also taken place outside this region. Between 2005 and 2016, three lionfish sightings were confirmed off the coast of Rhode Island and many more during this time period along the east coast of the United States. In 2014, there was a single lionfish captured off the coast of southern Brazil, however, as of the study in 2016, it was undetermined whether or not lionfish were established off the coast of Brazil (Schofield et al., 2019). Currently, the only thing that is preventing lionfish from establishing permanent habitats outside the present existing zones is the cold Atlantic Ocean water of the winter months. It is currently believed that lionfish cannot sustain waters below 50° F or 10° C (Harrell).

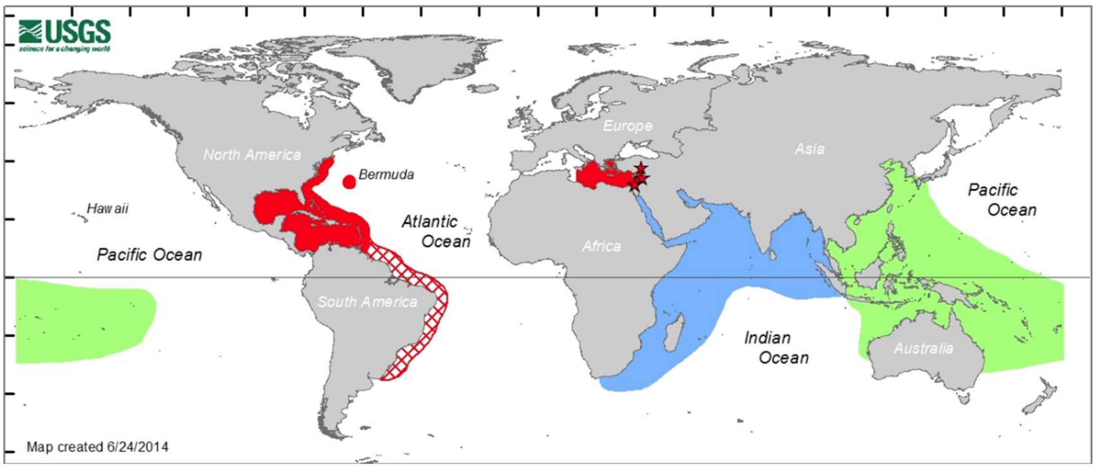

Figure 1: Map of Native and Non-Native Lionfish Territories
Native range of *Pterois volitans* (green) and *Pterois miles* (blue);
Non-native range of *P. miles* through Lessepsian Migration in Mediterranean (red);
Non-native range of *P. volitans* in the Americas (red);
Predicted future migration of *P. volitans* along South America (red hash)

There are two genetic species of lionfish present in the Atlantic, however, they are visually identical. Both the *P. volitans* and *P. miles* species have been transported to the Atlantic waters, however, during their time there, they have undergone visual changes from their counterparts in native waters. Today, the majority of the fish in the Western Atlantic Basin are *P. volitans* with a small population of *P. miles* scattered throughout the rest (Schofield et al., 2019). Unfortunately, the invasive species in Atlantic do not have any known predators and as a result, they are unchallenged as their population continues to grow and cause damage to various aspects marine life in the Caribbean.

2.1.2 Lionfish Population in the Mediterranean

The population of lionfish in the Mediterranean are of the species *Pterois miles*. They reached the Mediterranean from their natural waters in the Red Sea, by traveling up the Suez Canal. As of 2019, there have been consistent sightings of lionfish along the eastern edge of the Mediterranean off the shores of Israel, Lebanon, Turkey and Cyprus. Lionfish have also been seen as far west as Italy (Schofield at al., 2019). These sightings first took place off the coast of Israel as shown in a study by Golani and Sonin in 1992. Since then, sightings have increased exponentially around Cyprus causing destruction to the environment, similar to what has been observed in the Western Atlantic. An organization, RELIONMED-EU has partnered with the University of Cyprus to work against the invasion and make Cyprus the "first line of defense" (*RELIONMED-LIFE - Preventing a LIONfish Invasion in the MEDiterranean Through Early Response and Targeted Removal.*). Cyprus was the first European Union member country to be affected by lionfish. As of 2019, little action has been taken by the EU to address this issue. In 2003, Mediterranean countries passed the an *Action Plan concerning species introductions and invasive species in the Mediterranean Sea*. This plan stated, "it is imperative to take immediate steps to prevent the introduction of non-indigenous species, control the spread of those already introduced and endeavor to mitigate the damage they cause to the marine ecosystem." (UNEP-MAP-RAC/SPA 2005). However, since then, no further action has been taken by Mediterranean governments or the EU (Galil).

2.2 Invasive Impact in the Western Atlantic

Since the arrival of lionfish in the Western Atlantic Basin in 1985, they have done extensive damage to the all aspects of life in these waters, including impacting the natural environment, coastal and reef ecology and the national and international economies of Caribbean countries.

2.2.1 Environmental Impact

Adult lionfish primarily consume other fish. Studies have shown that a single lionfish can reduce native fish populations on a reef by 79% (Fisheries, 2018). As the species continues to increase their population at exponential rates, their impact on the environment continues to grow. Lionfish are known to be able to eat any fish that they can fit in their mouths; up to two times their own body length (Harrell). Mark Hixon, an OSU professor of zoology, said, "they [lionfish] feed in a way that no Atlantic Ocean fish has ever encountered. Native fish literally don't know what to do with them." (Oregon State University, 2008).

Additionally, a mature female lionfish can lay upwards of 2 million eggs each year. Scientists also believe that lionfish are well-suited to survive in coastal brackish waters, leaving open the possibility of the species invading the swampy regions of the southern coast of the United States in the Gulf of Mexico (Fisheries, 2018).

2.2.2 Ecological Impact

With the unprecedented consumption of native herbivorous reef fish, lionfish pose a dangerous threat to the delicate ecological balance of reef environments. Since their arrival in the Atlantic, lionfish have helped contribute to extensive disruption of coral reef ecosystems (Cox, 2015). The majority of reef dwelling fish are herbivores and their presence in the ecosystem controls the growth of algae and seaweed. In return, the reef offers the fish a relatively safe place to live. With the loss of the native fish, the carnivorous lionfish leave the already stressed coral little protection from other natural organisms. As seaweed and algae cover the reef, the survival rate of the coral is decreased significantly (Cox, 2015). As a result of this, there is a decrease in biodiversity across the Caribbean Sea and a significant reduction in coral and sea sponges (Bellis et al., 2012).

2.2.3 Economical Impact

The region of the Caribbean has been called the "most tourism dependent region of the world." (Barbados Today, 2013). In 2016, tourism to the region sustained 2,319,500 jobs (13%) and contributed $56.4 billion (14.9%) to the region's gross domestic product (Turner and Freiermuth, 2017). The region boasts numerous tourist attractions including, coral reef diving, cruises, sailing, fishing, golf, botanical gardens, parks, caves, hiking, cycling and many others. Lionfish are known to prey on common native commercial fish, significantly depleting stock numbers, which directly impacts the local island economies. Jamaica is a primary example of similar situations occurring across the region. Jamaica is surrounded by coral reef habitat, which produces an attraction for tourists and a supply of fish for local fishermen. The presence of the lionfish has impacted the fishing industry and damage to the coral environment likely has impact on tourism, however, the exact amount lionfish has impacted these two sectors is hard to determine, due to the numerous factors in play. However, a 2012 study showed that the potential damage caused by the lionfish invasion in Jamaica alone was $11,187,937 (Moonsammy et al., 2012).

2.3 International Setting of the Caribbean

The Caribbean is commonly referred to as a single region or entity, however, it is a group of islands and coastal countries, many with their own government, history and language. These distinctions are lost when we discuss the "Caribbean" as a single region of the world. In order to understand problems that the region faces, it is important to have at least a general understanding of the composition and operation of the region, its people and its laws.

2.3.1 Historical Politics of the Caribbean

The islands of the Caribbean played a significant role in the colonial period of the European powers. Soon after the arrival of Christopher Columbus in Hispaniola in 1492, Spanish and Portuguese sailors sought to make a profit from the islands. They forced the native population to work in mines and fields; mining gold and growing crops. By the early 1500s, all the islands in the Caribbean had been claimed by European powers. They continued to use the native population as slaves, until Spaniards protested the treatment of the slaves. Instead, the European powers imported slaves from Africa to continue the industrial work. Between 1492 and 1870 over 3 million African slaves were brought to the Caribbean (King, 2010). Starting in 1807, slavery in the colonial territories was slowly outlawed. In 1817, slavery in every colony had been abolished, with the notable exception of Cuba where slavery was finally abolished in 1886. While slavery was abolished, the colonial powers retained their claims on the islands.

The first Caribbean country to receive its independence was Haiti in 1804, when the predominantly black population of the island revolted and declared their national sovereignty from France (Skidmore et al., 2013). In 1844, the Dominican Republic declared themselves separate from Haiti. Many South American states achieved independence in the nineteenth century, and the Monroe Doctrine in 1823 limited the later intervention of other states from outside the region. In 1898, the United States declared war on Spain and invaded Cuba and Puerto Rico. That same year, Spain surrendered to the United States several Caribbean and Pacific Colonies and granted Cuba independence. Cuba was released from its United States Military Government control in 1902, however, the United States continued the practice of intervening in the political affairs of Central American and Caribbean nations. In 1953, Fidel Castro led the Cuban Revolution against the Cuban government, which was backed by the United States. In 1961, several years after the Cuban revolution, the United States attempted a covert invasion of Cuba in order to regain influences on the island and prevent the spread of communism. In the early 1960's, the British organized their colonies into the West Indies Federation, an independent entity that fell apart in 1962 when Jamaica declared its independence, followed by Trinidad and Tobago. Between 1962 and 1983, another 11 countries had gained their independence, while others including, Montserrat, the British Virgin Islands, the Cayman Islands and the Turks and Caicos Islands remained territories with limited self-governance ("Independence in the Caribbean", 2019).

2.3.2 Caribbean Today

Today, the Caribbean is place of tourism and social entertainment. Populations from all around the world travel there each year in the millions. The islands that compose the Caribbean still maintain varied international statuses. There are 16 independent countries and 15 dependent territories. Most the dependent territories today maintain some form of self-governance. Citizens of dependent states, with their limited self-governance, generally retain citizenship of the imperial country to which they are subject. The history of the region still has impact on its politics. It was only this decade that the United States formally re-established relations with Cuba and even that new relationship has been tense. The United States' involvement in the Caribbean brings with it a historical caution, since the earlier colonial interventions in Caribbean and South American affairs continues to influence interactions between United States and local actors in this region.

3.0 Caribbean Community Council

3.1 Community Council History

The Caribbean Community Council was formed in 1973 from the remnants of the West Indies Federation and the existing Caribbean Free Trade Association (CARIFTA). CARIFTA was formed in 1965, initially between Barbados and British Guiana, what today is Guyana. The goal was to establish free trade between the islands. The discussions later included several other Caribbean countries and by 1968 Antigua, Barbados, Trinidad and Tobago and Guyana signed a free trade agreement. By August of that year, several other countries from the region were included. The goal of the organization was to increase trade, limit tariffs, promote fair competition and ensure the benefits of the trade union were equitably distributed among member states. In 1973, the Prime Ministers of Barbados, Guyana, Jamaica and Trinidad and Tobago signed the Treaty of Chaguaramas, which established the Caribbean Community (CARICOM) as an economic union promoting a single market. In April, 1973, the Eighth Conference of Heads of Government of Commonwealth Caribbean Countries signed the Georgetown Accord, which effectively ended the Caribbean Free Trade Association and made the member states of CARIFTA members of the newly created CARICOM (The Georgetown Accord, 1973). In 2001, the member states agreed to a revision of the Treaty of Chaguaramas which created the Caribbean Single Market and Economy or CSME, as a separate, but integral part of the Caribbean Community. In addition to the single market, CARICOM also maintains the Caribbean Court of Justice, which was created under the provisions of 2001 (Rowe, 2015).

3.2 Community Composition

The Caribbean Community is composed of 15 member states with 5 associate members and 8 observer nations. Figure 2 shows a rough map of the region, with full members, associate members and observers listed.

Figure 2: Map of Caribbean Community Members

The Caribbean Community is broken into several different components and states are afforded the right to join or remain independent of each part. For example, there are 15 members of the Caribbean Community, however, there are only 12 members currently part of the Caribbean Single Market and Economy, with another 2 countries (Haiti and Montserrat) in the process of joining. The Bahamas, however, are the only CARICOM member state that has refused to join CSME, due to organizational requirement for the freedom of movement of people between member states (Jamaica Observer, 2019).

Member states of the Caribbean Community and/or the Caribbean Single Market and Economy are not strictly bound by the international representation of CARICOM. Several Caribbean countries belong to one or more international organizations that operate similar to

CARICOM. Figure 3 shows a Venn-diagram of the countries in the Caribbean and international organizations to which they each belong.

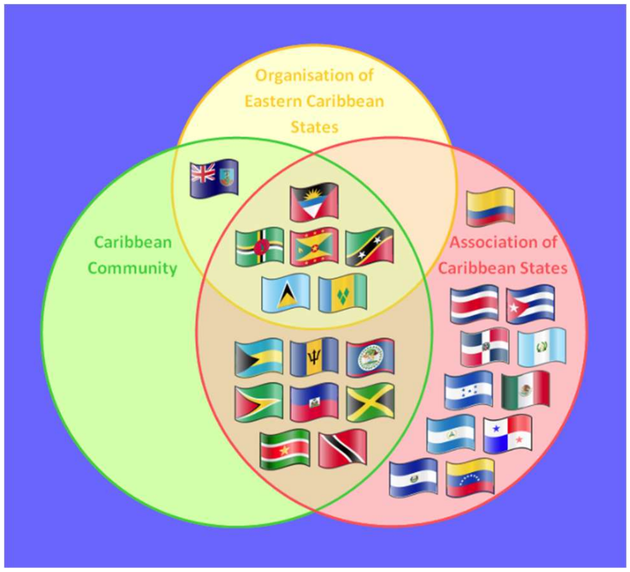

Figure 3: Diagram of Caribbean Country Memberships to International Agreements

3.3 Community Structure and Operation

Under the revised Treaty of Chaguaramas in 2002, the organization is broken into organs, bodies and institutions. Each of these components serve an integral part in the operation of the Community Council for the purpose of economic integration, foreign policy coordination, human and social development and regional security (Who We Are — Caribbean Community). The Community is headed by the Caribbean Community Secretary General.

3.3.1 Community Organs

The Organs of the Community are the CARICOM Heads of Government and the Standing Committee of Ministers. The Heads of Government is composed of the heads of state for each of the member states and associate states. The chairman of the Heads of Government Organ is rotated between the member states. The Standing Committee of Ministers is responsible for CARICOM Affairs in each member state. The Committee of Ministers meets one month before the Heads of Government meeting, in order to prepare and draft a provisional agenda. They act as an advisory committee to the Heads of Government in decision making. The Heads of Government are also responsible for choosing the Community Secretary General who serves the role of the chief executive. The Heads of Government sets policy and direction that is then represented on the international level by the Secretary General.

3.3.2 Community Bodies

The Caribbean Community has three bodies that provide assistance to the functioning of the organization. The bodies are the Legal Affairs Committee, the Budget Committee and the Committee of the Central Bank Governors. The role of each body is distinct and is designed to assist the Heads of Government in their decision making process.

3.3.3 Community Institutions

CARICOM has an additional 23 institutions that serve a similar role to agencies of the United States Federal Government. These institutions include: the Caribbean Disaster Emergency Management Agency, the Caribbean Meteorological Institute, and the Caribbean Environment Health Institute. Each serves an assistant role to the operation of the Heads of Government.

3.4 Community Impact

The structure of the Caribbean Community allows for unified initiatives on a large scale. CARICOM has implemented a single market to promote trade and in many countries, a customs union that allows for the free travel and relocation of Caribbean citizens. Its authority, however, has not extended to the individual laws and regulations of each independent country. CARICOM negotiates on the world stage as a single entity with common values, and business between the islands flows largely unimpeded, but businesses must still take into consideration each island's individual laws.

As an economic union, its role is largely confined to policy that directly effects the regional economy. In a separate treaty that was signed subsequent to the 2002 Treaty of Chaguaramas, the Caribbean Community agreed to allow the *CARICOM Regional Organization for Standards and Quality* (CROSQ) to unify and set business regulations for the region

(*Community Institution Profile — Caribbean Community (CARICOM)*). With regard to fishing, the Caribbean Regional Fishing Mechanism (CRFM), established in 2002, serves as a regional institution for the Caribbean Community. The CRFM promotes economically sustainable practices and assists the local institutions of each member state in implementing sound fishing policy (*Agreement Establishing the Caribbean Regional Fisheries Mechanism*, 2002). Since 2002, members of the CSME have advocated for the implementation of the CRFM as a binding addition to the single market. Such proposals have cleared all necessary treaty hurdles for the CSME; however, it has failed to be ratified by 8 members of the Caribbean Community Heads of State Conference (*The Caribbean Community Common Fisheries Policy*).

4.0 Requirements and Design Impacts

4.1 Engineering Goals

Our team set out to create a submersible platform capable of navigating a reef and capturing lionfish. The intention was to use this platform to assist in the eradication of lionfish from the Caribbean, through the application of modern technology, such as computer vision and autonomous functions. Initially, the autonomous platform envisioned by the team would be required to submerge, efficiently map the environment, identify lionfish from the surroundings and accurately track its position.

Each of these items present their own engineering challenge, particularly when each function must be done without human instruction. Each problem is compounded by the list of requirements that must be met in order to receive acceptance by each of the more than 16 countries in the Caribbean, as well as, the United States. In any function, there is a "reasonably acceptable margin of error," however, in our case, these error margins are subject to the requirements of the strictest country with which we are dealing.

4.2 Operating Environment

The platform is required to operate underwater, specifically around coral reef environments. Coral is an extremely intricate and fragile organism. Simply brushing or touching coral can kill an entire colony (US Department of Commerce, 2015). For this reason, it is a difficult environment in which to operate. The system must be durable enough to withstand the harsh effects of the ocean elements, while also being reliable and agile enough to navigate the reef. Ocean depths also have limited natural light, which can have an effect on the reliability of cameras and computer vision, further complicating the requirement of navigating the reef without coming in contact with any coral. Ultimately, the unique and harsh environment, coupled with the extremely small margin of error makes the design of the platform an engineering challenge.

4.3 Legal Considerations

The Lionfish Bot project presents potential legal issues that need to be taken into consideration, particularly given the number of countries in which the device is intended for use. While each country addresses issues differently, the existence of the Caribbean Community creates a unified organization that the team can use to stay within the bounds of law in all Caribbean Community member states.

The primary concern is the laws that govern the use of autonomous underwater vehicles and any laws that govern the methods through which fish can be collected. The United States does not currently have any laws that directly govern the use of remotely operated vehicles (ROV) in the ocean, nor the use of autonomous underwater vehicles (AUV), unless their construction is intended for military purposes (US Defense Department, 2012). Use of the platform, however, would have to comply with the U.S. Aids to Navigation System that is maintained by the United States Coast Guard. This system is a set of rules that determine navigation, etiquette and vessel operation in territorial and international waters. Secondly, electrofishing in the United States is defined as "using electricity in aquatic habitats to sample or control fish" (Occupational Safety and Health, 2016).

In the United States, the laws on electrofishing are controlled on a state level, however, many states only allow electrofishing for biological studies. Florida for example prohibits the use of electricity to capture freshwater fish (Florida Fish and Wildlife Conservation Commission, 2018). The State of Delaware states "[electrofishing] is only allowed for use by permitted researchers in Delaware" (Delaware Division of Fish & Wildlife). Electrofishing is generally discussed in freshwater contexts, and a general ambiguity exists as to the legality of using it recreationally in a saltwater environment.

The Caribbean Community, while they operate collectively under the Revised Treaty of 2001, is still a collection of independent states. As such, when the Heads of Government agree to a new legislation, or other initiatives that requires changes to a country's laws, it must go through the country's appropriate channels, most commonly through the country's legislative body. This structure is virtually identical to the operation of the United Nations. It does, however, complicate the legal guidelines for consideration. Reviewing the fishing regulations of the Bahamas and Jamaica (chosen for their size and political prominence within CARICOM), the use of electrofishing is ambiguous. The Bahamian regulations make no mention of the allowance or prohibition of electrofishing (Fisheries Resources Regulations, 1986). The Jamaican Fishing Industry Act of 1975 outlines "Specified means of fishing", however, electrofishing is not included (Fishing Industry Act, 1975). Less ambiguous in these documents is the express prohibition of fishing in restricted areas. In the Bahamas, coral environments are strictly regulated by the Department of Marine Resources. In areas designated as a reserve, fishing is prohibited. Recreational fishing is allowed, pursuant to regulations in national parks ("Bahamas").

4.4 International Project Communication

The design project is dependent on the successful implementation of a device that can capture lionfish in coral reef environments in a manner that will be acceptable by the majority of Caribbean countries. The RSE team recognized this early on and received preliminary advice from the Bermudan Minister of the Environment to help guide their design. Through this communication and regional research, the team was able to design their platform in a manner that would meet the requirements of the regional governments.

The team at WPI, prior to teaming up with RSE used contacts in the Cayman Islands to learn about, and brainstorm, the problem. Communication with the Cayman Island representative to the Caribbean Community helped the team understand the impact of the lionfish problem in the Caribbean. The individual also provided the team with information on general criteria that would need to be met before the system could be deployed in a coral reef environment. This criterion included, but was not limited to, the requirement that the platform absolutely refrain from contacting the reef; that the platform not be designed to capture other species of fish; and that the platform refrain from using a spear-like mechanism (Cantor, 2018).

The RSE team has used its relationship with the Bermudian government to conduct field tests of their platform. They are, however, in uncharted territory when it comes to general approval of the platform. As of now, it appears as though the RSE team does not intend on presenting the platform to any agency outside the Bermudian government. It is unclear whether other Caribbean governments will be accepting of the platform. Reefs in the Caribbean are very strictly controlled areas due to their fragility, but the problems caused by the lionfish invasion has prompted Caribbean officials to be open to new ideas. Throughout their design process and foreign interactions, the RSE team received very little pushback and are hopeful that the next version of their platform will be allowed to operate in the Caribbean reef environments.

4.5 Acceptance Criteria & Approval

Based on research and communication with officials in the Caribbean, the design process described in the other MQP documentation for Lionfish Bot 2.0 was shaped to develop a suitable platform. Some countries have strict laws on the use of spears, with drove the team toward the non-contact, electrode method. The team was also advised to ensure that the platform could only be used for the purpose of capturing lionfish. During its operation, the platform must also be capable of navigating the reef without contacting any of the coral.

One requirement that remains in question is a tethered vs. untethered system. The RSE team opted for a tether, since their first version is a remote controlled platform, not an autonomous one. The officials in the Cayman Islands had expressed concern of a tether being deployed on the reef, however, the same concern was not found by the RSE team.

Using this criteria, the optimal solution for an engineering team, would be an autonomous, untethered platform that employed a non-contact capture method. Through software implementation, the system should be programmed with safeguards to ensure it can only target lionfish. Once the WPI-designed platform is ready for field testing, it should be tested in coordination with local Caribbean governments, similar to the testing employed by the RSE team. This would allow the team to test their platform, while also maintaining healthy and professional relationships with the region's officials.

Once the system is operational, the goal should be to present the platform to the Caribbean Community through the appropriate agencies. The Caribbean Environmental Health Institute and the Caribbean Regional Fisheries Mechanism are two institutions within CARICOM that could serve as good starting points. Through these agencies, the platform could receive general approval through CARICOM, which would reach the 20 collective member states. While the platform would still need to comply with each countries laws, the approval of CARICOM would better position the platform to be deployed in large scale fashion throughout the region to address the lionfish invasion.

5.0 Public Concern and Response

5.1 Project Media Attention

The lionfish invasion in the Western Atlantic Basin is an issue that has received increased media attention in recent years. While invasive species exist in every region, the lionfish invasion serves as the poster child for the damage that an invasive species can cause. The platform that was originally being developed by the WPI team received media coverage, with mixed reception, in over 80 news outlets (Baron, 2018). The platform was featured in *Engadget*, *Popular Mechanics*, *DigitalTrends* and *TechSpot*. The device was referred to as a "robotic legionnaire" (Grossman, 2018) and the "aquatic version of the [Terminator] T-800" (Mahon, 2018). While these comparisons are somewhat humorous, they also paint the platform, and the technology itself, as something to be feared.

Prior to this year's group of WPI students joining the MQP team, each student was informed that the project was not without controversy. Some members of the WPI community are opposed to this project. In fact, during the 2017-2018 school year, one group of students felt so strongly that they worked to protest this MQP project. The argument put forth by these individuals is that technology should never be used to do harm, regardless of any positive outcomes. The counterargument is that the damage done by lionfish to the Atlantic ecosystem and the responsibility of conscience individuals to protect the environment warrants the application of an autonomous platform. Further, the use of such a platform is not in violation of the Progessional Engineers Code of Ethics, which guides the conduct of engineers across the world (Seider et al., 2009). Given the concerns of autonomy, press reports that characterize the platform as a "Spear-toting robot" (Dormehl, 2018) mischaracterize the technology and spread fear of autonomous platforms.

5.2 Animal Protection Advocates

Animal protection agencies, such as People for the Ethical Treatment of Animals (PETA) have also voiced concern with the platform. In an interview on *The Daily Show* in November of 2018, Ashley Byrne, a campaign specialist for PETA, stated that the agency was very opposed to any form of electrocution of lionfish and that the platform sounded very inhumane (Noah, 2018). While there has been no official statements by PETA, it is clear that the platform faces opposition from animal rights advocates, due to the assumption that it causes harm to the lionfish, as well as, to a misunderstanding of the good that lionfish removal can do for human, other coral fish and the environment.

The RSE team specifically opted for a non-lethal and non-contact stunning mechanism in order to capture fish in the quickest and most humane way possible. This was intended to help address the concerns of organizations like PETA. Through their own testing, the RSE team has shown that shock administered by the RSE platform does not cause any lasting harm to the fish. After each experiment, the test fish immediately recovered and accepted food, indicating it was not experiencing any heightened stress levels (Cantor, 2018). The RSE team, through their test results, are confident that the capture mechanism serves as a humane way of harvesting lionfish. Nevertheless, the wealth of misconceptions surrounding the platform and its application creates strong negative opinions both locally and online.

5.3 Concerns about Autonomous Technology

Though the general concern for the lionfish and the disapproval of technology being used in a fish harvesting mechanism presents concerns, the issues of autonomy and of artificial intelligence impact a much larger group of people. In American culture, a common fear is that machines will one day rise up over the population and take control. This has been a staple of science fiction horror stories for the past 50 years (Noe, 2017). The real issues arise when the idea of autonomy and lethality are combined. This topic is far greater than an underwater-fish harvesting platform. It also encompasses the use of drones and robots on the battlefield, which has been a heated debate for several years. Peter Aruso, co-founder of the International Committee for Robot Arms Control, said, "We want a worldwide ban so that there will always be a human meaningfully supervising targeting and kill decisions." (Thomas, 2013)

Speaking specifically to the application of the lionfish platform, people have expressed similar concerns of allowing a robot to shock and capture fish without a human "meaningfully supervising" the platform's decisions. Through the Internet media attention, several individuals from across the world shared their opinions of the system, including a man by the name of Joey Racano, who wrote a poem about the platform and how its automation and machine learning brought it to kill the human population (Fingas, 2018). Another compared the system to automated cars and expressed concern that the system would malfunction and start threatening divers (Cal, 2018).

Even if we dismiss the concerns of misinformed individuals, there still exists legitimate concerns surrounding the possibility that an autonomous system could make a mistake and cause unintended harm, and that is what scares people about lethal autonomy. No system is ever perfect and even those intended to help can cause catastrophic damage when something goes wrong. While public apprehension about lethal autonomy may seem like misinformation to an engineering team, it is critically important that design teams take these concerns and issues about a platform into consideration and not dismiss the issue outright. Engineering teams and companies can do this in two ways. First, concerns that are misinformed can be dispelled through outreach programs to better educate the general public on the facts of the issue; this misinformation will also likely quiet as the platform operates successfully. Second, if there is informed legitimate concern about the platform, engineers can either address the issue, or conclude the legitimate concern is perhaps too great for them to continue forward. An example of this second point is seen in the actions of *Google, Inc.* in 2018 when they decided to cease their cooperation with the United States Government on the creation of military automated intelligence or *Project Maven*. *Google, Inc.* employees were concerned the creation of the software violated engineering ethics principles (Statt, 2018).

6.0 Comprehensive Project Approach

6.1 Globally-Minded Engineering

Over the past 50 years, the world has become increasingly interconnected. Engineers from across the world work on projects that effect large groups of people from every corner of the globe. As such, it is imperative that engineers employ globally-minded approaches to their projects. Engineers are taught to tackle problems in a structured fashion and as a result it is easy to consider the engineering problem without asking the larger questions of global scope and international ramifications. This has been a common point in STEM higher-education for the last decade and has been a core value of WPI for fifty years. In order to take into account varied interests and cultural differences, however, engineers must consciously exercise different practices during their design process. Instead of just tackling the problem itself, engineers must first look beyond the problem statement to determine how their solution is going to impact the larger picture. What might seem like a good solution could fall flat in practical application. The team must also consider the varied cultures in which their solution will operate. In a similar sense, public opinion and concern must be taken into consideration. Even a brilliant solution is irrelevant if people are afraid to use it. Finally, the collective solution must tie these different considerations together into a single, comprehensive and globally-aware solution.

6.2 Thinking Beyond the Problem

Engineers often think in a structured fashion. Tackling a problem becomes second nature and they become accustomed to looking at problems in a technical manner. In order to be more effective in an interconnected world, engineers need to look beyond the specific problem statement and examine the larger picture of the world in which the problem exists in order to understand the intricacies of the issue. This is done by developing global and local knowledge of the issue (Warnick, 2011). Using the lionfish project as an example of thinking on a larger scale we can see global competency being used.

The team's goal is to develop a platform that is capable of autonomously capturing lionfish from coral reef environments. Questions that are important to the engineering project include anything related to required specifications, operational environment and intended usage audience. A globally-minded engineer, however, must think about the larger picture. Where in the world is the system intended to be used? How else might this system be employed in the future? What is the international importance or impact of the problem? These are all things that the WPI team investigated in the early stage of the project. The system clearly has international impact, since lionfish know no national boundaries and the affected area is home to over 20 nations. The system is currently intended for the Caribbean region, however, the RSE could easily be employed in countless places across the globe. By asking questions, outside the normal scope of an engineering perspective and consulting various resources, globally-minded engineers develop local and global knowledge on the issue and are thus better equipped to find an acceptable solution to 21st century problems.

6.3 Cultural Considerations

A study on global competency in engineering concluded that engineers should have "a developed awareness, appreciation, and understanding of … other cultures and countries" (Warnick, 2011). It also says that engineers must understand that cultural considerations have an impact on design decisions. The world is an incredibly diverse place with countless different customs and cultures. When implemented properly, a better understanding and deeper appreciation for differing cultures within an engineering problem makes the solution a better one. Cultural considerations must also include being conscious of religious differences.

Religion and culture are best understood by the people who live them everyday. When tackling these problems, engineers should speak to the people who have direct knowledge of the culture surrounding the problem. These considerations were the primary factor that drove the RSE team to make contact with the Bermudian Minister of the Environment. His knowledge of the lionfish problem in the Caribbean, and what other governments might think of the proposed solution, helped the team create a robust product idea. For example, he expressed concern that the platform could be used for the capture of other species of fish and advised the team to design against such a practice. The WPI team also had a contact in the Cayman Islands who operates a dive shop and interacts with lionfish regularly. He informed us that the widespread consumption of lionfish in the region has created a large demand for the fish. This allowed the team to have a better idea of the potential demand for the resulting lionfish harvest, as an added benefit outside the protection of the coral environments. This information collection, however, was dependent on the team asking questions of those living in the culture in order for those people to share their ideas, and this further highlighted the importance of developing local connections and knowledge.

6.4 Power of Public Opinion

The level of communication that transcends the world is unparalleled in human history. A person in the most remote region of the world, with the right technology can communicate with anyone they wish, instantly. This level of communication has made it very easy for people to develop strong opinions on issues that have little or no direct impact on them. Opinions often range from obscure to impractical to helpful. Understanding the public opinions surrounding topics of the problem allows engineers to be better equipped to solve the problem at hand.

In the lionfish project, the team was aware that the idea of an autonomous lethal robot was seen as irresponsible and dangerous by groups of people. Instead of dismissing the idea, the team chose to be aware of the concerns in order to develop a better system. Adopting the perspective of a sort of "devil's advocate" keeps engineering solutions grounded in reality. Comments on the lionfish platform were often times helpful as well. The team's original design used buoyant spears to capture fish. One unaffiliated individual questioned the use of floating spears, concerned that if a shark tried to eat the fish it might also consume the spear tip. This was a question that prompted thinking within the team, since no team member had considered the possibility of sharks eating the floating fish. By accepting critical feedback and opinions from people outside the project and understanding public sentiment, engineers exhibit important tendencies of globally competence that allow them to better solve international and local problems.

6.5 Collective Solution

Throughout any engineering problem, the final solution must exhibit a comprehensive understanding of the application of the solution within the determined cultures and societies. At each step, engineers must be willing maintain open minds and exercise globally competent practices. Engineers are in many ways servants of the people of society. They are uniquely trained to solve problems and assist in the progression of society. As society works to bring people and places closer together, engineers cannot effectively do their job if they are detached from the people they serve. Globally-minded engineering is the product of this fact.

As engineers, the WPI team worked to ensure their project embodied these tenets of global competency. The team took the required time to truly understand the problem they were trying to solve and the larger impact of the project. They established communication with those who are working through the problem, in order to gain local knowledge, and they researched the issue to understand the larger global issues. The team welcomed public opinion and criticism of the general public in order to create a robust solution to a complex problem. The technical components of our project were only one outcome of our project. Another equally important final product of this work is that we have developed a better understanding of the complex forces that shape us and our world, one of the signs of global competence and in keeping with the core values of our teaching and of WPI.

7.0 Conclusion

The lionfish invasion of the Caribbean and surrounding waters is having a significant impact on marine life, ecology and the Caribbean economy. The lack of natural predators of lionfish in the Atlantic means that human intervention is required to keep their population in check. Divers cannot keep up with the pace at which lionfish breed, nor can divers reach the depths inhabited by lionfish. Robots in Service of the Environment's platform is developed for this purpose, to autonomously collect lionfish and save the Caribbean waters from the significantly negative impact of these creatures.

Outside the regional impact, the interdependent, globalized world in which engineers operate today, allows people from across the world to share ideas and opinions on a topic. It is important for engineers to listen to this public sharing of ideas in order to prevent an "echo chamber" environment in which engineers fail to think about all possible solutions. Taking a multitude of opinions and concerns into consideration allows for a more durable and comprehensive engineering solution.

Lionfish know no bounds of territorial or international water. As a result, it becomes the jobs of engineers to design a platform that can legally and successfully operate in areas as diverse as the Caribbean. In order to do this, engineers need to understand the composition and culture of the region. In this case, the Caribbean offers a long history of events that impact the current situation and various issues that engineers need to understand in order to go about designing a product that works for the majority of impacted groups.

In any project, engineers need to be vigilant in their application of globally-minded engineering. Thinking beyond the base problem, taking into account cultural considerations and weighing the value of public opinion allows engineers to create a comprehensive and global solution. This is the type of engineering that is required in our interconnected and global world. This is the type of engineering the WPI team worked to incorporate in our designs and through that solution we can protect the Caribbean from the lionfish invasion.

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