Extinction Stories

Edited by
Marja Bakermans,
Mickaela Gunnison,
William San Martín

WPI

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MARJA BAKERMANS AND WILLIAM SAN MARTÍN

Contents

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Gratitude

MARJA BAKERMANS AND WILLIAM SAN MARTÍN

This text would not be possible without the support of Kris Wobbe and WPI's Great Problem Seminar (GPS) Program. In addition, we would like to acknowledge the support of WPI's Humanities & Arts Department, WPI's Global Lab, and its Global Faculty Fellow Program. This text was inspired by discussions in a Peer Mentoring Network on Social Justice, Equity, Diversity, and Inclusion hosted by SCORE-UBE (Sustainability Challenges for Open Resources to promote an Equitable Undergraduate Biology Education). Furthermore, Brian Lower and Ella Weaver, from The Ohio State University, provided critical and generous advice in their experience producing a similar open text with students.

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The students who embraced the challenge, conducted research, and wrote the following chapters are the ultimate stars of this text. We want to thank students in *GPS: Extinctions* and *BB 1045 Biodiversity* for exploring these topics and digging deep into the causes, consequences, and solutions facing our planet's precious biodiversity.

Introduction

MARJA BAKERMANS AND WILLIAM SAN MARTÍN

The causes and consequences of global biodiversity loss and species extinctions are complex and rapidly changing across spatial and temporal scales. They have both local and global manifestations and are entangled with biological, socio-cultural, economic, and political processes. Many of these challenges demand novel approaches, including innovative research and interdisciplinary analysis. They need new skills and methods from various disciplines and expert communities, including the humanities, social sciences, and biophysical sciences. They also require rethinking who conducts research and communicates findings and how knowledge is produced at the intersection of research and higher education institutions and social change.

This book aims to respond to these challenges. ***Extinction Stories*** was co-authored by undergraduate students at Worcester Polytechnic Institute, a private research university in Worcester, Massachusetts (USA), while exploring issues of extinction, environmental conservation, and biodiversity loss. The following twenty chapters combine the final projects conducted by students in the *Great Problem Seminar* (GPS) *Extinctions* course during the Fall of 2020 and the *Biodiversity* course in the Spring of 2021. Both courses took place while the world was still facing the impacts of the COVID-19 Pandemic—a global crisis that, as our current sixth mass extinction, is also profoundly rooted in long-lasting processes of habitat destruction and human-induced environmental change.

The *Great Problem Seminar* Program offers a two-term course that immerses first-year students into university-level research and introduces them to the project-based curriculum at WPI. It invites WPI faculty from different disciplines and areas of expertise to co-design and co-teach a class addressing critical contemporary problems. The *GPS Extinctions*' faculty included Marja Bakermans and William San Martín. Dr. Marja Bakermans is a wildlife field biologist with expertise in conservation biology, migratory bird species, and their anthropogenic disturbances in North and South America. Dr. Bakermans is affiliated with WPI's Biology and Biotechnology Department and the Department of Integrative & Global Studies. Dr. William San Martín is a historian and a science & technology studies scholar with expertise in global environmental sciences and policy, socio-environmental justice, and sustainable development issues in Latin America and the Global South. Dr. San Martín is affiliated with WPI's Humanities & Arts Department, and the International & Global Studies, the MS Community Climate Adaptation, and the Great Problems Seminar Programs.

WPI's Biology and Biotechnology Department offers the *Biodiversity* class as an introductory course in its Conservation and Applied Ecology track. The class is also part of WPI's Environmental & Sustainability Studies Program and it is designed and taught by Marja Bakermans for a variety of WPI students from first-year students to seniors interested in the science and the practice of environmental conservation from a problem-solving and applied research approach.

The following chapters combine these perspectives and highlight key insights of current students in their quest to create a better world. Students co-authoring this book strongly believe in creating an open-access text so that others may learn and build upon their work and knowledge. Throughout the text, students investigate critical challenges in biodiversity: Habitat Destruction, Overexploitation, Conservation and Management, Pollution, and Climate Change. They explore the complex roots and changing consequences of extinctions and the challenges to address the research and practice of human-nature interactions.

Image: Elph painting on May Lane, JAM Project, CC BY-SA 2.0

Extinction Stories reminds us that the answers to our current socio-environmental challenges are entangled on local and planetary trajectories and that our ability to understand and face them from various perspectives and scales will be essential for our shared future on Earth.

The editors and co-authors of this volume firmly believe that our current ecological crises require new ways of thinking about research, education, and their place in public debates and decision-making. We hope this volume contributes to expanding discussions about environmental change and biodiversity conservation across disciplines. We hope it can assist in uncovering new paths to reimagine the essential role of open-access resources and undergraduate research and education in the strategies we need to face our current and future challenges.

PART I

HABITAT DESTRUCTION

Habitat destruction, driven by **habitat loss**, **fragmentation**, and **degradation**, is the **leading cause** of extinction of biodiversity (Pimm and Raven 2000). These processes result in reduced amounts of original habitat and altered conditions within the remaining habitat. Drivers of habitat loss include agriculture, mining, **trawling**, urbanization, and **suburbanization**. Some regions of the world (e.g., **biodiversity hotspots** and islands) and ecosystems (e.g., mangroves, wetlands, prairies) suffer the highest rates of habitat destruction.

The chapters in this section explore areas that exemplify challenges of and solutions to habitat destruction. For example, students explore the drivers of deforestation of the Amazon and then highlight species (e.g., jaguars, tree frogs, and snakes) that are intertwined with the fate of tropical forests. Finally, students investigate the dangers of urban habitats for migrating birds. and describe mitigation strategies.

Deforestation due to agricultural intensification in Bokito, Cameroon. "Forest Transition" by Mokhamad Edliadi/ CIFOR. CC BY-NC-ND 2.0.

1. The Ultimate Demise of the Lungs of the World: The Deforestation of the Amazon

Anna Kelly, Duncan D'Olimpio, Gavin Scannapieco, and Giovanni Ramirez

Abstract

This chapter will discuss the question "How can Brazil keep a healthy economy while still protecting the Amazon?" South America's agriculture boom has led to the expansion of the cattle industry in Brazil. This requires the **deforestation** of the Amazon in order to increase pasture land. The Amazon, referred to as the lungs of the world, produces 20% of global oxygen and boasts 2.5 million species. The chapter will discuss deforestation in Brazil and the threats to **biodiversity** that it poses. This chapter will explore these topics through expert interviews and research.

Figure 1: Illegal logging in the Amazon. "Illegal logging on Pirititi indigenous amazon lands with a repository of round logs on May 8, 2018 (Felipe Werneck/Ibama via flickr via AP)" by quapan, CC BY 2.0

Background of the Problem

A growing global demand for meat has changed the agriculture industry to increase its soy harvest to fatten and feed the new livestock (Marcio da Silva). One of the areas greatly impacted by the increase in agriculture is South America, specifically Brazil, home to the Amazon Rainforest (Pereira et al., 2012). In the past 50 years, roughly 17% of the Amazon has been destroyed (Nunez, 2019). The Amazon is referred to as the lungs of the world (Francombe, 2019; Woodward, 2019). A large portion of the Amazon is rainforest, and rainforests yield some of the highest rainfall per year in meters. It holds a huge carbon deposit and contains 20% of the world's freshwater (Brazil and the Amazon). The Amazon is not just a rainforest, even though that is the most biodiverse and largest part of it (Rogers, 2020). There are also the Savanna and the **Cerrado**. This is the site of the biggest agricultural transformation Brazil has seen in many years (Rogers, 2020).

Figure 2: "[Amazon rain forest monkey]" by [Mariusz Kluzniak], [CC BY-NC-ND 2.0]

The Amazon is also home to one of the most biodiverse ecosystems in the world (Thomson, 2020). Protecting and conserving the Amazon not only saves countless species of known and unknown organisms but is also a fighter against climate change (The World Bank, 2019). The Amazon holds nearly 2 billion tons of carbon (Eaton, 2018), and with a potential die out in the forest, much of that carbon would be released into the atmosphere (Marshall, 2020).

This pristine land is facing a major crisis of deforestation largely because of the growing demand for certain crops and pasture land for cattle (Prager, 2019). The land being used for cattle is four times the amount of land being used for crops, even though cattle have a very low yield—sometimes just one cattle per **hectare** (Yale, 2020). The process of turning land from forest into cropland relies on the slash and burn method, a method that last year started 40,000 fires (Hauser, 2019) in the rainforest and led to the destruction of thousands of acres of forest. Slash and burn is a method of igniting a forest or brush until it has burnt to the point of complete ash (Lindsey, 2004). The rate of deforestation in the Amazon has been increasing, as July of 2019 saw a 39% increase compared to the rate of deforestation in July 2018 (Woodward, 2019).

The free-range cattle industry, which relies on grazing to feed the animals, also relies on the practice of **slash and burn** deforestation to clear new land for grazing (Lindsey, 2004). Recently under the new administration in Brazil, fires have been increasing in numbers as well as in size and unpredictability (Woodward, 2019). With many of these fires getting out of control to the point where they cause serious damage (Woodward, 2019), we need to address these issues in a proper and realistic manner to conserve this important environment. How can Brazil create a healthy economy while still protecting the Amazon? What can other nations do to support the protection of the Amazon and slow deforestation? With these leading research questions, we will be investigating a resolution that can work for both the farmers and the Amazon.

Figure 3: Aerial view of the Amazon rainforest. "Amazon 6" by CIAT, International Center for Tropical Agriculture, CC BY-SA 2.0

Why Should We Care?

This project holds an answer to a pressing problem that has recently been ignored and will inevitably impact every member of this planet if not dealt with. We are at a historical moment where the health of the entire Amazon is dependent on what the next couple of decades hold. Our research can be used by other nations to see how they can support the Amazon instead of supporting its deforestation. Our hope is that with our research and our conclusion, practitioners of forest management will have a better idea of what the guidelines should be for logging and clearing land for farming purposes.

Our research can also be used by **livestock economics** to see how to better use the land. Land can be used in a more **sustainable** way in order to stop the need for expansion of said land. Our conclusion should also help with environmental conservation because, if put in place, the steps we outline and recommend should lead to a decrease in the deforestation of the Amazon, leading to the decrease in loss of biodiversity.

How Did We Collect Our Information?

Figure 4: "DSC_7366-wild flower Amazon rain forest Ecuador" by av320phile, CC BY-NC-SA 2.0

In order to approach this problem, our team read many articles about the Brazilian economy and why the Amazon is being deforested. These articles have been discussed throughout the chapter and are linked here for those who want to read more in-depth. In our search to fully understand this project, we also conducted interviews. We interviewed four people: Dr. Charles A. Hall, Kathy Wolf, Dr. Claiton Marcio da Silva, and Professor Thomas Rogers. Dr. Hall, a systems ecologist, discussed during our interview the Law of Conservation of Evil. This is the theory that as one problem is fixed, another arises in its place. This is important in our project because we need to make sure that as we try to stop the deforestation of the Amazon and the loss of biodiversity, we are not ruining Brazil's economy and people's source of food.

Kathy Wolf, a research social scientist with ties to the USDA Forest Service and the University of Washington, discussed during our interview how there can be a better spatial efficiency of people. We can use what we have a lot better than how we are currently. One way this is being done is by Biophilic City Networks. This is an initiative to use nature and its resources more efficiently and effectively. Many cities are innovating by redesigning land to have multiple purposes. This relates to our project because if we can use our land more effectively and with multiple purposes, then we do not need to use as much land and the Amazon can stop being deforested.

Figure 5: "Canoeing in the Amazon Rain Forest" by Albert Michaud, CC BY-NC-SA 2.0

Figure 6: Soybean Harvest by UnitedSoybeanBoard, CC BY 2.0

Dr. Marcio da Silva, a professor at the Universidade Federal da Fronteira Sul (UFFS) in Santa Catarina, Brazil, gave us a lot of background on the problem. He talked a lot about the soy industry. He told us that most domesticated animals are fed by soybeans and Brazil is one of the largest producers of soybeans in the world. He also mentioned that every year about 73% of Brazilian soybeans are exported to China, which means that stopping deforestation of the Amazon could lead to a major decline in Brazil's economy. This is something that is a major factor when determining solutions and recommendations for this problem.

Thomas Rogers, a professor in labor and environmental history focusing on Brazil, discussed mainly what various steps can be taken when trying to stop the deforestation of the Amazon. His remarks can be found in the Recommendations section.

Our Findings

Through this investigation, we have uncovered a significant amount of information surrounding our research questions. It was unfortunate to uncover how little power one person has on this issue or even 10,000 people do, as this problem is controlled by a few powerful people in only a few countries. Another significant note is how severe this problem can become if nothing is done in the next couple of decades. The Amazon is an ecosystem like any other that requires a certain amount of vegetation to create its water supply that leads to its rainforest qualifying precipitation. Many reports indicate that 15-17%of the Amazon has already been lost, and if more than 25% of the Amazon is lost a severe irreversible problem will arise (Irfan, 2019); there will not be enough vegetation to cycle the water supply (Irfan, 2019). The eventual demise of the Amazon will not lead to a massive plot of soy farms, but a **savannah**.

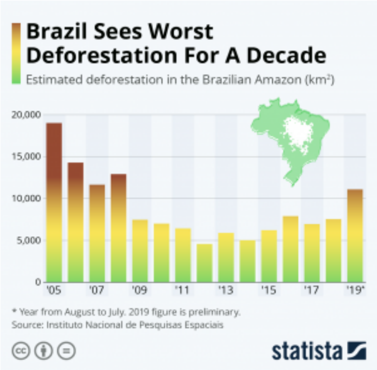

Figure 7: "[Estimated deforestation in the Brazilian Amazon]" by Instituto Nacional de Pesquisas Espacias and Niall McCarthy (Statista), [CC BY-ND 3.0].

Through our research, we were able to compare different administrations and their impact on the environment. Generally, presidents before 2003 did not care about the environment to an effect that there were any significant decreases in deforestation rates. Then things began to change under the administration of Luiz Inácio Lula de Silva. Lula de Silva was able to lobby for more land to be considered protected and gave more to indigenous tribes. Though Lula de Silva's presidency came to an end in 2011, his outlook on the environment continued under the administrations of Dilma Rousseff, his successor. Things began to degrade from there as more conservative, agriculturally minded congressmen were elected leading to the current President, Jair Bolsonaro. Under Jair Bolsonaro, in 2020 Brazil had seen its worst year of deforestation in a decade.

Through our interviews, we were able to collect a lot of information that would lead to us understanding this problem more and finding realistic solutions to this problem. To understand the problem, Professor Rogers and Dr. Marcio da Silva helped a lot. Professor Rogers talked about how small-hold farmers are getting blamed for a lot of the deforestation when in reality, it is the farmers with a greater wealth that are doing this. There are a lot of small-hold farmers deforesting the Amazon, so many people think that they are the cause. If we look at the acreage of their deforestation, we see it is a lot less than more established farmers. Another thing we learned from our interview is that the soil in the Cerrado is not good for growing crops, so in 1973 there was a mandate to make the Cerrado bloom (The Economist, 2013). This worked very well and soil amendments were found in order to enrich the soil and make it amenable to cropping. This happened at the same time Asia had a rise in food needs and was looking for “high quality, protein rich animal feed” (Rogers, 2020). They were looking for soy, and Brazil quickly became one of the largest soy exporters in the world behind the US. In 2019, they took over the role of the largest soy exporter in the world because of Trump’s trade war with China.

In 2006, there was a soy **moratorium** signed by all of the biggest producers of the world producing out of the Amazon. This moratorium basically said that they will not produce out of the Amazon, and it worked. The deforestation of the Amazon decreased steadily over the early 2000s. Unfortunately, the rates came back up. Just last week the reports for this past year said that 10,000 kilometers squared were deforested, which is 34.4% higher than last year (Butler, 2019). It is said that most of the deforestation is caused by illegal burning, and in 2018, 90% of the fires were illegal (Rogers, 2020).

Dr. Marcio da Silva touched upon what needs to be done in Brazil in order for anything to change. He said that the European Union is important, and it is important that they put some pressure on the Brazilian government to decrease deforestation. He continued to say that though the EU is important, nothing will change much unless China also puts pressure on Brazil, because 73% of Brazilian soy export goes to China. Unfortunately, at this moment China is not doing anything (Marcio da Silva, 2020). He also told us that the main change will not come from social pressure on the Brazilian government, but rather from work pressure. Brazil wants to protect its economy and the livelihoods of its workers, so unless a majority of their workers demand change or China does, our recommendations in the following part will only be steps to helping the problem, not the full solution.

The main conclusion of our research is that something needs to change now. The Amazon needs to start being protected more now. If we wait too long it will be too late. Though this sounds intimidating, it is not. The next section will talk about our recommendations for this problem. If these recommendations are followed, along with what we believe still needs to be done, it is realistic to assume that the Amazon can be saved. For the general public reading this, it may seem like a big problem that you alone cannot fix. That is true, but you are not alone. Many people are trying to save the Amazon. The French government, along with Ireland and others, are trying to save the Amazon (Corbet & Leicester, 2019). This may seem like a big undertaking, but our conclusion is not that one person can save the Amazon. Many people need to take action. There are already a lot of people, but more people discussing this issue will only help to get it resolved faster.

What Now? Our Recommendations

Figure 8: "[Foto Oficial do Presidente da República, Jair Bolsonaro]" by [Palácio do Planalto], [CC BY-NC-SA 2.0]

Although this is a huge issue, it can be solved. In 2006 there was a soy moratorium that was signed by all of the biggest producers of soy saying that they will not produce out of the Amazon. This worked very well and deforestation decreased at pace. That stopped when Jair Bolsonaro became president. He is, unfortunately, not a friend of the environment, so when the 2002-2016 worker power got cut, so did the IBAMA budget. Though this is unfortunate, it shows what the solution to stop deforestation could be.

Figure 9: "I[llegal deforestation in Matro Grosso is the target of an IBAMA operation] (Photo: SEMA / Christiano Antonucci)" by Brasil de Fato, [CC BY-NC-SA 2.0]

When trying to find solutions, we reviewed our interviews. The interview with Dr. Hall was very important because it made us think about the implications of our proposed recommendations. We considered the **Law of conservation of evil** in all of our recommendations and believe that our recommendations will not cause any harm. The interview with

Professor Rogers was particularly helpful. He advised us to look at what has already been done and has worked. This is when we looked at previous environmentally friendly governments in Brazil and how they drove down deforestation rates drastically. So what were they doing differently? That's a simple answer: they were giving funding to various companies and empowering the agencies that were dealing with the Amazon (Rogers, 2020). He told us about all the wonderful laws that Brazil has in place that unfortunately are not enforced. So now that we know this, what is a solution we should propose? With the help of Professor Rogers, we decided that political will needs to be generated to enforce the laws on the books. We know this is realistic because it happened in 2017 (Lorenzon, 2017). As Professor Rogers put it, "We need to do more than just what the British see." Now is the time for the world to come together as a union to protect this special ecosystem of the Amazon before it is too late. Many people seem to think this is not an issue right now, that we can come back in the future and worry about it then, but that is simply not the case.

One recommendation is instead of boycotting agencies involved with deforestation, we pay them not to harm the Amazon. This is something that an outside power can do. Agencies would be more open to this idea than having groups lobbying against them (Rogers, 2020).

Figure 10: "[One and Other-Amazon Rain Forests](#)" by [Feggy Art](#), [CC BY-NC-ND 2.0](#)

Another recommendation for an outside power would be to partner with Brazilian companies. In the past, Brazil has not taken too kindly to foreigners coming in because they do not understand how closely linked the Amazon is to Brazil and Brazilian culture. By partnering with Brazilian companies, such as environmental **NGOs**, the people of Brazil would be more open to the ideas suggested by the people that live there and understand their culture and way of life. This would also allow new ideas to come in from outside powers without it seeming like they are trying to change Brazilian culture. In the 1992 Earth Summit held in Rio, environmental groups in Brazil got a big boost. The groups developed more and proposed laws. Brazil has a lot of really great laws, but they are not enforced. This leads to our third recommendation.

We recommend that companies involved with Brazilian companies try to get those companies to generate the political will to enforce the laws Brazil already has. These laws have already been passed by legislature and just need to be enforced. A 2012 forest code protected 80% of the Amazon from being deforested. When it was revisited, it was revised to give landowners more power over their land. Though they allowed increasing how much of their property they could deforest, it was still a small enough amount that would save the majority of the Amazon. If that law is enforced, then already a large amount of the Amazon is protected.

Figure 11: “[Vegetarian food](#)” by [Nahid-V](#), [CC BY 2.0](#)

Our fourth recommendation is something that will be hard to change, but if it is done, it will be very positive. The various trends in food change frequently and rapidly. Due to this, changing food habits should not be the sole thing being done in order to protect the Amazon, rather one of a few things. Brazilian beef consumption has increased to 5 times as much as the start of the 20th century. One reason for this increase is aspirational eating. This is when people mimic the eating patterns of what has been shown in commercials. If eating more plant-based diets becomes popular in commercials, then the public will be more likely to change their diet. This will lead to less need for pasture land for cows and the land that they have for other products should be enough. This is a recommendation for the general public: change your diet. We are not saying boycott meat from Brazil. We are saying to try to eat less meat. One of Brazil’s most important exports is soy. By reducing the general public intake of meat, it will not bankrupt the Brazilian economy. Brazil exports a lot of soy to feed China’s animals, but animals produce more than just meat. Reducing how much meat you eat will not make China stop feeding their animals and needing a lot of soy to do that.

All of our recommendations are things we believe are practical and will help the Amazon. That does not mean that the problem is solved once these steps go into place. There are other things that need to be done. One of those things is more research on co-beneficial land, as talked about by Kathy Wolf. This is something that will maximize what the land has to give. She told us that we can use what we have so much better in terms of efficiency. We also believe that there should be more research on sustainability and more steps taken to achieve that. Finally, one last thing that, at this time, our group believes still needs to be done is for the Brazilian workforce to care. They are worried about their livelihood, which is understandable, but with reasonable change, they can keep their livelihood and save the Amazon.

Figure 12: "Sustainability graphic on Performance.gov" by Innov8social, CC BY 2.0

Conclusions

In conclusion, we believe that things need to change now. As already stated, 15-17% of the Amazon has already been lost and we cannot let it get to 25% (Irfan, 2019). The current administration in Brazil is contributing to this problem, but they have shown little effort to prevent the fires or deforestation in the Amazon. The next Brazilian president needs to care about the environment and be more like Lula da Silva, someone who cares about the land and its protection. Although it is good to have some agriculturally-minded congressmen in the government, we also need environmentally-minded congressmen who have more of a say. The Amazon does not just impact Brazil, it impacts the world. Likewise, the destruction of the Amazon will not just impact Brazil, it will impact the world.

Our research proves that this issue is not only ecological and economic but also social and political. The social aspect is the culture of Brazilian people. The indigenous tribes that Lula da Silva gave more of the Amazonian land to identify the Amazon as part of their culture. Another social aspect is something that can also be considered political. Brazil is not inclined to let foreign governments or companies come to Brazil and demand things. In order to get things accomplished, there needs to be a balance between foreign governments and companies demanding things and respecting the Brazilian people. If Brazilian companies are the ones to demand changes and are backed by foreign companies, things are more likely to change. Another political aspect is that there are environmentalists in Brazil, but as Dr. Marcio da Silva stated, "Brazil's right-wing and left-wing are committed to development to increase exportation and to increase money to build infrastructure." (Marcio da Silva, 2020).

Through this study, we were able to investigate the agricultural impacts on the Brazilian environment and just what exactly is at risk. The ecosystem surrounding the Amazon river is biodiverse like no other corner of the globe with 2.5 million species, some at risk of extinction now and many more in the inevitable future. As a species of this planet that has benefited from the Amazon's medicinal and carbon controlling components, we have an ethical responsibility to protect and converse this ecosystem. This research and proposed solutions will benefit society because they will help save our planet. Otherwise, 2.5 million species will lose their homes, and many of them will go extinct. We will lose one of the most biodiverse ecosystems in the world (Thomson, 2020). We will also lose 20% of the world's freshwater (Brazil and the Amazon). One of the most concerning things that could happen though is the

2 billion tons of carbon that the Amazon holds (Eaton, 2018), which could be released into the atmosphere (Marshall, 2020).

We believe that there are other situations when a similar solution may be helpful. There are a lot of other forests being deforested, not just the Amazon. The Amazon is what we decided to focus on for this project, but with some tweaking of our recommendations, they can be beneficial for other forests. Something that we believe others can learn from our project is that we need to think outside of the box sometimes. Who would think that in order to solve a problem, we should backtrack and do what those in the past did? That is what needs to be done in this case, though. Another thing we think people can learn from our project is that a big problem requires a big effort to solve. Time and research need to go into understanding the problem. Then the problem needs to be analyzed, and then it can be solved. The solution will not be only one step, rather it will be multifaceted. It will not be able to be fixed in a matter of days or weeks or even months. It may take years, but if energy is put into understanding the problem and analyzing it, the solution will show it. We also want to remind people that some steps of the solution may not work or may need to be revised. Most solutions are not 100% accurate to start. It takes time to perfect them, but if you put in that time, they will work.

Acknowledgments

We wanted to acknowledge and thank Dr. Charles Hall, Kathy Wolf, Dr. Claiton Marcio da Silva, and Professor Thomas Rogers for taking the time to talk to us. Without these interviews, our chapter would not be what it is. We also want to thankProfessor William San Martin, Professor Marja Bakermans, andour PLA Blaise Pingree.

Additional Resources

We would like to recommend for more information, the reading of an article called “The Root of the Problem: What’s Driving Tropical Deforestation Today?” This was a very helpful article for us when writing this chapter and provides a very detailed account of what is happening in the Amazon. The link to the article is here. We would also like to recommend that this video be watched. It is a video detailing what is happening in the Amazon. It presents the information of the causes of deforestation and their effects in a clear way. We recommend visiting both of these sites because they complement each other well.

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2. The Jaguar: From Apex Predator to Mankind's Prey

Robert Belmonte, Sol Giesso, Alana Lue Chee Lip, and Mikayla Raffin

Abstract

Panthera onca is the largest feline in the Americas. They are **apex predators** that feed **opportunistically** on a wide variety of prey and thus regulate their ecosystem from the **top-down**. Historically, they have been found in areas stretching from the southern United States to Argentina, but their range is now concentrated in Central and South America due to habitat loss. Humans are a major threat to jaguars being responsible for habitat loss, poaching, and retaliatory killings. Given the jaguar's ecological, cultural, and economic significance, conservation efforts need to be implemented by many countries to help preserve jaguar populations.

***Figure 1**: The jaguar (Panthera onca) and its physical appearance.* "Jaguar at Chester Zoo" by Steve Wilson, CC BY 2.0.

The jaguar (*Panthera onca*) is the largest cat in the Americas, measuring five to six feet long (not including its tail) and weighing up to 250 pounds (about 113 kg). Males are usually slightly larger than females in both size and weight (Law et al. 2020). As such big creatures, jaguars are **apex predators**, meaning that they prey on many different species within their habitat without being preyed upon themselves. Their lifespan ranges between twelve and fifteen years in the wild, around the same as most large felines (Law et al. 2020). Their coats are pale yellow with rosettes, similar to the coat of a leopard, as shown in Figure 1.

Jaguars live mostly in Central and South America, with their habitats ranging as far north as Mexico and the southern United States, and as far south as Argentina (Quigley et al. 2017). They can live in various habitats including mountainous areas, jungles, and grasslands, but they primarily live in dense forests near water. Vegetation is particularly important for their hunting style, in which they rely on surprising the prey in proximity rather than chasing them. They tend to avoid arid and dry climates as they need water for temperature control and food (Crawshaw and Quigley 1991). By the turn of the 20th century, jaguars had a geographic range of approximately 19,000,000 km^2, but this range is a reduction of over 50% from their estimated range in 1900 (Sanderson et al. 2002).

Given that the jaguar has inhabited the Americas since it evolved about two million years ago (Law et al. 2020), it has been the subject of many myths and indigenous beliefs. One old Mayan legend tells the story of the mighty jaguar's origins, and it goes like this:

> *Many years ago, in the rainforest of the Mayan World, all animals were great friends; the deer, the curassow,*

*the **peccary**, the crocodile, and the monkey treated each other with respect and did not prey on each other, instead feeding on herbs, fruits, and seeds.*

The most admired animal was the jaguar, who had no spots at the time. His blonde skin glowed and he would often approach the water to see his reflection. "No one has skin as perfect as mine," he would say, boastfully.

One day, some monkeys found an avocado tree and started eating the fruits that had fallen and throwing them at each other. The jaguar got close to the monkeys, and one of them jokingly threw an avocado at him, staining his back. They all started laughing, but the jaguar felt humiliated and enraged. He captured the monkey and took him to his cave to eat. The rest of the animals escaped, horrified.

Nearby lived Yum Kaax, the god of vegetation and guardian of the animals. The monkeys explained what had happened and asked for help. Yum Kaax responded, "We will give this arrogant animal a lesson," and sent the piccaries to help.

*The next morning, the strongest **peccaries** arrived at the jaguar's cave and led him to the black sapote tree, where the monkeys awaited. They threw the tree's fruits at the jaguar, staining his entire coat. The feline escaped to wash himself, but the spots would not come off – they were magic ones from Yum Kaax.*

*The jaguar roared and threatened the others: "From now on you are my enemies, and I will never leave you alone!" For some time, the monkeys and the peccaries were captured by the jaguar with ease. Yum Kaax realized they were at a disadvantage, so he gave the monkeys long tails so they could climb up high and the **peccaries** thicker skin and sharp fangs.*

Now the monkeys do not come down from the trees *often; they learned to live almost entirely on them. When the jaguar starts climbing a tree, the monkeys yell and flee. The* ***peccaries*** *remained on the land, but when the jaguars approach, they huddle up and defend themselves with courage.*

The jaguar now needs to work harder to catch its prey. He learned not to be narcissistic and to live hidden within the vegetation. Only like this he can surprise his prey.

Regardless, the jaguar was still feared and admired, not only by the animals but also by the Mayans, to whom it symbolized power and fierceness.

As a top predator, the jaguar is an **opportunistic**, **generalist carnivore**, so its prey ranges from capybaras, deer, and armadillos to tortoises, livestock, and fish (WWF 2020). They typically kill by attacking with a deep bite (Figure 2) to the neck that suffocates the prey, although they have more specific techniques for certain animals. For instance, they use their paws to scoop out the meat from a turtle or a porcupine's body, whereas to hunt crocodiles they paralyze them with a bite (Law et al. 2020). To some, it may sound strange that jaguars hunt aquatic prey, such as turtles and fish, since cats are commonly thought to be averse to water, but the jaguar is actually an avid swimmer and diver and likes to spend time near water.

Figure 2: *Photograph of a jaguar's deadly jaw and fangs. [Photo](#) by Arcaion, [Pixabay license](#).*

Jaguars tend to hunt alone since they are **territorial** (Garcia Fontes et al. 2021), but they have occasionally been observed hunting in pairs as young siblings (Law et al. 2020) or when they form temporary pairs during mating periods (SDZGL 2020). They are **nocturnal** and spend the majority of their time resting and hiding so they can ambush their prey, with little time in transit (Crawshaw and Quigley 1991). Their coat pattern aids this method of hunting as it allows them to blend in with the dappled shadows on the forest floor. Furthermore, food is not a limiting factor for jaguars since they are **generalists**, so they are not regulated from the **bottom-up** in their natural habitats. Instead, their low population density (shown in Figure 3) is mostly determined by their own territoriality (de Azevedo and Murray 2007). The fact that they are rarely regulated from the **bottom-up** is particularly important because it means that they are less threatened by the extinction of prey species that may be more susceptible to human impacts. Instead, jaguars regulate the ecosystem through **top-down regulation**.

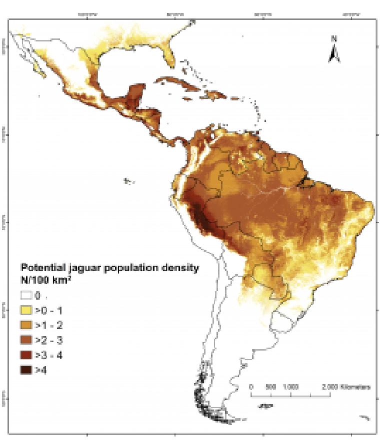

Figure 3: *Potential population density of jaguars in Central and South America. "[Predicted spatial variation of jaguar potential densities across North and South America](#)" from Jędrzejewski et al. (2018), [CC BY 4.0](#).*

Since they strongly influence the populations of other species (especially those in lower **trophic levels**) in the region through this **top-down regulation** (de Azevedo and

Murray 2007), the jaguar is regarded as a **keystone species.** A study found that around 60% of the mortality of jaguars' prey species is due to predation by jaguars, and 91% of the predation incidents in the area were carried out by jaguars (de Azevedo and Murray 2007). However, since the jaguar often prefers larger species, they sometimes consume them indiscriminately, which can lead to drastic decreases in the prey's population size and ultimately result in destabilization of the ecosystem (de Azevedo and Murray 2007).

Although the jaguar may appear to be a fierce, cruel creature with regards to its prey, it is equally as terrorized by humans. The main threats facing *Panthera onca* are habitat loss and **fragmentation**, killing for trophies, illegal trade of body parts, retaliatory killings associated with livestock **depredation**, and competition with human hunters for wild meat.

High deforestation rates in South America related to soy, palm oil, and cattle ranching contribute to habitat loss and **fragmentation**. As the jaguar's habitat is invaded by humans for agriculture, its native prey is displaced. As a result, jaguars resort to hunting cattle, but this often leads to them being killed in retaliation by angry farmers. This problem is exacerbated by the fact that the demand for wild meat (much of which includes jaguars' prey items) increases with the increasing population of Latin American countries (Quigley et al. 2017).

Another major threat to jaguars is illegal trafficking, where poachers sell their furs, teeth, skins, and claws as clothing or jewelry (Arias et al. 2020), as illustrated by Figures 4 and 5. Although commercial hunting for jaguar fur has drastically declined since the mid-1970s, the demand for their paws, teeth, and other parts remains (Quigley et al. 2017). Since most jaguar trafficking occurs locally and is not highly organized, it is difficult for governments to regulate it. This matter is made even more complicated by the fact that their range includes many different countries, each of which has its own unique laws against poaching.

Figure 4: *Photograph depicting the illegal wildlife trade of large felines, including the jaguar.* "Illegal Wildlife Property" by *Ryan Moehring, USFWS, CC BY 2.0*.

Figure 5: *Exhibit in the South American collection of the American Museum of Natural History, Manhattan, New York City, New York, USA of a necklace featuring jaguar teeth.* "Necklace, jaguar teeth on palm fiber cord, Tucano people – South American objects in the American Museum of Natural History" by Daderot, CC0 1.0

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The remaining jaguar population size is very difficult to determine because of their secretive nature and low-density distribution. Their population density varies (as previously shown in Figure 2), but the jaguar is found more commonly in areas with less human interaction (Quigley et al. 2017) farther away from cities and human development. Most estimates of population size range between 64,000 (Quigley et al. 2017) and 173,000 individuals (Jędrzejewski et al. 2018)—an unusually disparate range for such large mammals. Because of this, it is difficult to gauge how extensive and detrimental the human impact on jaguars truly is. There is typically about a 1:1 ratio of male and female jaguars both in the wild and in captivity (Baker et al. 2002), so chances of reproduction are not often a limiting factor in large subpopulations, although the number of cubs one mother can support at one time can be limiting.

It is during reproductive periods that jaguars break some of their normal behavioral patterns. Female jaguars roam widely throughout their habitat during **estrus** (a 6-17 day period) to advertise that they are receptive to mating (CSCOZ 2020) and increase their chances of finding a mate. Males and females form temporary pairs, traveling and feeding together until they separate after copulation (SDZGL 2020), as males sometimes kill and eat the cubs (Law et al. 2020). Since females go into **estrus** every 47 days, reproduction and births can occur year-round (SDZGL 2020), but births in temperate regions are often concentrated in the summer when food is most abundant (CSCOZ 2020) since mothers need to find enough large **ungulate** prey to feed their cubs. Gestation lasts 100 days and litters contain 2-4 cubs (shown in Figure 6), which are completely dependent on their mother for the first year of life (SDZGL 2020). By two years old, the juveniles are finally independent of their mother and go on to reach **sexual maturity** by the age of four (SDZGL 2020).

Figure 6*: Photograph of a jaguar mother in captivity and her newborn cub. "Mother jaguar and cub" by Jim Bauer, CC BY-ND 2.0.*

Given their small litter size and the cubs' extended dependence on their mother, along with habitat loss and other human threats, the overall status of the *Panthera onca* is near threatened according to the **IUCN Red List**. However, this designation varies across different regions and subpopulations (Quigley et al. 2017). For instance, populations in 70% of its range have a high probability of survival, while those in 18% of its range have a medium probability of survival and those in 12% of its range have a low probability of survival (Quigley et al. 2017).

The jaguar has already become **extirpated** from El Salvador, Uruguay, and largely the United States. It is also suspected that the jaguar population has declined by 20-25% over the past three generations, and their range has decreased by 20% between 2002 and 2015 (Quigley et al. 2017). However, these numbers could be significantly underestimated due to their secretive and solitary nature. Connectivity between populations has also declined, leading to more frequent **extirpations** and loss of **genetic diversity**. Moreover, these increasingly isolated groups have smaller populations and fewer chances for reproduction. Out of the 34 different subpopulations of jaguars that live in Central and South America, 73% of them met the **IUCN Red List**'s criteria for being **critically endangered**. The largest subpopulation, which lives in the Amazon rainforest and hosts 89% of all individuals, was considered to be **Least Concern** (Quigley et al. 2017), but this could change quickly as habitat loss continues.

The loss of jaguar populations has adverse effects on the environment, as well as on human society and the economy. In terms of the environment, the loss of large **carnivore** species such as the jaguar leads to **trophic cascades**, due to the previously discussed **top-down regulation** afforded by such species. This **trophic cascade** involves dramatic changes in the population numbers of species in lower trophic levels (Estes et al. 2011), as well as changes in the **abiotic environment**. For instance, if the jaguar were to go extinct, herbivore populations would increase. This would then lead to increased feeding upon the area's vegetation, and would ultimately result in a decrease in plant abundance and possible changes in the distribution of plant species. Furthermore, a change in plant species distribution could change factors such as the ratio of carbon to nitrogen in the soil, which could then lead to further changes in the ecosystem (Ripple et al. 2014). On the other hand, if jaguars ate too many herbivores, producer density would largely increase and this increased competition between plant species may also lead to changes in their distribution.

In addition to this regulation of the environment, jaguars are also regarded as **umbrella species**, meaning that their conservation benefits that of other species. In a study that looked at mammals in the Americas, they found that the best habitats for jaguar conservation also hosted between 70% and 81% of the other mammalian species found in the region (Thornton et al. 2016). Since jaguars are charismatic species, they could also act as **flagship species** to encourage the conservation of whole ecosystems in their natural range, helping to achieve a greater goal of regional conservation.

With regards to human society, jaguars have historically held ritualistic, social, and cosmological importance in many different cultures (The jaguar: a… 2020) from the Mesoamerican time period to the current day (Morales Garcia and Morales Garcia 2018). They are both a symbol of balance between life and death and a symbol of strength and protection in addition to being viewed as the perfect animal that lives in a perfect state of balance with its environment (The jaguar: a… 2020). In many ancient cultures, the jaguar was venerated and admired, as shown by the legend at the beginning of this chapter as well as the statue in Figure 7. The extinction of the jaguar would therefore have a significant cultural impact on the native people of the Americas. Moreover, the cultural importance of jaguars could be very beneficial in planning conservation efforts. The bald eagle is a relevant example here as its journey towards recovery was largely aided by its symbolism and importance in American culture (Davis and Nagle 2015, p198-199), and the jaguar could utilize a similar strategy in its conservation efforts.

Figure 7*: Ceramic representation of a man-jaguar from the Mayan classic recent era (600-900 CE).* "Homme jaguar maya" by Jebulon, *CC0 1.0*.

Jaguars are also important to many local economies in the Americas. **Ecotourism** in Central and South America has increased dramatically in the last few decades as more people are visiting national parks to observe unique organisms in their natural habitats. The jaguar in particular has been a boon to the region with regards to this recent boost in **ecotourism**, helping to bolster local economies (Tortato and Izzo 2017). The Matogrossense National Park in Brazil has even established a management plan for jaguars, allowing ecotourists to observe them within conservation areas (Tortato and Izzo 2017). By learning more about jaguars, people are also more likely to spread awareness about their plight and help fight for their conservation.

Following this theme, one of the most common conservation efforts used in the effort to protect jaguars is educating local communities and collaborating with them to implement new conservation strategies. Agricultural and timber workers are often specifically targeted since their actions can greatly harm the jaguar population if they are not properly aware of the consequences they can cause.

Furthermore, studies have found that people tend to be scared of jaguars, and those who are afraid or have known a person/animal that was a victim of an attack more often favor jaguar persecution (Knox et al. 2019). This is an important factor to consider when planning community-based jaguar conservation strategies. Additionally, older people were more likely to have killed a jaguar, while younger people tended to view this action negatively (Knox et al. 2019), likely because of changing values and growing awareness about the importance of wildlife conservation. Attitudes about jaguar persecution also changed by region, as shown by Figure 8. Since this cultural background also plays a part in people's perception of jaguars, addressing concerns with locals to lead united efforts for conservation is crucial, especially since a large part of the damage being caused to jaguar populations comes from direct human actions.

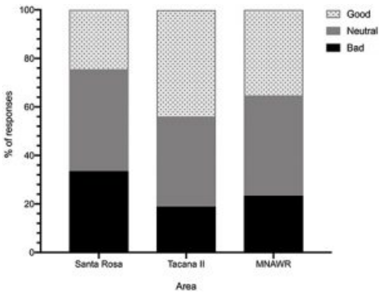

***Figure 8**: Proportion of attitudes towards jaguar killing by area in protected territories of the Bolivian Amazon. The figure shows that there are differing opinions between territories and that around 30% of all respondents favored jaguar persecution. "[Proportion of residents who reported killing a jaguar in the past, by area]" from [Knox et al. (2019)], [CC BY 4.0]*

Another common conservation strategy involves monitoring the jaguar population in specific areas to see how they interact with the land and the status of the land (i.e., whether it is used by humans) in order to come up with targeted conservation efforts that will have maximum efficacy in that specific area.

Since habitat loss and **fragmentation** are two major dangers to jaguar populations, some conservation groups—such as Costa Rica's National Program of Biological Corridors (Zeller 2021)—have bought land to form protected **ecological corridors** to connect isolated populations. Although this is not the most effective long-term strategy, it helps conservationists in the short-term by allowing them to devise more efficient long-term plans for maintaining these corridors and ultimately protecting the jaguar population (Root 2019). The importance of these **ecological corridors** cannot be overemphasized, as they allow for increased **genetic diversity** by facilitating the breeding of unrelated jaguar populations.

While these privately funded conservation efforts are undoubtedly beneficial, governments must also be engaged in the work of conservationists. To this end, there have been federal recovery goals recently set in place to guide jaguar conservation efforts, which vary by region. Once these have been achieved, the species' status should be considered for

downlisting. Its habitat has been classified into two distinct regions known as recovery units: the Pan-American Recovery Unit (PARU), which encompasses 18 countries from Argentina to Mexico, and the Northwestern Recovery Unit (NRU), which extends from southern Arizona to southwestern New Mexico (USFWS 2018).

In the PARU, the jaguar should be considered for **downlisting** when its status is changed to Least Concern according to the **IUCN Red List** criteria. This denotes that threats to the species have been reduced so that its population is no longer at risk of a greater than 30% decline in size (USFWS 2018).

In the NRU, the species should be considered for **downlisting** when, in key areas over a period of 20 years, it maintains a roughly 60% occupancy in each of the designated core areas, **inbreeding coefficients** do not increase, an average of at least 30% of the adult population is female, and a large network of high-quality habitat is maintained. This network of habitat must include at least two trans-border linkages that allow jaguar dispersal and there must be strategies in place to mitigate impediments to all such **ecological corridors**. Furthermore, effective laws must be put in place at all levels of government to ensure that the killing of jaguars is regulated/prohibited, as the threat of direct human killing of jaguars must be decreased in order for **downlisting** to be considered (USFWS 2018). These laws would ideally also protect other native species that the jaguar relies on (Jaguars… c2021).

The mighty jaguar is at a crossroads. Our actions have not yet damaged them beyond recovery, but unless changes are made the jaguar will suffer the unfortunate fate of so many other species on our planet. The loss of such a culturally, socially, economically, and ecologically significant species would have major repercussions in many communities in the Americas, so it must be fought against at all costs. This is why the previously mentioned conservation efforts are so important, but these are only just the beginning. More needs to be studied about this spectacular species to guide proper action. Further initiatives must be put forward in order to engage people in every level of society across the jaguar's wide range so their plight will not continue to worsen. In doing so, we hope that one day the jaguar will return to its former glory at the top of its food chain, just as the Mayans observed.

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3. Greater Bromeliad Tree Frog: The Prima Donna of Herpetofauna

Nazanin Beigi, Erin Bryan, Hannah Dobson, and Niralya Sundararajan

Abstract

When one is told to imagine a frog, they would likely think of a species that is the size of their palm. However, the species this chapter will be dedicated to is not nearly as large, but make no mistake—it is certainly a persistent little creature. *Bromeliohyla dendroscarta*, also known as the greater bromeliad Tree Frog, is part of the Hylidae family. Located at high altitudes within the cloud forests of Mexico, *B. dendroscarta* nests in the **phytotelmata**, or water-filled cavities, of bromeliad plants. A combination of its secluded habitat and declining population rates have left *B. dendroscarta* mostly unknown to the world; in fact, it had been classified as extinct from 1972 to 2017, a staggering 45 years. This chapter will discuss the characteristics and traits of *B. dendroscarta*, alongside factors for its decline and conservation strategies.

Figure 1: Adult *Bromeliohyla dendroscarta*, by Victor Vásquez-Cruz in Vásquez-Cruz et al. (2019), BY-NC-ND

Introduction

Legend has it, when the vast sea of fog in the cloud forest parts and the rays of the sun shine down upon the mossy earth, witnessing the golden shine of the greater bromeliad tree frog is an experience surpassed by none other. Prowling through the fields of moss and the labyrinths of trees in Central Mexico, researchers have been on the hunt for the frog since its last sighting in 1972. As stories and tales are routinely passed down about this fabled creature, the line between fact and fiction has been blurred. However, through all these stories carved on tablets, passed from word of mouth, or written in novels, one identifying factor remains consistent—a small, golden head poking out of a blooming bromeliad affixed to a tree.

Physical Traits

This species is, in fact, endemic to Mexico (Bañuelos et al. 2017). The greater bromeliad tree frog (*Bromeliohyla dendroscarta*) is a small frog—only a 30-millimeter snout to vent length (which measures from the nose to the cloacal slit) for males and a 36-millimeter length for females. One eye is equal in length to the snout, and the toes are webbed and about one and two-thirds of a millimeter. The adults have a variety of yellow and white tones across their bodies and gold irises (Vásquez-Cruz et al. 2019). Most of *B. dendroscarta*'s skin is generally smooth but the **ventral** surfaces of the stomach, throat, and hind limbs are granular. Although most physical traits across relative species are similar, other species in the Hylidae family include terrestrial and semi-aquatic tree frogs.

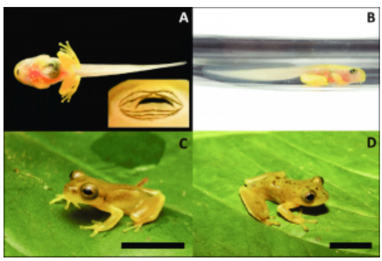

Figure 2: Side and top view of *Bromeliohyla dendroscarta*, photos by Alfonso Aceves-Aparicio (A, B) and José Luis Aguilar López in Bañuelos et al. (2017), CC BY-ND 4.0

Habitat

Bromeliohyla dendroscarta are generally located in the cloud forests that are found in the highlands of Central Veracruz, Mexico. The cloud forest is one of the most biodiverse vegetative **assemblages**. However, due to this, it is highly threatened by deforestation. (Peralta-Hernández et al. 2020). Knowing more about general amphibian **species richness** in cloud forests may help to understand the general context of

B. dendroscarta population trends (Hernández-Salinas and Ramírez-Bautista 2012). Of course, as important as the habitat is to these frogs, it's what's in the habitat that is crucial.

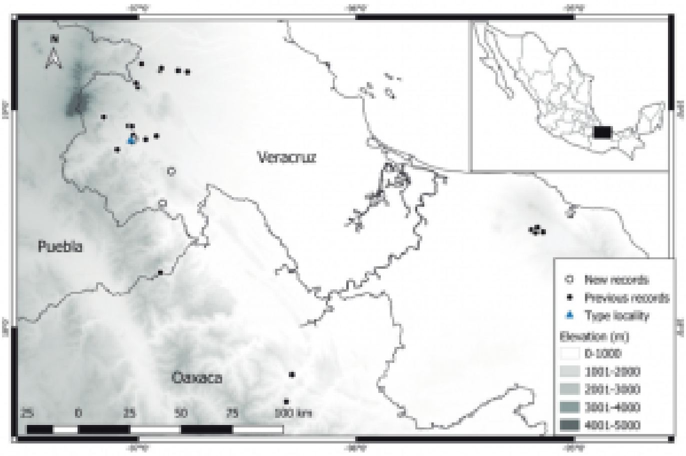

Figure 3: Bromeliohyla dendroscarta range map. "[Geographic distribution of Bromeliohyla dendroscarta, showing the new localities]" in Vásquez-Cruz et al. (2019), [BY-NC-ND]

Micro-Frog in a Micro-Habitat

The habitat that current bromeliad tree frogs live in presents a mutually beneficial relationship between themselves and the bromeliad plant. Generally, bromeliad tree frogs inhabit damp cloud forests. Since frogs are reliant on plants and trees (both for development and nutrition), they have a very close relationship with bromeliad plants within their habitat. Some bromeliad plants are extremely colorful and have lots of branches, while others are a solid green color. The structure of the plant is formed in such a way that it is able to capture water, almost like a pool—that is where the famous name, the bromeliad pool, is derived from. Insects also flock to these pools supplying the tree frogs with ample nutrition. This micro-habitat and its amenities have led to an incredibly strong relationship between bromeliad tree frogs and the bromeliad plant.

Relationship With Bromeliad Plant

Many factors of the bromeliad plant contribute to the survival of *Bromeliohyla dendroscarta*. The big leaves by themselves provide shade for the frog as well as protection from predators by camouflage. Another benefit of the leaves is for the eggs. At times, the frogs will lay their eggs into a water-filled cavity within the plant, known as the phytotelma, to ensure the eggs have access to water (a semi-aquatic style). Based on the greater Hylidae family, some frogs will use ponds or go into trees to lay their eggs. Upon hatching, the tadpoles have an average total length of about 7 mm. Once hatched, the species have suckers that allow them to latch themselves onto rocks, an important adaptational skill that helps with protection and survival. In addition, the **microbiomes** the leaves of the bromeliad plants create for the bromeliad tree frogs benefit the frogs early in their life. The population of this tree frog is intrinsically linked to the population of the bromeliad plant as it is the plant that makes up the frog's habitat for much of its life (Stuckert et al. 2009). The tadpoles of the bromeliad tree frog eat a variety of things found in bromeliad plants, such as detritus, and the adult frogs mostly consume insects and other invertebrates.

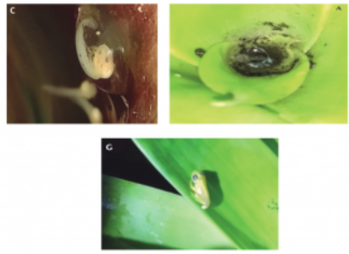

Figure 4: Top left) *B. dendroscarta* embryo. Top right) *B. dendroscarta* tadpole feeding off detritus. Bottom center) *B. dendroscarta* juvenile. Photos by Arleth Reynoso-Martínez (top left), Arleth Reynoso-Martínez (top right), Víctor Vásquez-Cruz (bottom) in Vásquez-Cruz et al. (2019), BY-NC-ND

As important as the bromeliad plant is for the tree frogs, the tree frogs are just as beneficial for the plants. Bromeliad trees and frogs that dwell within present an example of a mutualistic **symbiotic** relationship. Together, the bromeliad plant and the greater bromeliad tree frog aid in nutrient cycling, provisioning food and water, and maintaining community structure and **biodiversity** (Ladino et al. 2019). These plants form a virtual aquarium holding up to 20 liters of water which attract insects, spiders, mites, etc, that the tree frogs feed on. These tree frogs that live in bromeliads bring nutrients to the plant in their droppings. The consumption of these insects in their larval and mature forms helps to keep vectors for disease to a minimum. Litter decomposition in tanks aids in the redistribution of nutrients at the same time as the feces of the frog adds nitrogen to the plant (Ladino et al. 2019). Tree frogs also play an important aspect in the local **food web** as they are prey to larger predators such as snakes.

Figure 5: Distinct photos of bromeliad plants of the genus Tillandsia. Photos by Alfonso Kelly-Hernández (left) and Raul Andrés Díaz-Ramos (right) in Vásquez-Cruz et al. (2019), BY-NC-ND

Life History

Researchers holding a study between 2015 and 2019 in Mexico heard the call of an unidentified tree frog up within the canopy (IUCN 2019). Upon further investigation and location of a specimen, it was made clear that this frog was not a member of one of the local, more well-known species but rather a member of the long thought extinct greater bromeliad tree frog (IUCN 2019). They have been found in single populations across areas in Belize, Guatemala, Honduras, and regions of Brazil. Our focus will be on Mexico. Spending its life in the upper canopy of the cloud forests, it is incredibly hard to get an accurate account of the frog's population and thus local ecologists had thought it had died out in 1974. With this discovery, some very interesting things can be deduced about the relationship between amphibian population and humans' impact on the environment.

Fractured by Humanity (Population Trends)

Demographic characteristics of the Mexican tree frog, Hylidae family, fluctuate due to the ripple effect of changes in environmental factors, precipitation, and temperature. (Cruz-Ruiz et al. 2015). This contributes to changes in the amphibian population and conservation status. These small frog species are at a high disadvantage due to habitat **fragmentation**. The study indicated a 2:1 sex ratio for male:female. In the Central Mexican Plateau, 44.7% of the area is used for agriculture. This presents the possibility of a reduction in the suitability of existing habitat patches which may affect pond-breeding amphibian population dynamics. Even though it is not the bromeliad tree frog, it is the same family located in the same exact habitat (Central Mexico). Simultaneously, the miscategorization of geologically and visually close tree frog species also heavily contributes to the preserved population size. In the past ecologists have believed that the *Hyla cembra* had gone extinct, but further research had shown that living specimens had been misclassified as *Hyla mykter* (Mendelson and Canseco-Márquez 2002).

While other research has found B. dendroscarta to be present as of 2017 in Veracruz, *B. dendroscarta* are reported as still missing from the Sierra Juarez as of 1972. Callings of unidentifiable frogs were heard from bromeliads in trees near Oaxaca and Veracruz (Delia et al. 2013). This is additional confirmation of *B. dendroscarta* being traditionally located in the highland region of Veracruz.

In addition, there was noted to be a link between **altitudinal** habitation and risk level in amphibian species, with many critically endangered species being located at higher elevation levels. This is due to the low dispersal rate and high fidelity towards breeding sites, which are reducing in number due to deforestation. *B. dendroscarta* was found to be located at an elevational range of about 1450 km, with a max elevation of 1900 km (Caviedes-Solis et al. 2020).

Due to limited research findings, it is important to understand the history of amphibians and their trend of decline/extinction throughout the world (Stuart et al. 2004). In the Hylidae family, enigmatic decline and reduced-habitat are leading to amphibian declines and extinctions (Stuart et al. 2004). This is illustrated as tank bromeliad frog species and arboreal frog species were absent from second-growth forests, forests that had previously **slashed and burned** to make space for agriculture (Galindo-Leal et al. 2003).

Over 64% of amphibians are suffering some sort of population decrease in Mexico, in contrast to only about 1.1% of amphibian populations increasing, with *B. dendroscarta* included in the former. It was also documented that the IUCN Red List had registered several species of threatened frogs as being non-native to Mexico when further studies confirmed that they were indeed endemic, such as *Ambystoma mavortium* and *Craugastor galacticorhinus* (Frías-Alvarez et. al. 2010). The potential risks of losing species entirely through extinction were documented in terms of the phylogenetic information lost. *B. dendroscarta* was noted to have a fairly high level of evolutionary distinctiveness (Caviedes-Solis et al. 2020).

Ecological and Societal Impacts

A majority of frog species today speciated from tropical frogs, and *Bromeliohyla dendroscarta* is no exception. The tropical conservatism hypothesis explains that groups with high species diversity originated in the tropics and speciated, spreading from there. *B. dendroscarta* is the result of years of evolution and has unique **phylogenetic** information. In addition, Middle America contains the second-highest root age (the age where Hylids emerged within the area) of any Hylid habitat at 60.65 million years, so it presents the most time for species to specialize themselves into niches (Wiens et al. 2006).

Though *Bromeliohyla dendroscarta* is one of many endemic species in Mexico that occupy two **physiographic** regions and are highly vulnerable, each individual species of endemic amphibian plays a significant role in their ecosystem (Johnson et al. 2017). Endemic **herpetofauna** make up 61.1% of the herpetofauna in Mexico (Johnson et al. 2017). *B. dendroscarta* is a part of the majority of the amphibians in the ecosystems of the country, making it a member of a group with considerable ecological impact. The greater bromeliad tree frog is part of understanding the effects that the complex changes to the hydrosphere, atmosphere, and lithosphere are having on Earth's biodiversity.

Developing Conservation Strategies

The greater bromeliad tree frog and its survival rate have been changing due to the modified landscapes (Bañuelos et al. 2017). Reports showed how **deforestation** and disturbance of the cloud forest are major threats to its persistence. Knowing how dependent the tree frogs are on bromeliad plants for survival emphasizes exactly why deforestation causes a sharp decline in population size. A decline in habitat to lay eggs, to provide nutrients to the tadpoles for development, to protect themselves against predators—all are reflected in their continuous extinction. Because the tree frogs have not been found in suitable habitats since 1974, species like the chytrid fungus, *Batrachochytrium dendrobatidis*, are a serious threat to its survival. The chytrid fungus is a fungus that causes the disease chytridiomycosis in amphibians. This disease is deadly and has caused a sharp decline toward extinction for many species, including the bromeliad tree frog. Based on several sampling methods, reports have shown that the habitats they were in years ago, compared to the habitats they occupy now, have seen an extreme decline in both frog size and population size.

Amphibian populations in Mesoamerica are in sharp decline due to human economic factors (Wilson et al. 2013). The usages of slash and burn forests as a profitable cultural and economic staple of local agriculture leads to intensive loss of habitat (Galindo-Leal et al. 2003). The rehabilitation of this land usage also does little to help as second-growth forests are also not proper habitats (Galindo-Leal et al. 2003). Second-growth forests are inhospitable for bromeliad tree frogs because the main staple of their habitat the bromeliad plants can only survive on old-growth trees. Wilson et al. (2013) make it clear that in order to reverse the damage human and market factors have had on these species' population, steps must be taken to understand the root of the issue, continue to document the issue, fix the immediate issue, and create policies to stop this from happening again.

Another reason that *Bromeliohyla dendroscarta* may be especially vulnerable is that it is one of the Hylids that lives in smaller, more isolated subpopulations that have been made small and isolated by deforestation and other modes of their habitat being fragmented (Urbina-Cardona and Loyola 2008). One of the suggestions for mitigating the negative ecological impact of the endangerment of these amphibians is to create conservation area networks to better coordinate the protection of species like *B. dendroscarta*. These conservation area networks will restore connectivity through the efforts of conservation groups being coordinated in a network, as well as eventually creating corridors between fragmented populations (Urbina-Cardona and Loyola 2008). In addition to developing these coordinated networks, restoring connectivity between fragmented populations is another recommended conservation strategy (Urbina-Cardona and Loyola 2008). Since there are seemingly no conservation effort precedents for *B. dendroscarta* due to its recent rediscovery, all conservation recommendations made are based on those of endemic amphibians at large (Loucks et al. 2008). This is one of the unique challenges of addressing the conservation of a species thought to be extinct until 2017.

Conclusion

And thus, the tale of the elusive little critter, the greater bromeliad tree frog, lives on. A history of destruction, disappearance, and the return of a monarch… such a quaint species should persist for future generations, don't you think?

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4. A Terrifying Island of Snakes that could Hold a Medical Treasure

Eric Adams, Nicholas Kenny, and William Miller

(An important factor to note is the lack of research conducted on this specific species due to the remote nature of the island they inhabit. Much information must be taken from its close relative, *Bothrops jararaca*.)

Natural History

Bothrops insularis, also known as the Golden Lancehead, is known to grow to an average length of 70cm and 90cm but can grow to around 118cm (Guimarães et al. 2014). As the common name implies, the Golden Lancehead is a pale yellowish-brown color and has a head common to the genus *Bothrops* that is triangular in shape (more like the head of a spear than a lance).

The diet of an adult *B. insularis* relies mainly on various bird species. Two species, in particular, *Elaenia chilensis* and *Turdus flavipes*, are some of the most abundant on the island. *B. insularis* is an **opportunistic hunter**, and with these two main bird species being migratory, they are not present on the island year-round (Marques et al. 2012). The diet of an infant *B. insularis*, on the other hand, relies mainly on **ectothermic prey** such as centipedes and frogs (Zelanis et al. 2007).

B. insularis is both terrestrial and **arboreal**, with the latter being mostly for hunting. As for shelter from storms or during digestion, the species is found to hide under leaves or rocks.

Range

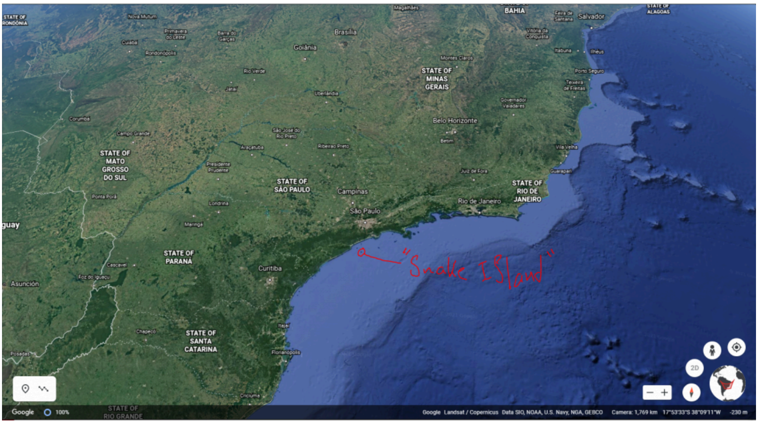

Fig 2: Google Earth screenshot of the island in relation to Brazil

B. insularis is native to Queimada Grande (Guimarães et al. 2014) island off the coast of Sao Paulo, Brazil. Known colloquially as "Snake Island", the home of *B. insularis* is also home to a variety of other exotic and rare snake species and is the only place *B. insularis* has been found. The island is home to a few different **biomes** including rocky areas, small plains, and rainforests—which are the main habitat of the *B. insularis*. The Rainforests are in the lower regions of the island and cover about 60% of the island allowing for the snakes to have a relatively large range.

The *B. insularis*' close relative, *B. jararaca*, is **endemic** to southern Brazil, Paraguay, and northern Argentina. Due to this, it is expected that *B. insularis* could survive and grow in numbers should they be introduced to mainland South America.

Role in Ecosystem

The venom itself is some of the most powerful in the world. It not only has the effects of other powerful venoms like breaking apart red blood cells and causing **hemorrhaging**, but it is actually powerful enough to melt skin. The reason for such potent venom is due to the nature of the species' prey: birds. The venom needs to act quickly enough to immobilize the prey before flying away or to ward off any potential threats, unfortunately also including researchers.

Life History Traits

B. insularis have been found to mate terrestrially and arboreally around August through September (Marques et al. 2012). This species gives birth to live offspring with an average of 6.5 snakes per litter (Zelanis et al. 2007). Likely due to frequent **inbreeding** on the small island, intersexes have been found to be prevalent. This is an important factor in the endangerment of the species, as most of these intersexes are sterile (Guimarães et al. 2014).

Population Numbers/Trends/ Pools

Fig 3: Google Earth Screenshot of "Snake Island" with the mentioned lighthouse marked (small white dots in the water are small fishing style boats for scale)

There are between 2,000 to 4,000 members of the *B. insularis* population on the Queimada Grande island and most are located toward the center of the island. There are some points on the island that can have up to one snake per meter (Geiling 2014). The Brazilian navy has been reducing the vegetation of the island which affects the area in which the population can flourish (Geiling 2014).

The last monitoring of the *B. insularis* population was completed in the late 2000s. It concluded that, while **critically endangered**, the species was stable. This may have changed from then to today as the population has been increasingly affected by human activity and inbreeding as their habitat is condensed.

The *B. insularis* species has two major known pools, the captive population being held by conservationists and the aforementioned wild population on their native island. "49 specimens belonging to an ex-situ population maintained at the Laboratório de Ecologia e Evolução (LEEV), Instituto Butantan (São Paulo State, Brazil),"(Salles-Oliveira et al. 2020) according to the source, a significant captive population is being held and monitored. This is important as these two populations, while the same species, runs the risk of diverging just as *B. insularis* did from its common brethren, *B. jararaca*. This is mainly due to the significant inbreeding that occurs in both the captive and wild populations (attributed to their small and dense numbers). "Isolated, small, and critically endangered populations tend to present low values of genetic diversity and inbreeding occurrence relative to continental or unthreatened populations"(Salles-Oliveira et al 2020).

Population Speciation

The mainland species *B. jararaca* and *B. insularis* are closely related and likely come from a recent common ancestor (Barbo et al. 2002). The main anatomical differences between *B. jararaca* and *B. insularis*. are the body form and number of scales. *B. insularis* scales are golden in color and are more slim and slender in appearance, which differs from the darker color and comparatively thicker body of *B. jararaca* (Barbo et al. 2002). Venom differs between the two as well. The *B. jararaca*'s venom acts as an **anticoagulant**, causing excessive bleeding within its prey. In contrast, the venom of *B. insularis* is corrosive in nature and was important in its evolution to hunt birds before they could fly away.

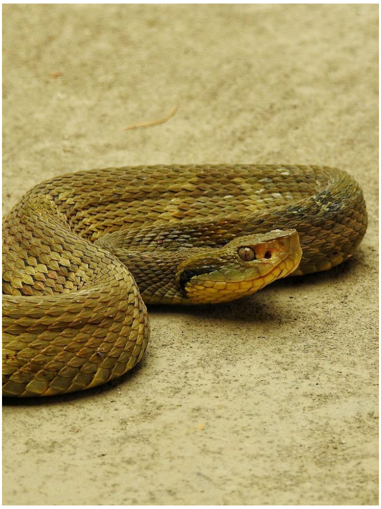

Fig 4: B. jararaca. "[Bothrops jararca]" by Leandro Avelar, [CC BY-SA 4.0]

Just as *B. insularis* speciated from *B. jararaca* when isolated in a small, dense island, the *B. insularis* is not running the same risk on the native island. Rather, the risk is heightened between the captive population at LEEV and the wild population. As the population on the island and in captivity are so small, inbreeding can quickly speciate the two populations. Additionally, being able to remove individuals from the island to **homogenize** the captive population is extremely difficult, and the captive population is also inbreeding and speciating. "Furthermore, the existence of inbreeding may reduce the genetic fitness in the population, leading, in some cases, to a decline in fecundity and survival rates, as well as sexual abnormalities."(Salles-Oliveira et al. 2020) According to the source, inbreeding is causing many issues in both populations, and should these abnormalities be reproduced further within their populations, **speciation** will occur even faster.

Medicinal Value

Most sources never mention *B. insularis* by name as a contributor to already developed medicine; however, sources frequently mention many of its close relatives such as *B. jararaca*, *Bothrops asper*, *Bothrops atrox*, and *Bothrops alternatus*. This is especially interesting as it suggests that thorough research (in terms of medicinal value) has not yet been conducted on *B. insularis*. But the fact is that *B. insularis*' close relatives have been proven useful in this field means that *B. insularis* very well could too. The study of *B. insularis* snake venom that has been conducted so far is underdeveloped, to say the least, but two parts of the venom have been found to be useful or at least could show potential within the medical field. C-Type Lectin can be isolated from the *B. insularis* snake venom, and it has a variety of uses in medical practice serving as an anticoagulant and has 'platelet modulating' properties (Braga et al. 2006). These C-Type Lectin proteins are found in many animals, and the lectin proteins extracted from *B. insularis* have similar effects as other snakes within the *Bothrops* genus. In addition, researchers affiliated with the Federal University of Ceara have extracted and found biological effects from the L-amino acid oxidase found in the venom of *B. insularis* (Braga et al. 2008). The team is the first to analyze this amino acid within *B. insularis* venom leading the way with a valuable piece of research within this underdeveloped field. The L-amino acid oxidase is used to activate platelets within the blood and help slow blood flow in the affected region. When introduced to a rat kidney, the L-amino acid oxidase allowed for increased filtration and **tubular reabsorption**, a property that could temporarily help kidneys function better (Braga et al. 2008).

Cultural Value

Aside from the potential medicinal value of the snake, the snake, in tangent with the island itself, has a cultural value in Brazil apparent through the stories told of them. There are three that appear to be most popular and widespread. They include a story of pirates who hid treasure long ago on the island and then let free hundreds of venomous snakes to guard it, a story of a family of lighthouse keepers who were all found dead after snakes made their way into the lighthouse, and finally a story of a fisherman who came onto the island in search of food and was later found on his boat in a pool of blood adrift in the ocean (Dimuro 2018). These stories demonstrate the horror and mystery that surrounds the island in Brazilian culture, proving the island and its snakes to be a phenomenon that, while understood to simply be an island of many poisonous snakes, would be a cultural blow to Brazil should they not be preserved. While fear of the island is mostly attributed to fear of the unknown, researching these snakes is no easy feat. As these snakes are some of the most poisonous in the world, it is difficult to study and preserve due to the dangers of the island. Just going to the island requires special equipment and personnel to bring a level of safety. A video called " Take a Trip to Brazil's Snake Island: Home of the Golden Lancehead Pit Viper" showed a reporter and researchers going to and traversing snake island. From this video, you could see some of the equipment they use, most notably foot and shin armor. Additionally, it appeared that there was a person who stayed on the boat in the case of an emergency and they needed to leave quickly. A person has at most 6 hours to live after a snake bite, but living that long after a bite from *B. insularus* is extremely rare (ABC News 2014).

Conservation Efforts

B. insularis has been labeled critically endangered by the IUCN (International Union for Conservation of Nature) as the population size is extremely small and inhabits a singular, small island off the coast of Brazil. As the human presence, in the form of the Brazilian navy and lighthouse staff, continues to degrade the island's already limited habitat, the species risks dwindling further. Snake venom has an abundance of research potential and thus the species is very desirable to keep afloat.

Fig 5: B. insularis in captivity. "[Bothrops insularis in Instituto Butantan, São Paulo, Brazil](#)." by Miguelrangeljr, [CC BY-SA 4.0](#)

The Brazilian government has completely shut off the island to any visitors and the navy is in charge of enforcing this restriction. The government, however, is causing **habitat degradation** as they attempt to maintain a lighthouse on the island. Not only this, but they are also clearing some of the vegetation around the island and it could only be imagined this is for safety reasons. This habitat loss could be very impactful since the land the species lives on is very small to begin with. Anti-poaching measures are in place but appear to not be very effective. They mainly consist of cameras, but there is not much stopping a poacher from sneaking in. Additionally, no one is on the island to monitor potential poaching (Brethauer 2018).

As mentioned before, there is a captive population that is used not only for research purposes but also to be used in the case of reintroduction on the island. For this reason, conservation efforts need to focus on keeping the two population's gene pools homogenous for that possibility. Consistent interbreeding, while also preserving the native population (through the measures mentioned above), is extremely important for future conservation efforts.

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5. Through the Bird's Eye View

Andrew Hariyanto, Gautham Rajeshkumar, James Tasto, and Valerie Bennett

Abstract

Approximately 1 billion bird collisions happen in North America yearly, and Chicago is the city where most incidents happen. Consequently, Chicago has solutions to reduce bird collisions, and our goal is to explore both Lights Out Chicago and bird-friendly window designs as viable solutions. Our findings conclude that the two programs have an impact on bird collision fatalities in the city, making both solutions viable and beneficial for bird collision reduction. This chapter discusses several possible improvements for the solutions including the reporting of the solution's status on a city-wide scale, providing more incentives, and increasing public awareness.

What is the Issue?

Urbanization is the essence of **anthropogenic** drivers of extinctions as all man-made structures are obstructing and altering the very lifestyles of living organisms. Of these living organisms, birds are among those that die as a direct result of urbanization as they tend to collide with buildings. Even though collisions with buildings are not considered as a high-threat driver of extinction, it is "an added burden for populations already in decline for other reasons" (Arnold & Zink, 2011). The leading research questions to address this problem include: what exactly are the main drivers of bird collision, which area has the highest number of bird collision fatalities, and does the problem have any solutions? Consequently, this project narrowed down the scope to Chicago and the solutions that have been implemented there. This project has the potential to advance knowledge in areas of ecology and urban animal conservation. The major focus of this project is on birds. By emphasizing the dangers that these birds face in an urban setting, it can inspire more research to see how other flying species like bats are affected. Additionally, one of the research methods conducted in the project emphasized the importance of city-wide reports. Similar methods could be used for many urban conservationists to create unique, multi-faceted reports from economic, ecological, and geographic perspectives. This comprehensive data will map out a wide array of implications that urban conservation solutions have on the area it is implemented in.

Lights and Windows – A Deadly Combination

Lights and windows are the two biggest drivers that result in bird collisions. How exactly do these two seemingly unharmful objects cause an estimated 1 billion bird deaths in North America (Briscoe & Damier, 2019)?

Bird species, especially migratory ones, use light as a visual cue to navigate (Gauthreux & Belser, 2005). When they see a glow on the horizon because of a concentration of city lights, they will be attracted to it. Data from many studies have shown that there indeed was a correlation between the number of birds present in the area and the amount of light being emitted

(Gauthreux & Belser, 2005; University of Delaware, 2018; Van Doren et al, 2017). Lights disorient the bird's internal **geomagnetic** compass and causes them to stray from their straight migratory flight path. They end up circling around the light source, expending huge amounts of energy (The City of Chicago, 2020). During that time, they become vulnerable to collisions with buildings, the surrounding environment, and even other birds that are attracted to the source (Horton et al, 2019). Birds that have successfully evaded the physical obstacles, however, are forced to rest and recover the lost energy from circling the light source in the city itself. This can potentially cause further risk to the birds as they can still collide with buildings the next day (Furuya, 2017).

The detrimental effect of light exposure is not only limited to lights in the exterior of buildings, however. Especially in Chicago where the skyline is dominated by glass buildings, interior light that penetrates the glass into the night sky can cause many fatalities (Briscoe & Damier, 2019). Birds cannot see glass and, thinking that they can directly go to the light source, collide with some invisible wall. Even without the addition of lights, windows still pose a threat. This is not only because birds can't see windows, but because of what might be near windows. Many collisions with windows would not happen unless the bird finds something appealing on the other side, such as a tree or bush to sit on. Seeing a reflection of vegetation makes the bird think that there is more place to rest, leading them to take the path to the window. Furthermore, most birds have eyes on the sides of their heads, which gives them a wide field of view for predators. However, this added benefit comes at the cost of not seeing depth, which is why they are easily fooled by reflections of vegetation (EarthSky, 2017). Birds not being able to see this sort of depth as we do makes it harder for them to differentiate physical from reflected vegetation.

In a Chicago Tribune article, conservation ecologist Douglas

Stotz summarizes, “The windows are what kills them, the light is what brings them into danger” (Briscoe & Damier, 2019).

Chicago – A Trap In Disguise

Spanning a total of 288 square miles, Chicago is a city known for its magnificent architecture and city life (Schallhorn & Duis, 2020). However, Chicago is also very notorious for being a dangerous city for birds. Every year, it is estimated that 5 million birds migrate through the city on their way to their breeding habitats, and approximately 6,000 bird fatalities occur per square mile (Briscoe & Damier, 2019). The reason why Chicago is such a dangerous area is because of its light emissions at night, as well as the nature of its architecture. Chicago is the city with the highest light emissions in the United States, ranking above Houston and New York City (Horton et al, 2019). Many of the buildings also have windowed surfaces (Briscoe & Damier, 2019). Through a bird’s eyes, it is like going through an invisible maze. Because of how vulnerable birds are to lights and windows, it is not surprising that Chicago is ranked as the most dangerous city for birds to fly through (Horton et al, 2019). This is the reason why Chicago was chosen as the scope of this project (Figure 1).

Figure 1: A summary of why Chicago was chosen as the project scope

Our Methods

Because the two biggest drivers are lights and windows, we found solutions that directly address them: Lights Out Chicago and bird-friendly window designs. After narrowing down our scope to the Lights Out program and bird-friendly window designs in Chicago, the next step is the analysis of these two solutions to determine whether they have an impact on bird collision rates. In order to do this, we determined three steps that must be done for both Lights Out Chicago and bird-friendly window designs. First, there must be a clear explanation on what the solution details. This includes guidelines as well as the theory behind the implementation of the solution. Second, the analysis of the impact of the solution on bird collision rates will be done. For Lights Out Chicago, a combination of existing studies, reports on the implementation and effect of the program, and news articles will be used. Because Lights Out is a large program, its reports will be useful in gaining in-depth information. Chicago is also fairly famous for its Lights Out program and media attention through news articles definitely can widen our pool of information. For bird-friendly window designs, existing studies would be used to determine which window designs would be most impactful, as well as whether removing surrounding vegetation has an effect on bird collision rates. Through this process, we can determine if the two solutions are viable. Lastly, we would also develop improvements based on our findings in the previous steps.

Lights Out Chicago – Dark Is The New Light

Lights Out Chicago

Considering that Chicago is the city with the highest light emissions in the United States, it is a no-brainer that Chicago became the first city in the United States to implement a Lights Out program (Bird Collision Monitors, 2012). Starting in 1995 by the Chicago Audubon Society, Lights Out Chicago has been trying to raise awareness on the impact that artificial light has on migrating birds and promote the idea of a city-wide minimization of light emission during important **migratory seasons** (The City of Chicago, 2020). Building owners and managers can opt to join in on this program by following guidelines that the organization has set up (Figure 2).

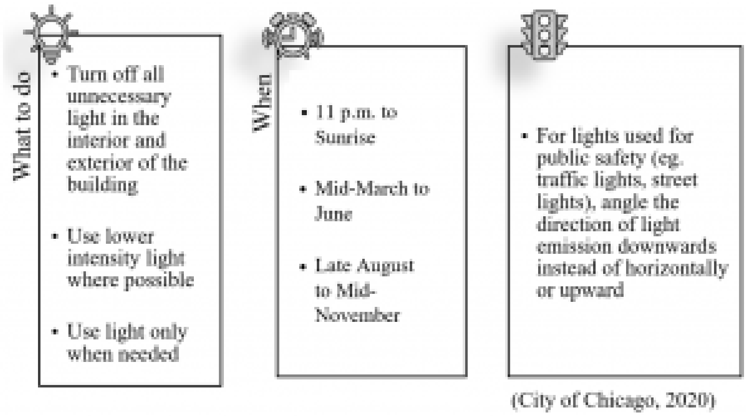

Figure 2 : General Guidelines for Lights Out. Graphic created based on information from City of Chicago (2020)

As can be seen in the guidelines, buildings should aim to limit as much interior and exterior light as possible, especially those that are solely for the purpose of decoration. Most decorative lights are flashy and bright in nature and are the most dangerous for birds. Buildings do not have to follow this year-round, but only during the spring and fall migration as that is when bird fatalities are greatest (Bird Collision Monitors, 2012). The period of time where it is guaranteed that lights are not needed is 11 P.M. to sunrise. By turning off the majority of lights during this time, many of the migratory birds will not be ensnared by the lights (Bird Collision Monitors, 2012). Lights Out Chicago is voluntary which means that it requires the public's participation as well. Unfortunately, there are many that say that lights are an integral part in making the aesthetics of the city beautiful, leading to some resistance (Villagomez, 2019). Figure 3 shows the Lights Out program in effect.

Figure 3. Side by side comparison when lights are on (left) and Lights Out in effect (right) in urban areas. Photos by Portland Audubon featured in "Lights out for migrating birds", USFWS, Public Domain.

Analysis on the Impact of Lights Out on Bird Collision

A study done by Field Museum scientists at the McCormick Place in Chicago aimed to see the number of bird fatalities in response to whether windows were lit or dark (Appendix 1). The infamous McCormick Place was the site where half of the collisions in Chicago occur (Foderaro, 2019). When all windows were dark, there was an estimated 88% decrease in bird collisions, and when there was a mix of both lit and dark windows, there was an overall 83% decrease in bird collisions once variances in lighting conditions have been accounted for (Field Museum, 2002).

Unfortunately, Lights Out Chicago has not conducted a city-wide report on the current success and status of the program, but there are other places that have implemented a Lights Out program. Another city that has done extensive research into the impact of a Lights out program is Toronto. The Fatal Light Awareness Program (FLAP) conducted a city-wide study from 1997 to 2001 analyzing the effect that their Lights Out program had on bird collision rates (Evans Ogden, 2002). Because Chicago and Toronto share many of the same migratory bird species (School of Environment Sustainability, 2014; Birds of Toronto Working Group, 2011), this study by FLAP can potentially be used to map out the effectiveness of Chicago's

Lights Out program. Appendix 2 summarizes the bird collision and light emission data that FLAP gathered over a 4-year period at 16 buildings, and Figure 4 is a representation of the data.

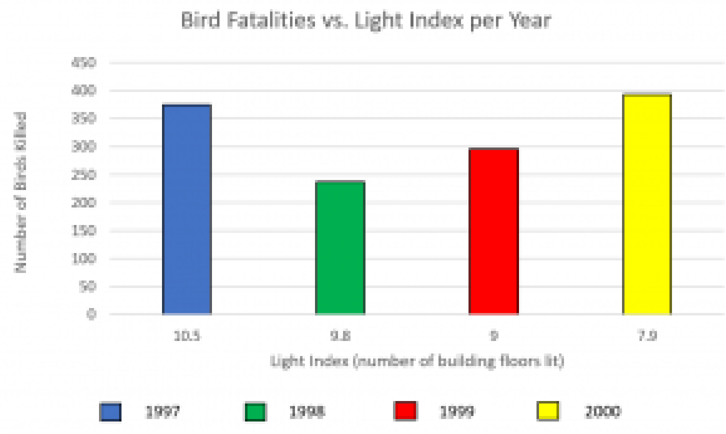

Figure 4 : Graph of number of birds killed vs. light Index for each corresponding year. Data from Evans Ogden (2002), Courtesy of The Internet Center for Wildlife Damage Management.

Although it may seem as though decreasing light emission has no effect on decreasing bird collision rates, it must be pointed out that there are other variables that affect the number of birds passing through the city. Such variables include climate change, success of the breeding season, etc. (Miller-Rushing et al., 2008). The data in the graph does not accurately portray the effect of decreasing light emission on collision rates.

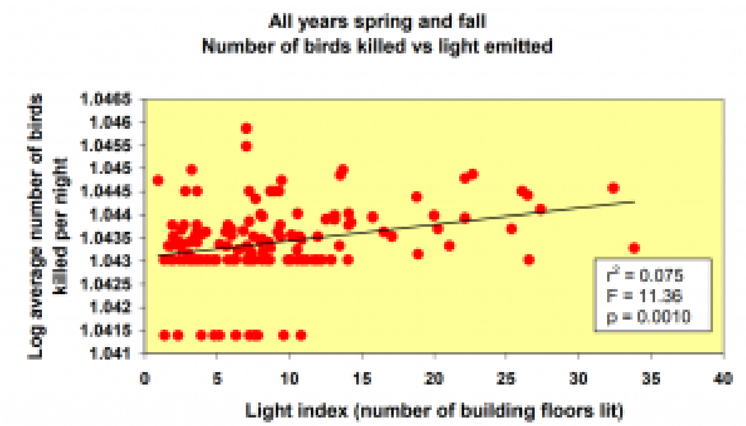

Figure 5 : Graph of log average number of birds killed per night vs. light index per day. It shows a slight increase in birds being killed as light index increases (Evans Ogden, 2002). Courtesy of [The Internet Center for Wildlife Damage Management](#).

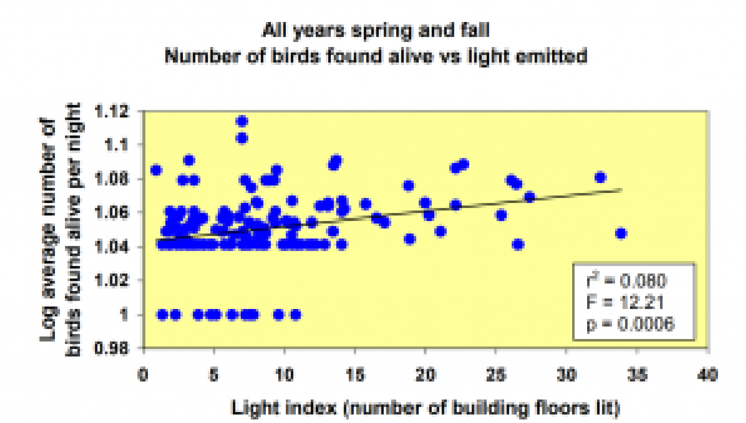

Figure 6 : Graph of the log average number of bird found alive per night vs light index per day. It shows a slight increase in birds found alive as light index increases ([Evans Ogden, 2002](#)). Courtesy of [The Internet Center for Wildlife Damage Management](#).

To compensate for the many factors influencing collision frequency, the study combines data of birds killed (or birds found alive near the area from all the days during the fall) and spring migration. This data is then plotted against the light index of buildings where each data value was taken. The graph in Figure 5 shows the data of birds found alive against light emission. These birds are considered as those that were forced to rest after being attracted to a light source and circling around it for extended periods of time. The graph in Figure 6 shows data of birds killed against light emission. Through the information discussed, the study found that "the number of fatal bird collisions increases with increasing light emissions" and that "the number of birds entrapped by lights emanating from particular buildings increases with increasing light emissions" (Evans Ogden, 2002).

Both studies done by the Field Museum and FLAP showed a positive relationship between light emission and bird collision, thus reinforcing the Lights Out program as a viable solution to decrease bird collision fatalities. However, the estimated 83% decrease in collisions from the Field Museum is not reflected in the graphs provided by the FLAP study. In Toronto, there seems to be much less than 83% reductions in collisions. This could be due to the different geographic areas in which they are located. It could also be attributed to the fact that the FLAP study incorporated data from 16 buildings all over the city, while the Field Museum study only used data from the McCormick Place. Geographically, the McCormick Place is a relatively isolated building, making it the brightest building in the area. It does not have other surrounding buildings with high light emissions, while the 16 buildings in Toronto do. Regardless, a program like Lights Out Chicago, whose sole purpose is to decrease light emissions in the city, will be effective in mitigating bird collisions in the future.

Improvements

There are some possible improvements that could be done based on the studies that were analyzed. First, unlike FLAP in Toronto, Lights Out Chicago does not have a city-wide report that maps out the effectiveness of the program so far. In order to see trends specific to Chicago only, a study must be done at that location. Although there was a study done at McCormick Place, it is only one building and does not provide as comprehensive a report as one that is large-scale. As information and data are essential in measuring progress, a possible next step for Lights Out Chicago is to conduct that report. Also, the reports are not recent, and a newly updated account will help in providing more current information. However, to conduct reports that are dependent on a data set derived over a period of years, it is very difficult because, as shown in Figure 4, the number of birds migrating per year fluctuates. This report must have a method that is independent of the years focusing only on the relation of collisions with light index. Second, Lights Out Chicago is voluntary, and building managers participate at their own accord. Another improvement to Lights Out Chicago would be to further incentivize the program. According to the study done by FLAP, seven of the building managers commented on the savings and cost-efficiency now that most of the lights are dimmed at night. One building was able to save 200,000 CAD per year (Evans Ogden, 2002). These cost savings could potentially become a huge incentive that buildings managers would consider. Lastly, Lights Out Chicago would greatly benefit from spreading more awareness of the situation. It was mentioned that there are some that resisted the idea of Lights Out Chicago, but with more awareness of the problem and as more people join in, the resistance will gradually fade.

Bird-Friendly Window Designs – Seeing The Invisible Wall

Analysis of the effect window designs have on birds (BFWD)

There are two aspects of BFWD that need to be addressed, one with the window designs themselves and the other with vegetation changes. One of the solutions is with creating patterns in the windows, whether that is with stripes or dots. The purpose of this solution is to prevent the birds from entering the window by closing the path for the birds to enter through. Instead of seeing an invisible wall, birds see the patterns and avoid them.

One of the studies conducted by Christine Sheppard and her team tests what types of patterns on windows birds will try to go through or not go through. They would take some birds to a tunnel specifically created to test how effective certain types of patterns were. In the tunnel, the birds see two pieces of glass: one piece has a pattern and the other is a plain piece of glass. Once in the chamber, they observe which glass the birds try to go through in order to determine if the pattern is effective.

One important finding in the study is that vertical stripes that are at least ¼ inch wide with a maximum spacing of 4 inches, and horizontal stripes that are at least ¼ inch wide with a maximum spacing of 2 inches have been effective at preventing strikes of most birds (Sheppard 2011; Klem 2009). Analyzing the data found in the study, 94% of the flights tested with horizontal stripes went to clear windows while only 90% of flights tested with vertical lines went to clear windows. Both of these findings show how effective patterned windows can be when it comes to decreasing bird collision (Figure 7).

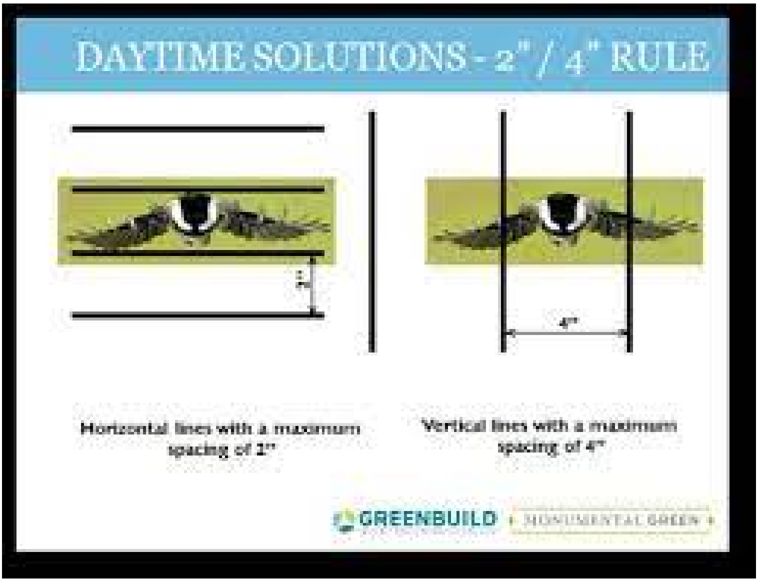

Figure 7 : This is a good representation of why vertical lines are more effective for many types of birds. Birds can vary in height but generally have a similar wing size. The vertical lines make it so that even though the birds may be smaller in width, their wings constrict the ability to move through. "The image shows how pattern spacing on glass can work to deter birds. Images by ABC and Roy Hancliff" in [Reducing bird collisions with buildings and building glass best practices,](#) USFWS, [Public Domain](#)

Analysis of the effect of surrounding vegetation on birds

There is a strong correlation between vegetation changes and bird collision frequencies near a building (Loss et al., 2019). Examining the situation, it makes logical sense that this would be true since the reason why a bird might accidentally hit the window is that it is attracted to a tree or shrub that is either reflected by the window or can be seen through the other side.

We can reference a study conducted by Scott R. Loss and his team which assessed factors influencing bird-building collisions in the downtown area of a major North American city (Loss et al., 2019). The study was conducted in downtown

Minneapolis, Minnesota which is near an important migration area for birds. 20 buildings were selected for monitoring of bird collisions, 16 of which were in downtown Minneapolis. This study looked at the effect building size and the surrounding vegetation has on bird collision frequencies. To put it in simpler terms, they found that a smaller building with some vegetation has a more detrimental impact on birds than a larger-sized building with no vegetation surrounding it.

The most effective and best solution is to remove some surrounding vegetation or limit the vegetation near windows. It is best to avoid creating an effect where landscaping funnels birds towards glass panes (e.g., walkways, passageways, edges), or where approaches to a building (vehicles or people) flush birds towards windows(U.S. Fish and Wildlife Service 2016, January). Furthermore, shrubs, plants, or any sort of vegetation near windows should be moved, if possible, farther from the window so it would be hard to reach for the bird and not as well seen. If none of these methods are possible, it is imperative that some sort of solutions with patterns or decals are created.

Many of these solutions that were mentioned are currently trying to be implemented in Chicago. As of right now, there is an ordinance that is still trying to be passed within the Chicago city. In the ordinance, there will be specific guidelines and requirements that would need to be followed such as “Avoid situations where plantings can be reflected on glass surfaces” and “ specify glass that provides visual patterns for birds that can prevent them from striking transparent or reflective surfaces.” (Prince, 2017). The city of Chicago understands the effectiveness of many of these solutions, as well as understanding where the root of the problem stems from. The ordinance was set to be passed soon in 2020 which will satisfy both birds as well as industries, but due to COVID-19, it might have to be set back.

Improvements

Knowing some of the information, it is evident that many of these solutions are easy and cheap to implement in an urban city. Especially when it comes to the glass designs, many of the buildings can simply add dotted patterns like the building in Figure 8. These very simple solutions will have a positive impact on birds and the overall ecosystem. This might be confusing as to why these are still not implemented or why this is still a problem even though the solutions described are effective. It is because many people are not aware of the problem. Without awareness of the problem, many people, as well as governments, do not see the need to implement solutions, and also it would be hard for other industries to see the need to do so. Another improvement when it comes to solutions is to try not to have decals on windows. Decals especially showing a bird are not going to be helpful even though birds might see it. Some birds are very territorial and seeing just a mere reflection of themselves provokes them to think that a bird is trying to contest it. They will then try to attack it and unfortunately die or become severely injured because they crash onto a window. The last thing we want to improve upon is being able to test out the results of the solutions at a city-wide scale rather than looking at individual buildings once most buildings implement them. Many of these studies' solutions are only tested in a controlled environment and it is difficult to see the effect they would have on a large group of buildings in a Chicago-like setting. Having this information will make it clearer that these solutions are effective for cities and can be easily implemented.

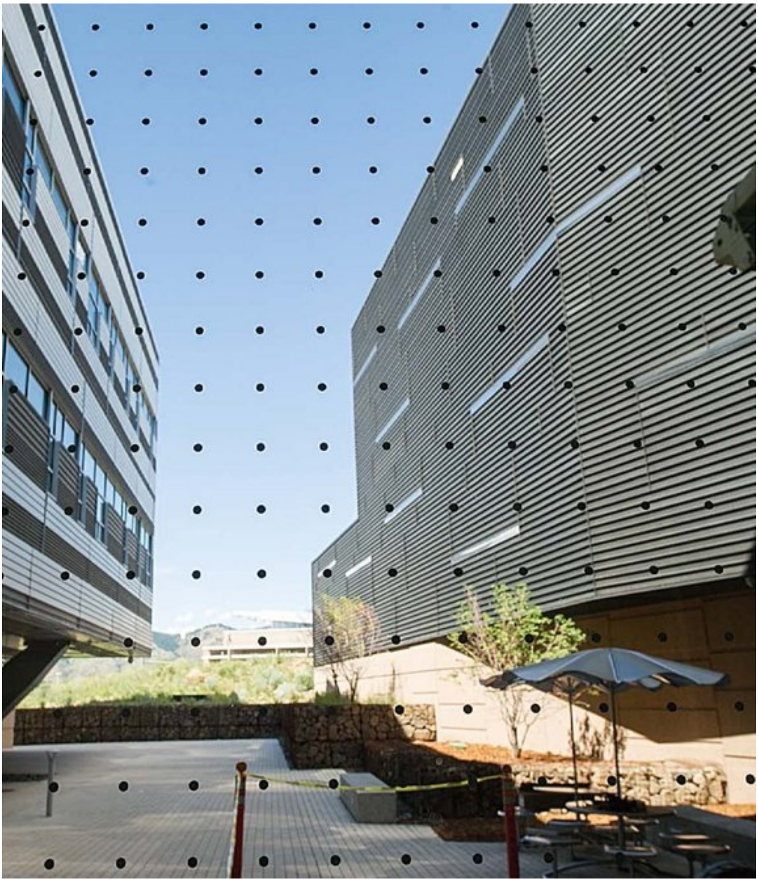

Figure 8 : This image is the exterior of a National Renewable Energy Laboratory (NREL). A dot pattern was used to help prevent bird collisions. Photo by Dennis Schroeder, featured in "Reducing bird collisions with buildings and building glass best practices", USFWS, Public Domain

Final Thoughts

Humanity's urban development has been causing many issues to birds. Building collisions especially are an added burden to some bird species that currently are in the process of going extinct. However, this burden can be alleviated by implementing the two solutions that are described in this chapter. From both the analyses on Lights Out Chicago and bird-friendly window designs, the two solutions are undoubtedly effective methods in reducing bird collision rates. The findings from this research have many benefits to society because it gives concrete proof that these solutions to bird collisions do work, inspiring more cities to implement similar programs. As more cities take part in this, the number of bird fatalities will decrease. Additionally, our findings also include information on what makes buildings dangerous to birds, raising public awareness on this issue. Furthermore, our findings also show that these solutions can be implemented anywhere. Around the world, all birds are the same. They are attracted to light, and they cannot see windows. It is our responsibility as the creators of these urban structures to make it safe for species like birds. One aspect of the project that was not discussed is how buildings affect other flying species. It would definitely be a step forward to see if other flying species are affected by the driver and if the solutions for birds are applicable to them as well.

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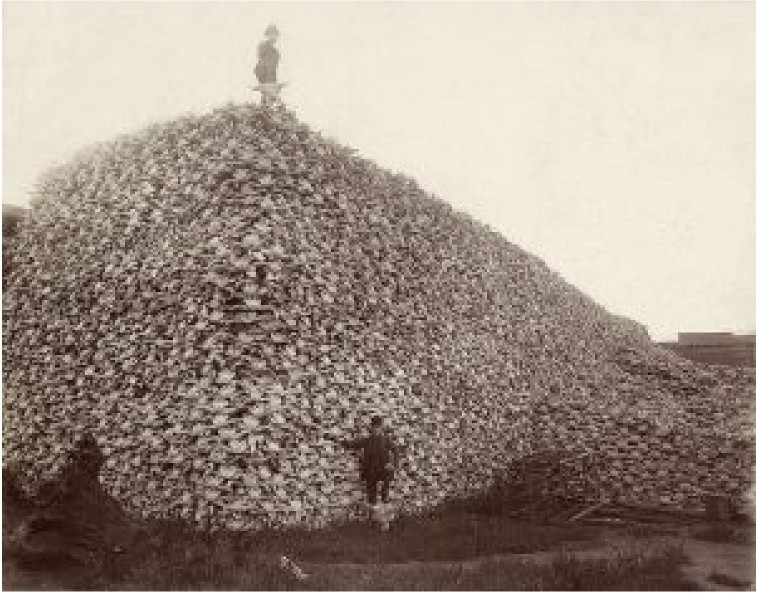
PART II

OVERHARVESTING AND EXPLOITATION

Broadly speaking, **overharvesting and exploitation** is considered the second greatest threat to biodiversity. However, for some species, like freshwater turtles in Asia, it is the lead threat to extinction. Fishing, hunting, logging, and grazing are typical resource-extraction activities, but exploitation of species can also occur through biomedical uses, pet trade, and use as status symbols. Economic and cultural aspects linked to processes of colonialism and economic growth have historically driven the overexploitation of ecosystems.

The chapters in this section explore different forms and reasons behind overexploitation. Biomedical uses are explored in the chapters on the use of shark squalene for vaccines, the use of horseshoe crab in toxicity testing of vaccines, and the harvesting of ginseng for medicinal uses. Students also investigated the emptying of our oceans for food resources, using Atlantic cod and Atlantic Bluefin Tuna as case studies for a future with sustainable fishing practices. Finally, one team of students took a broader approach and linked issues of wildlife trade to exposing human health.



American bison (Bison bison) is a classic example of a species that almost went extinct due to overharvesting by humans. Photograph from the mid-1870s of a pile of American bison skulls. "Bison skull pile", CiRC, CC BY-SA 3.0

6. Sharks: Protecting a Keystone Species in the Race to Produce a COVID-19 Vaccine

Holly Galvin, Charlotte Adams, Patrick Salisbury, and Nathan Shemesh

Chapter Overview

Squalene, found in shark livers, is a chemical that strengthens **immune responses**. 500,000 sharks would be killed if a shark-based COVID-19 vaccine is approved. The goal of this project is to find a viable vaccine alternative to those using shark-based squalene in order to preserve the shark population. **mRNA vaccines**, **DNA vaccines**, and plant-based squalene alternatives were found to be possible solutions, with ranging pros and cons to each.

Figure 1: "Grey Shark in Blue Water" by H. Wulschlaeger. Free to use via Pexels.

Sharks and Ecosystems

Sharks are one of the most biodiverse predators in the world, existing for over 43 million years and serving as an **apex predator** for the world's oceans (Ferretti et al., 2010). In the classic reef ecosystem, sharks act as generalists, meaning that they prey on a wide range of species within the reef habitat (Heupel et al., 2014). Sharks are also mobile predators, meaning they rarely spend their time at a single reef and can roam from reef to reef in search of prey, providing predation to many ecosystems (Ferretti et al., 2010). Due to these factors, sharks often act as **keystone species** in underwater ecosystems.

Studies have shown that when sharks are removed from an ecosystem, many negative effects are likely to occur within the reef habitat, including **trophic cascades** and even complete ecosystem collapse in some instances (Barley et al., 2017). One study found that reefs lacking the predation from sharks had less coral and instead more seaweed, as the lack of predation meant that coral-eating species were overabundant and able to consume an excessive amount of the coral (Ferretti et al., 2010). Another study showed that shark prey species often had smaller eyes and fins in habitats that had reduced populations of sharks due to the lack of natural selection in breeding patterns. This study shows the importance of sharks in creating predation to maintain healthy populations of species (Hammerschlag et al., 2018). Finally, another study showed that when sharks are removed from an ecosystem, the **zooplankton** population increases greatly. Zooplankton produces CO2, so this increase in population results in an increase in CO2 levels, which contributes to ocean acidification and **climate change** (Strafford, 2020).

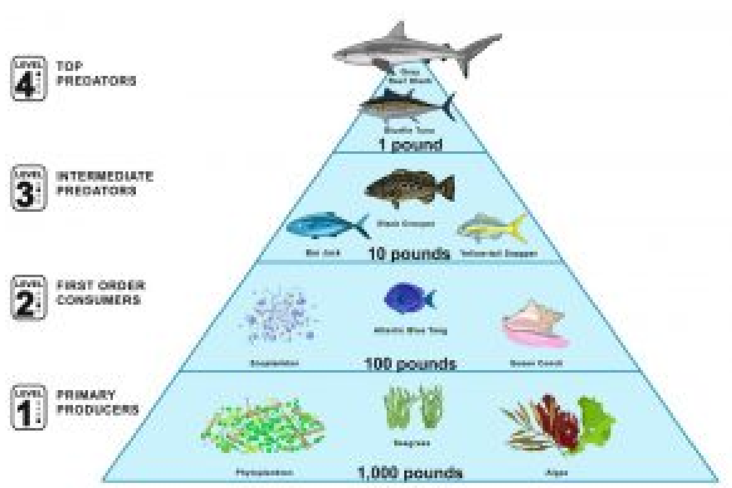


Figure 2: "Marine Food Pyramid" by Tim Gunther, National Geographic, Terms of Service.

Squalene and COVID-19

Squalene is a chemical compound often used for vaccine applications due to its properties that include high surface tension, stability in different situations, and **biocompatibility** (Fox, 2009). Squalene can often be found being sold alone as a supplement or in other cosmetic products. Along with these uses, squalene is a type of compound known as an **adjuvant**, meaning that squalene elicits a stronger **immune response** when used as an ingredient in a vaccine. Using adjuvants can be helpful when vaccinating people with reduced immune responses (Gupta & Gupta, 2020). Squalene is used in the second most popular adjuvant, known as MF59 (Gupta & Gupta, 2020).

In December of 2019, the COVID-19 pandemic began in Wuhan, China, and spread globally in a few short months. The symptoms of the disease vary greatly from person to person, ranging from people that are asymptomatic all the way to effects such as organ failure, severe pneumonia, or even death (Gupta & Gupta, 2020). As of October 2020, the virus had infected over 37 million people and killed over a million worldwide (Johns Hopskins University, 2020). The effects go beyond deaths, costing the world an estimate of $8.1-15.8 trillion globally as of October 2020 and putting the world on the brink of economic collapse (Schwab, 2020). Although there is currently no vaccine for the disease, this is likely to change as several different companies are on the brink of having a vaccine available for public use.

Squalene Harvesting For Vaccines

Currently, over 3 million sharks are killed each year due to the harvesting of squalene. When added to the 100 million sharks per year already harvested due to **bycatch** and the shark finning trade, the pressure on shark populations becomes immense (Aridi, 2020). The most common types of sharks harvested for squalene are deepwater species because these species' livers contain a higher concentration of squalene than sharks living in shallow water. Due to deepwater sharks having longer lifespans and reduced breeding capabilities, these sharks are some of the most susceptible to overfishing because a lot of time is needed to allow the population to recover and grow (Aridi, 2020). In particular, a species known as the gulper shark is most commonly harvested for squalene. In the past, gulper sharks were a common bycatch, but as the need for squalene has risen, gulper sharks have more frequently become a target species in fishing operations (Roth, 2018).

Currently, 17 of 176 COVID-19 vaccine candidates contain squalene as an ingredient (Aridi, 2020). If one of these candidates were to be approved and distributed to a majority of the world's population, an estimated 500,000 additional sharks would need to be harvested to fill this demand (Aridi, 2020). New research on methods to save these sharks would not only assist in saving shark populations in the present day but could also create a more sustainable source of squalene for other applications in the future. Beyond saving resources, new research into squalene alternatives could help raise public awareness about the pressure on shark populations, along with their importance. Within the government, new research showing promising alternatives could help promote the regulation of squalene and subsequently reduce the targeting of shark populations. A vaccine using an alternative adjuvant or no adjuvant at all might be more likely to be approved if research showed that those vaccine types are more sustainable.

Approach to the Problem

The team referred to many resources to investigate viable alternative vaccine options to a shark-based squalene vaccine. There were many considerations to keep in mind when choosing an alternative that was appropriate for the COVID-19 pandemic. The vaccine should not compromise human safety or create more health damage when given to treat COVID-19. The vaccine also needed to be effective so that the majority of the population can be protected from the disease to limit spread. Public demand for the vaccine is very high due to the loss of life and money from the virus, so the vaccine needed to be approved as soon as possible to protect the world from more loss. The vaccine also needed to be affordable in order to allow everyone to access treatment regardless of wealth or status. Affordability was especially important when thinking of developing countries with high populations, and the economic requirements to make sure everyone in the world has access to a vaccine. Finally, environmental impacts were examined to see which vaccines preserved the shark population without creating an adverse environmental impact. To find these vaccines, research journals outlining different vaccine types were looked at in order to understand the functioning of each vaccine type. News articles were also examined to keep up-to-date information on the state of COVID-19 vaccine production, as new developments were announced each day. Finally, interviews with experts in the vaccine and health services industries, Derek Adams and Gregory Galvin, helped guide the research.

Squalene Vaccines

Squalene, as a component of the MF59 **adjuvant**, is used in a type of **DNA vaccine** called a fragmented or pieces and parts vaccine (Adams, 2020; Gupta & Gupta, 2020). In a fragmented vaccine, proteins from viruses are given and the body reacts and creates immunity to these proteins so that when it sees these proteins again, the body has an **immune response** (Adams, 2020). Adjuvants are typically required in these vaccines to be able to create a sufficient immune response that the body remembers long enough to protect against the disease the vaccine is targeting (Adams, 2020). Adjuvants can be different components of the vaccine depending upon the vaccine formula. Adjuvants, such as the MF59 containing squalene, can be excipients: an inactive substance that serves as a vehicle for the active vaccine ingredient or a part of the active vaccine itself (Adams, 2020).

Shark livers are not the only source of squalene. Squalene can be found in many other natural sources such as plants, fungi, yeast, or microbes. Olive plants are the most viable source of non-shark-based squalene. Extracting squalene out of other natural resources is a more sustainable alternative to shark-based squalene. The use of these other sources of squalene would not only help preserve the shark population but also help the long-term availability of COVID-19 vaccines because once the sharks are killed in production, they will not be a viable source of squalene due to the extinction of the species.

Plant-based squalene is more expensive than shark-based squalene. 30 kilograms of olive oil on average can make 300 grams of squalene, the same amount of squalene that one shark can make (Gohil et al., 2019). The process to elicit squalene from plants also takes much longer because plants need to be grown and harvested, while sharks are already available for capture in the ocean. Access to oil-based plants also varies from area to area, so certain geographic regions will not have access to plant-based squalene. In order to grow the number of plants needed to fulfill a COVID-19 vaccine, a subsequent amount of land would have to be converted to farmland, having a secondary negative environmental effect. Though plant-based squalene would help preserve the shark population, unfortunately, due to the timespan and demand for COVID-19 vaccines, plant-based squalene is not a viable option for the current pandemic. It is important to note that in the future with more research and development, plant-based squalene may become feasible for future vaccines.

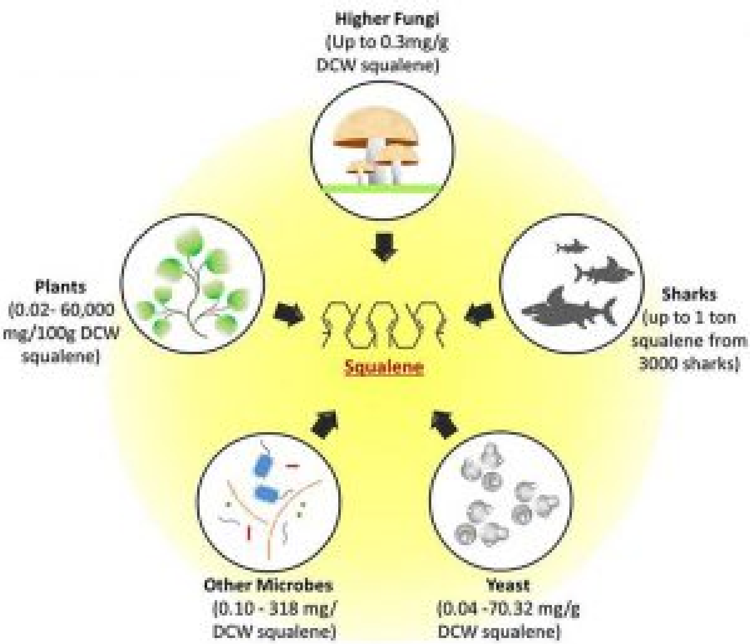


Figure 3: [Natural Sources of Squalene](#) in [Gohil et al., 2019,](#) [CC-BY](#)

mRNA Vaccine

mRNA vaccines are leading in the current COVID-19 vaccine production. Moderna and Pfizer are two of the vaccine companies currently petitioning for US FDA approval. The chemical composition of an mRNA vaccine is environmentally friendly to the shark population because there is no squalene used in the vaccine. Instead, mRNA from COVID-19 is inserted into human cells, tricking the cells into thinking that the COVID-19 mRNA is human mRNA. The cells will then translate this mRNA into protein, known as spike protein (CDC, 2020). The white blood cells then recognize that this protein is foreign, so they build an **immune response** to attack and eradicate the spike protein. This builds the body's immunity to the COVID-19 disease, similar to the way the body would naturally build immunity through infection. Since the vaccine does not use a living strain of COVID-19, there is no chance that the vaccine will transmit the disease and infect the patient (CDC, 2020). Contrary to a popular belief, the mRNA vaccine does not alter human DNA because the mRNA is converted to protein outside of the nucleus (CDC, 2020).

The original goal for the effectiveness of the COVID-19 vaccine set forth by the US FDA was 50% (FDA, 2020). Both the Moderna and Pfizer vaccines have shown to be much more effective in **clinical trials** than the original goal, at 95% effective in preventing contraction of COVID-19 (Gallahger, 2020). Two doses are required for both the Moderna and the Pfizer vaccines (Gallahger, 2020). 43,000 participants were a part of the Pfizer trial, and the only side effects reported were fatigue and headache (Pfzier, 2020). 30,000 participants were a part of the Moderna trial (NIH, 2020), and the only side effects reported were fatigue, muscle and joint pain, and headache (Wadman, 2020). About 2% of subjects given the vaccine reported more severe side effects such as high fevers (Wadman, 2020).

Though both the Moderna and Pfizer vaccines have been proven safe in clinical trials, mRNA vaccines have never been

FDA approved for any other disease (Cohen, 2020). Though mRNA vaccines have been used in trials for diseases such as Zika and Rabies, they have never been approved for public usage. Before COVID-19, the quickest vaccine to be produced was the mumps vaccine, which took four years (Akpan, 2020). In comparison, both the Moderna and Pfizer vaccines have been designed, tested, and applied for approval in under a year. Experts are unsure whether the fast-tracking through clinical trials for the vaccine has allowed potential side effects or long-term effects of mRNA vaccines to go unnoticed.

The Pfizer vaccine is ready to be given to the elderly and essential workers as early as mid-December 2020 in the USA, once they receive FDA approval (Pfizer, 2020). On December 2nd, 2020, the Pfizer vaccine was approved in the UK and has started to be distributed to high-risk citizens (Roberts, 2020). 50 million doses are expected to be completed by the end of 2020, with another 1.3 billion projected for 2021 (Pfizer, 2020). The ability of the vaccine to be produced in a short amount of time is essential for the timeframe of COVID-19. The Moderna vaccine costs $33 per dose and the Pfizer vaccine costs $20 per dose wholesale, putting them on the pricier end of the vaccine cost range (Gallahger, 2020). Though certain countries such as the UK are subsidizing the vaccine, this could overall affect the accessibility of the vaccine to poorer communities, especially those in developing countries.

Unfortunately, mRNA vaccines need to be kept at very low temperatures. The Moderna vaccine needs to be kept at -20 degrees celsius, and the Pfizer vaccine needs to be kept at -70 degrees celsius (Gallahger, 2020). Low refrigeration temperatures can add a secondary environmental effect on the production of these vaccines because energy is needed to keep them cold. Dry ice is usually utilized for this, which is CO2 gas that has been compressed (Pfzier, 2020). This can allow for the release of CO2 into the environment, which can contribute to **climate change**. Even with this added CO2 rate, it would not be more than the amount of CO2 created by zooplankton in the ocean if sharks are removed from the ecosystems. Overall, an mRNA vaccine is a viable and effective solution even with its flaws, and the vaccine will help preserve the shark population if approved.

DNA Vaccine

The leading **DNA vaccine** for COVID-19 is being developed by the company AstraZeneca in partnership with Oxford University (Johnson & Steckelberg, 2020). There are many types of DNA vaccines that have been proven to work on many infectious diseases such as chickenpox, Hepatitis A, Hepatitis B, and the seasonal influenza virus (Adams, 2020). The AstraZeneca vaccine is a viral vectored vaccine and uses an adenovirus, in this case, a harmless cold-causing virus that has been modified to include genetic material from the COVID-19 virus (Branswell& Feuerstein, 2020; Johnson & Steckelberg, 2020). When injected into a human body, the adenovirus introduces the immune system to the spike protein that sits on the exterior of the COVID-19 virus and causes cells to make replicas of the spike proteins, thereby training the immune system to recognize the protein as foreign and develop an immune response (Branswell & Feuerstein, 2020; Johnson & Steckelberg, 2020). Moreover, because the AstraZeneca vaccine is a viral-vectored vaccine, the vaccine does not contain adjuvants and does not contain squalene (Adams, 2020). Therefore, if the AstraZeneca vaccine were to be widely distributed, the production of the vaccine would not negatively affect shark populations.

Since the developing Oxford-AstraZeneca vaccine is a type of vaccine that has been extensively tested and proven to work on many diseases, a DNA vaccine is a more reliable type of vaccine than a new mRNA vaccine that has never been approved by the FDA. In addition, if widely distributed, AstraZeneca's vaccine would cost approximately $4 per dose, significantly cheaper than both mRNA options (Gallahger, 2020). Furthermore, the AstraZeneca vaccine can be kept at regular refrigerated temperatures for up to six months, making it more environmentally friendly and easier to distribute to more people as quickly as possible because specialized facilities to store the vaccine will not have to be built (Branswell & Feuerstein, 2020; Johnson & Steckelberg, 2020).

In contrast to the average 95% efficacy rate of the two mRNA candidates, the AstraZeneca vaccine has an average efficacy rate of 70% (Branswell & Feuerstein, 2020). Furthermore, the preliminary results from the clinical trials of the AstraZeneca vaccine have raised some concerns. The results were based on 131 COVID-19 cases among 11,363 participants; however, the company didn't release how many cases were found in each of the two groups of participants who were given different amounts of the vaccine (Branswell & Feuerstein, 2020; Robbins & Mueller, 2020). One group that consisted of 2,800 participants was given one half-dose of the vaccine followed by a full dose a month late, which yielded an efficacy rate of 90% (Robbins & Mueller, 2020). However, the second group which consisted of 8,900 participants were given two full doses of the vaccine at the same rate, which yielded an efficacy rate of 62% (Robbins & Mueller, 2020). These results are troubling to several experts such as Anthony Fauci especially since it was due to a mistake that the smaller group of participants received a half dose initially (Robbins & Mueller, 2020). This suggests that further testing needs to be done to be certain that the Oxford-AstraZeneca vaccine is safe and effective.

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https://youtu.be/yp9p0ieLZZ0
Figure 4: How the Various COVID-19 Vaccines Work. Video by CNBC Television, 2020.

Conclusion

Squalene-based vaccines are not a recent development, and the usage of squalene in vaccines such as those for influenza makes them more appealing to use in future COVID-19 vaccines. Vaccines such as FLUAD have been around for decades and produced effective disease immunity in people that otherwise would have difficulty reacting to the **antigen** within the vaccine. In particular, this characteristic of squalene and other adjuvants "boosting" the effectiveness of vaccines for those with compromised immune systems makes squalene and other adjuvants a very effective tool in creating a highly effective vaccine, especially for the high-risk population associated with COVID-19. However, what squalene gains in effectiveness it lacks in sustainability. Shark-based squalene for vaccines would only add to the already immense strain on shark populations due to overfishing, **climate change**, and habitat loss. The increased costs, timespan to produce plant-based squalene, and potential alternative environmental effects of production means that no plant-based alternative is appropriate for COVID-19, although it is worth noting that with further research and development, one of these alternatives may be viable in the future for other vaccines.

Although vaccines including adjuvants are a proven effective type of vaccine, the unprecedented nature and pace of development of the COVID-19 vaccine have led to alternative vaccine types becoming the more likely candidates for approval. mRNA vaccines such as the Moderna and Pfizer vaccine were unimaginable even a few years ago but have made it into the late stages of **clinical trials** showing promising results. Although these vaccines seem almost magical with their effectiveness, mRNA vaccines still have their own set of challenges. The biggest challenge is their cold storage temperatures which could lead to a possible secondary environmental effect. DNA vaccines, such as the Oxford-AstraZeneca vaccine candidate, follow a more proven vaccine composition and are less expensive. However, trials have shown inconsistent effectiveness suggesting that further development and trials will need to be completed to produce a safe, reliable, and effective vaccine for the masses. Keeping in mind that a possible squalene-based vaccine would likely have its own set of drawbacks even beyond environmental effects, these alternative vaccines provide several compelling reasons to ditch squalene. Instead of sacrificing the sharks for the greater human good, it appears as if advances in science and medicine have led to a situation where both sharks and humans will benefit.

However, this does not mean that sharks are out of the water. Both the cosmetic industries and other vaccines continue to use shark-based squalene, and in the future, alternatives to this shark-based squalene must be aggressively pursued to save a species already on the brink. Researchers will need to pursue further development of these alternative sources in order to create a sustainable source of squalene for the future. Governments will need to increase regulation of shark harvesting even further, possibly even regulating squalene as a substance to assure that the amount of sharks harvested is greatly reduced from current numbers. Finally, the public as a whole needs to take action and get involved. Saving shark populations needs to become a global effort, and every person supporting these efforts will make a difference.

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7. The Atlantic Horseshoe Crab: Are Humans Bleeding This Living Fossil Dry?

Abigail Cummings, Jillian Forauer, Chris Harvill, Vinh Tran, and Sai Vadlamudi

Figure 1: A stranded horseshoe crab on a Delaware Bay beach. Once on their backs, horseshoe crabs cannot flip back over if they are on land. "Stranded Horseshoe Crab" by Paul Williams, CC BY-NC 2.0

Chapter Summary

The horseshoe crab is one of the oldest **extant** species in history, and even predates the dinosaurs. They only now are facing the threat of being endangered. It's many unique characteristics are vital to various outlets, from ecology to medicine, ecotourism, and many more. There is no doubt that xzhorseshoe crabs are integral to our society. But in recent years, their population numbers have taken a dive due to many different factors, one of the biggest being human exploitation. Various conservation efforts have slowed this decline. However, much more must be done to reverse this population trend.

If you have ever wandered down the coastline of the Atlantic, the odds are high that you have at one point walked by a horseshoe crab. You may have seen its small round shell, never realizing that once you turn it over, you see a completely different creature with many legs and pincers. When you take the opportunity to see beyond the shell, there is a lot more than meets the eye in the life of a horseshoe crab. Although it is a mundane and peaceful creature, the Atlantic Horseshoe Crab has its share of environmental threats which contribute to its rich story. In this chapter, we will discuss not just what these prehistoric creatures have done for their natural ecosystem as well as humans, but what we can do to protect this relic of the past for many more years to come.

The Life History of the Atlantic Horseshoe Crab

Figure 2: Atlantic horseshoe crabs from Yucatan Mexico. "Horseshoe Crab" by Angel Schatz, CC BY 2.0

The Atlantic horseshoe crab (*Limulus polyphemus*) is a peculiar species with a somewhat alien-like appearance (Figure 1, 2). Its **phylum** and **class** are identified as Arthopoda and Meristomoata Dana respectively (Walls et al. 2002). Despite its title as a "crab", its phylum relates more to spiders and scorpions rather than actual crustaceans, and its class is one used for defining marine species that have been around for around 200 to 500 million years (Walls et al. 2002). As suggested in its name, these horseshoe crabs (apart from their relatives in the Southeast Asian Pacific) live along the Atlantic coastal range from Maine to Florida, and some in regions along the Gulf of Mexico and Yucatan Peninsula (Smith et al. 2016).

Horseshoe crab life cycles are unexpectedly long with a lifespan of up to 20 years. Most reach maturity at the ages of 8-10, with females taking longer to mature due to their larger sizes at maturity and **sexual dimorphism** (Walls et. al. 2002).

Figure 3: Horseshoe crab bottom view. "Horseshoe crab" by Angel Schatz,

These crabs are predators to mostly shellfish, using their pincer-like legs to dig and crush any hard shells of varying types of clams, mollusks, and mussels (US FWS 2006). Since horseshoe crabs do not have teeth, they use their claws to crush their food before passing it into their mouths (NWF n.d.). Besides these species, horseshoe crabs may feed on algae, especially as juveniles (Carmichael et al. 2009). As for species that prey on the horseshoe crab, different types of shorebirds, fish, and **arthropods** prefer to eat horseshoe crab eggs, larvae, and juveniles since they are less difficult to eat than adult crabs (Smith et al. 2016). Horseshoe crabs typically remain in intertidal regions and only move to calm shorelines for reproduction and laying eggs (Smith et al. 2016). Males typically latch onto the hindbody of females as the females move toward intertidal areas to release eggs (Figure 4). Some males may also fertilize eggs if they migrate to shores from ocean waters and are considered to be unattached, but this contributes to their ability to generate **biodiversity** as a species (Botton and Loveland 1989). Unfortunately, about 10% of crabs may become stranded on beaches during the spawning season and perish due to their inability to return to the water (Figure 1) (Botton and Loveland 1989). Although this species may seem like a simple marine animal with an unusual appearance, several of its unique characteristics and activities, such as its unique "blue blood" and spawning cycles, are surprisingly vital for other facets of ecological or human activity.

Figure 4: Mating pair of horseshoe crabs, larger female on left and male on right. "Horseshoe crab mating season" by Victoria Pickering, CC BY-NC-ND 2.0

Horseshoe Crabs Impact a Variety of

Industries and Surrounding Species

The first, and arguably most important role for horseshoe crabs, is within the local environment. Since this species plays a major role as a food source for some species and a primary predator for others, human-derived threats to horseshoe crabs also impact surrounding species in the Atlantic coastal ecosystem. Horseshoe crabs are mainly primary predators for different types of benthic invertebrates, such as the razor clam, macoma clam, surf clam, blue mussel, and wedge clam, which makes them a key factor in controlling the local population sizes of each of these species (Walls et. al. 2002, Krisfalusi-Gannon et al. 2018). In terms of predators, migratory bird species, such as the American red knot, land on horseshoe crab spawning grounds to eat recently released eggs. This feasting is essential to the birds because the horseshoe crab eggs provide a primary energy source necessary for the birds to complete the final stretch of their migration (Fisheries NOAA 2018). Overharvesting and habitat degradation of horseshoe crabs heavily reduces crab populations, and thus decrease the population of red knots. This can be seen from 1989 to 2008 where the observed red knot population dropped significantly from 100,000 to 15,000 (Rafferty n.d.)(**See more in Box 1 – Red knots and horseshoe crabs: Two vulnerable species make for an unsustainable relationship**).

Figure 5: The red knot searching for horseshoe crab eggs on a beach in New Jersey as they migrate north. "Red Knot" by Ann Marie Morrison, CC BY-NC-ND 2.0

Box 1 – Red knots and horseshoe crabs: Two vulnerable species make for an unsustainable relationship

The red knot is a migratory shorebird and can be found on every continent except Antarctica; however, their North American population has declined sharply due to the overharvesting of horseshoe crab eggs (Shrading 2016). These birds feed on the horseshoe crab eggs in order to survive their 9,000-mile migration from wintering grounds in South America to the breeding grounds in the Arctic. These birds migrate at the same time each year, landing in places like Delaware Bay just as the horseshoe crabs are beginning to spawn. However, horseshoe crab populations have been on the decline since the late 1990s due to overharvesting as bait for commercial eel and whelk industries, as well as for their highly prized blood used in biomedical testing. Local and state fishery and wildlife services are pushing for alternatives for both cases to help not just the horseshoe crab population, but the red knot as well (Shrading 2016).

Figure 6: Photographer visiting Delaware Bay where red knots feed on horseshoe crab eggs. "Red Knots & Horseshoe Crabs" by Paul Williams, CC BY-NC 2.0

Horseshoe crabs are a very important species also in terms of tourism since many restaurants depend on the effect that horseshoe crab eggs have on the arrival of shorebirds, and as a result, tourists (Figure 6). Peak spawning season for horseshoe crabs is from May through June, which marks the beginning of the summer season in some of the most popular horseshoe crab spawning sites in the Atlantic, such as Cape Cod and Delaware Bay (Smith et al. 2016). People come from all over the world to see the shorebirds landing at these sites. One economic study found that 30 million dollars was generated by shorebird watching in southern New Jersey alone. (Rafferty n.d.).

The horseshoe crab is not only vital to society in terms of tourism, but also for the biomedical industry. These crabs have a special compound within their blood called limulus amebocyte lysate (LAL)(PBS 2008). This is used very heavily within the biomedical industries in LAL tests which determine if a sample is contaminated with endotoxins, and the process of harvesting the blood itself generates over $50 million in revenue each year (PBS 2008). This itself is a huge industry, but every company that produces medicine, biomedical implants, and prosthetics relies on LAL. This is because every one of these drugs and devices must pass a LAL test to follow FDA regulation (PBS 2008). Horseshoe crabs are “bled” in biomedical labs to harvest their blood which contains high amounts of LAL (PBS 2008) (**See more in Box 2: Crabs and COVID-19: The molecular miracle of horseshoe crab blood**).

Box 2 – Crabs and COVID-19: The molecular miracle of horseshoe crab blood

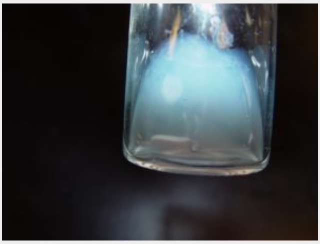

Figure 7: Blue blood harvested from horseshoe crabs. "Blue blood" by FWC Fish and Wildlife Research Institute, CC BY-NC-ND 2.0

Biomedical bleeding of horseshoe crabs is the process of collecting the hemolymph, or the blood from horseshoe crabs. Blood is collected by puncturing the cardiac sinus and continuously taken until a clot forms, preventing further collection (James-Pirri et al. 2012). It is estimated that about 25% of a horseshoe crab's weight is from its hemolymph (Hurton et al. 2005), and typical biomedical extractions taken each year are from over 600,000 crabs (Dykstra 2020). It is the **amebocyte** cells within this blood that is the vital resource needed for LAL tests. The potency of current LAL tests for bacterial toxins makes horseshoe crabs a vital resource for research purposes and for the safety of all vaccines and other injectables (Sandle 2015).

FUN FACT: The "blue blood" of horseshoe crabs is blue due to the presence of hemocyanin, which is similar to hemoglobin— the protein that makes human blood red (James-Pirri et al. 2012)

LAL's primary ingredient is amebocytes, or blood cells, from horseshoe crabs. When broken down, "limulus" is the species from which the product is derived, "amebocyte" is the type of blood cell taken from the horseshoe crabs, and "lysate" is the product formed when cells are broken down for their contents. LAL functions in horseshoe crabs as a potent clotting agent in response to lipopolysaccharides (LPS), also known as endotoxin, which is present in gram-negative bacterial cell walls (Sandle 2015). When endotoxin is detected by the amebocytes in the blood, the blood immediately prevents further infection through the release of coagulogen, a protein in horseshoe crab blood cells that forms coagulin gel in response to endotoxins (Sandle 2015). In humans, the presence of endotoxin triggers an immune response that can be as severe as sepsis, which is when an infection triggers organ damage and further immune system impairment (Rietschel et al. 1991). It's estimated that 11 million people die from sepsis each year, and 80% of these cases are caused by the toxin from gram-negative bacteria for which the LAL test is made (Tinker-Kulberg et al.

2020). This demonstrates the incredible impact LAL tests have made to improve the safety of injectables.

Since LAL is vital for testing injectables for safety and biocompatibility, the global COVID-19 pandemic and the development of the COVID-19 vaccine made horseshoe crab harvests essential and even more relevant. Considering all the COVID-19 vaccines, there was a concern that there would not be enough LAL tests available to properly test all COVID vaccines for safety. However, the concern was squashed by the chair of the Horseshoe Crabs Advisory Panel to the Atlantic States Marine Fisheries Commission. The number of horseshoe crabs harvested for their blood in the span of 3 days would provide enough LAL to test 5 billion COVID vaccines (Motsinger 2020). Imagining a world in which this was not the case is terrifying, for both humans and horseshoe crabs. If not for recent success with conservation strategies and strict regulations set on harvest numbers in the Atlantic region, fisheries could have inflicted irreversible harm on this invaluable species.

The COVID-19 pandemic and the application of horseshoe crab LAL in vaccine development illustrates the need for humans to protect and conserve horseshoe crabs. The blood that has saved horseshoe crabs from wounds or infections for the past few hundred million years could potentially save us humans from similar infectious agents for as many years to come.

The final major economic sector that targets horseshoe crabs is the fishing industry since harvesting levels are the most impactful variable that determines the overall population health of horseshoe crabs. Horseshoe crabs are specifically used as bait for catching eels and conch. While this industry is much smaller and has been declining their use of these crabs, it still is a threat to their population. Between 1850-1920, over 1.5 million horseshoe crabs were harvested annually for fertilizer and livestock feed (ASMFC 2019). However, this practice is no longer used and was replaced with commercial harvests for fishing bait in the mid to late 1990s (Maloney 2018). High harvest levels after this turning point led to greater population declines (Maloney et al. 2018). For example, the need for bait in whelk fisheries likely spiked horseshoe crab harvest in the 1990s, with a peak of nearly six million pounds in 1997 (ASMFC 2019). In the early 2000s, conservation efforts brought that decline to a halt, and recent stock assessments show that in some regions, the horseshoe crab populations seem to be recovering (Goodrow and Procopio 2021). In more recent years, the reported coastwide bait landings remained well below the established fishing quota at 1.59 million crabs, while in 2018 the annual harvest total only reached 658,589 crabs (ASMFC 2019). With the different ways that horseshoe crabs affect the economy and environment on both a local and worldwide scale, the dangers posed to their declining population are very concerning.

Threats to the Atlantic Horseshoe Crab and Conservation Responses

Unfortunately, humans have been contributing to species habitat loss which has disrupted many horseshoe crab populations. Since horseshoe crabs spawn in bay areas and tidal zones of beaches, any construction or commercialization of the Atlantic coasts poses a threat to the success of thousands of horseshoe crab eggs in the spring and summer months. Boating in the waterways surrounding the beaches where horseshoe crabs spawn prevents horseshoe crabs from accessing beaches before they can even spawn (Moore-Perrin et al. 2007). Beyond blockages of waterways, commercial beaches and boardwalks have higher foot traffic in warmer months which interfere with horseshoe crab spawning periods. Experts on horseshoe crabs on the Atlantic coast claim that the biggest threat to horseshoe crabs is **habitat loss**. There is erosion of suitable habitats and breeding areas due to the increased interest in developing coastal land (Berkson et al. 2009). Although harvesting horseshoe crabs for commercial and biomedical purposes may reduce the horseshoe crab population, there are many species management regulations in place to control populations (ASMFC 2019). However, there are no management practices to prevent the degradation of land and ecosystems by commercial development (Berkson et al. 2009).

Horseshoe crabs are currently listed as "**vulnerable**" and decreasing in population globally, according to the **IUCN** Red List. But, continued efforts to protect the Atlantic-specific species have increased in number and greatly improved in effectiveness over many years of dedication (Smith 2016). Starting from 1998, the Atlantic States Marine Fisheries Commission implemented an "Interstate Fishery Management Plan" to preserve the declining Atlantic horseshoe crab population, including regulations requiring states to identify horseshoe crab habitats, threats to the species as a whole, and the methods needed to protect horseshoe crabs from threats of overharvesting and habitat degradation (Schrading et al. 1998). The most significant conservation response has been seen with general fishing harvest regulations for bait along with a smaller effort for biomedical purposes as well (ASMFC

2019). In 2004, bait harvesting methods were regulated to help conservation efforts in Delaware Bay to prevent migratory shorebirds, like the red knot, from further diminishing horseshoe crab populations. In 2006, bait harvesting was limited to only 100,000 male crabs with a delay in the harvest season to allow for more reproduction in the spring months (ASMFC 2019). In response to these conservation plans, crab populations have been experiencing some population increase in areas with management plans in place, while in 2015, conservation groups also listed the red knot as an endangered species in the U.S., which also resulted in further protection for horseshoe crabs. These efforts have done well to allow population recovery: Atlantic horseshoe crab population has nearly doubled in size from an estimated 1.4 million crabs in 2014 to just over 3.3 million in 2019 (Swan et al. 2019). Looking at the overall effort on regulating unsustainable overfishing and the population response specifically for the Atlantic species, future prospects seem to be very promising for this strange-looking crab's future.

However, while these conservation efforts have been put into motion in recent years by heavily addressing unsustainable practices, some regions still continue to decline despite protective regulations in place (Smith et al. 2016). Most areas of concern, like the coast of Florida and the Gulf of Mexico, have limited data as to why these population numbers continue to decrease, but it is suspected that the main cause is the continued habitat degradation from land development in surrounding regions (Smith et al. 2016). Since there is limited evidence applying this indirect threat, regulations for land development methods that negatively impact horseshoe crabs have proven to be difficult to implement (Smith et al. 2016).

Figure 8: Returning horseshoe crabs after biomedical industry bleeding.. "[Harvesting horseshoe crabs for blood Chincoteague, VA]" by [Jonathan Sawyer], [CC BY-NC 2.0]

In terms of the impacts of the biomedical bleeding industry on horseshoe crab health, there are negative effects, although the process itself is considered non-lethal. Specific studies found that protein concentration, a common indicator for health, was lower in bled crabs than control crabs indicating that there are negative impacts on overall crab health (James-Pirri et al. 2012). Additionally, although the majority of horseshoe crabs are released after the bleeding process (Figure 8), there are negative impacts on the mating abilities of the crabs, thus impacting reproduction and population growth over time (Owings et al. 2019). Most harvesting companies and LAL manufacturers report that less than 3% of crabs die because of this process, while many recent studies disagree, as their estimations lie between a 15-30% mortality rate for the crabs (PBS 2008, Maloney et al. 2018).

There are new studies aimed at improving the conservation of horseshoe crabs by finding alternatives to traditional harvesting and bleeding for biomedical purposes. Many grants have been sponsored by the National Science Foundation to help promote the well-being of horseshoe crabs and find better bleeding procedures for biomedical purposes (Dellinger 2017). A current alternative that exists today is a "laboratory synthesized **recombinant** Factor C” (rFC) assay, which has the same endotoxin detection ability that resides in horseshoe crab blood (Maloney et al. 2018). The use of rFC has already been endorsed by the U.S. FDA and the European health ministry since 2012 as a result of its equal or even improved effectiveness in comparison to horseshoe crab blood (Maloney et al. 2018). Although this product is already commercially produced and accepted, it has hardly become widespread for LAL test use due to pharmaceutical companies’ hesitation to switch from horseshoe crab blood, since the potency and effectiveness of the LAL test are much more reliable than the rFC assay (Maloney et al. 2018). If companies are convinced to convert from LAL to rFC over time, a substantial stressor on current horseshoe crab populations would be removed as a result. While it is unclear whether or not further protective efforts will be implemented to allow this ancient organism to thrive, along with the many other species reliant on its presence, only time and continued dedication in conservation will tell in the future.

There are more alternatives to help horseshoe crab populations in the biomedical industry beyond just finding a molecular alternative for the LAL tests. Techniques are emerging to replace traditional horseshoe crab harvests from the ocean. A recent study suggested that alternatives to harvesting horseshoe crabs by growing the crabs in aquaculture would eliminate the need for harvesting new horseshoe crabs every year (Tinker-Kulberg et al. 2020). Only 45,000 crabs in aquaculture could provide the number of LAL tests needed for the biomedical and pharmaceutical industries, and analysis of the LAL tests from aquaculture suggests significantly more potent enzymatic activity due to the freshness of the collection (Tinker-Kulberg et al. 2020). Perhaps in the next few years, aquaculture will be accepted as the main source of horseshoe crabs and their blood instead of wild-caught crabs.

Next time you walk down a beach on the Atlantic, perhaps you'll encounter another horseshoe crab. But maybe this time they could be turned over, unable to flip over, and stranded. After knowing their story and how valuable they are to keep us as humans healthy and their ecosystems balanced, maybe you'll take the chance to flip the crab back over to return to its home in the sea.

Figure 8: Horseshoe crab returning to its home at sea. "[You can make it!!](#)" by [LelahO](#), [CC BY-NC 2.0](#)

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8. American Ginseng: Addressing the Root of the Problem

Allison Walker, John Puksta, and Lorenzo Lopez

Abstract

The overexploitation of American ginseng (*Panax quinquefolius*) stems from its highly demanded medicinal properties. Through research gathered in field studies about population distribution and information about the ecological life cycle provided by the [United States Fish and Wildlife Service (USFWS)](), conservation policies have been developed to help address the status of the American ginseng. This chapter discusses the historical and economical aspects of the American ginseng and then explains how distribution and predatory factors influence conservation efforts.

American ginseng, Panax quinquefolius. by Larry Stritch, US Forest Service, Public Domain

Historical

The discovery of American ginseng is accredited to two French Jesuits. With the assistance of Native Americans, in 1716, Jesuits discovered the American ginseng . The Native American tribes would utilize different parts of the ginseng to treat various ailments. For example, the Muscogee tribe would use a **poultice** containing the ginseng's root to prevent continued bleeding and a tea for respiratory infections (Stevenson 2019). American ginseng is believed to possess cooling and moistening properties. The most prevalent uses of ginseng are in Chinese medicine and Western herbal tradition.

The Chinese began to trade American ginseng in 1718. By 1751, China was importing enough American ginseng from Quebec that the Company of the Indies [1] monopolized the market for these roots. The first recorded mention of the American ginseng as a medicinal herb was detailed in ”Ben Cao Gang Mu Shi Yi”.[2] This publication consisted of over 800 medicinal texts with an additional working experience of 30 years in the field. Nearly 200 years later, the Ministry of Health of the People's Republic of China published the first edition of the Chinese Pharmacopoeia[3] in 1953. By 2000, the American ginseng was added to this resource. For over 300 years, China has used the American ginseng in traditional medicinal practices including the “daodi” ginseng, which has acclimated to the Northeastern Provinces, Beijing, and Shandong (Brinckmann and Huang 2018).

Economical

Prices of the American ginseng were once $200 per pound, but as of 2016, the threat of over-harvesting and poaching from Chinese consumers have caused the ginseng to rise to a staggering $1,000 per pound. Unfortunately, the ginseng's special importance to Chinese natural medicine combined with raised prices have further provoked poaching of the plant. In Chinese culture, the American ginseng root is used for medical care and they find the shape of the root to be very important in dictating what the root is used for. More ideal shapes (*Figure 1*) bring in more money from Chinese consumers (Arnold 2016).

1. Exporter of American ginseng roots.
2. A historical text published in 1765
3. Descriptions of traditional Chinese medicine, Western medicine as well as a compendium of drugs including their classifications, strength, and precautions.

Figure 1: Different ginseng root shapes are believed to have different health impacts. For example, this root looks like a person and may be used for energy. "[Panax quinquefolius, American Ginseng root, GFG, Howard County, Md](#)" by Helen Lowe Metzman, the USGS Bee Inventory and Monitoring Lab, [Public Domain](#)

Range and distribution

American ginseng can be found across the Midwest United States, throughout the Northeast, and into Eastern Canada (*Figure 2*). The species' **endemic** habitat is cool woods with ideal soil conditions ranging from moist, organic, and enriched humus (Panax quinquefolius 2019). Ginseng grows best in a climate with a range of 70% to 80% shade with 40 to 50 inches of annual rainfall and a climate temperature of about 50 degrees Fahrenheit. The American ginseng is adapted to handle occasional canopy disturbances (Wulfsberg 2019). Warmer environments due to climate change have negatively impacted the viability of the American ginseng because they have adapted to grow within a relatively narrow temperature range. However, early warming periods during the late winter give rise to a dangerous threat, cold arctic blasts that bring harmful frost that damage plant tissue (Souther 2011).

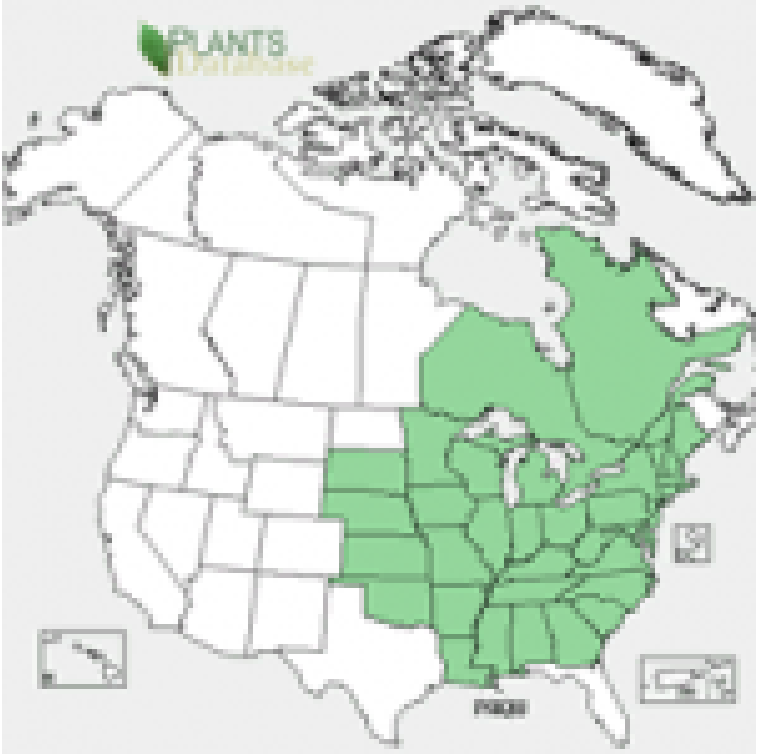

Figure 2. Areas (green) where the American ginseng are found in Canada and the United States. "[Range map of American ginseng, Panax quinquefolius](). " by the USDA Plant Database, [Public Domain]().

The survival rate of the American ginseng is directly correlated to its size. Smaller plants are observed to have a 69-92% higher annual mortality rate. These plants are expected to be around 12 to 15 centimeters with reliance on their respective **harvest intensity indices** (Wulfsberg 2019). This species has a long life cycle, which results in a low amount of mature American ginsengs that bear healthy roots. Seed propagation rates are fully dependent on the maturity of the ginseng, as its first germination will produce small seed amounts with subsequently increasing amounts as it matures (Vaughan et al. 2011). *Figure 3* provides additional information regarding the production of seeds.

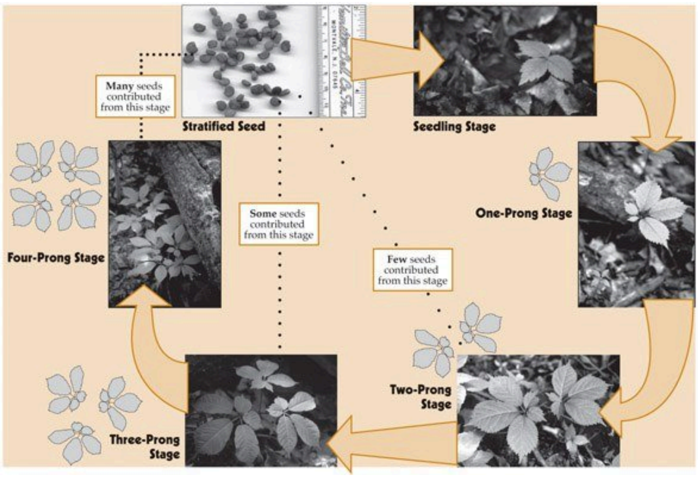

Figure 3: The maturation period of the American ginseng as well as the number of seeds produced during each germination period. Produced by Eric. P. Burkhart

The **germination** period for American ginseng requires 18 to 20 months in a temperate climate because this aids in maturing the seeds (Harrison et al. 2021). The American ginseng experiences a morphological dormancy, one of five dormancies that seedlings can undergo. To wake the ginseng from this, it is necessary that there is a series of cold and warm temperatures (Emerald Castle Farms 2016). Ginseng germination requires them to survive for a minimum of two years before they are eligible to produce seeds (Harrison et al. 2021). This specific type of dormancy can be harmful to struggling populations, as newly planted seeds will not show activity until this period is over. However, this also serves to protect budding seeds. If seed were to bud in early fall it would not survive since the time to develop a sustainable root is too great. Additionally, this dormancy makes it difficult to artificially reproduce, strengthening the need to protect young ginseng so that they may produce seeds on their own.

In 2009, a study from 1996 to 2006 was analyzed to measure the relationship between harvesting and population growth of the American ginseng, with information on the population size and harvest index measured for each of the 12 populations studied. The populations were experimentally harvested upon, and the intent was to provide an understanding of how harvesting affects ginseng population growth. It was found that the initial **stage composition** of the American ginseng in 1996 had not recovered its diversity 10 years later in 2006, which suggests a noticeable loss in **genetic diversity** (Mooney and McGraw 2009). The distribution and population of the American ginseng were seen to be heavily affected by harvesting, which is why conservation policies have been developed.

Predatory Factors

Massive over-harvesting has caused the rapid decline of American ginseng within the past 40 years. NatureServe Explorer has given them unofficial classification as a "vulnerable" species, as the **IUCN** Red List has not yet assessed the American ginseng. Along with over-harvesting, this herb is threatened by a variety of species because the American ginseng serves as a food source within its ecosystem. Increased numbers of turkey populations near American ginseng populations have contributed to the uprooting of these plants proven by clear scratch marks on their stalks. The white-tailed deer, an **herbivore** of juvenile American ginseng, generally eats the above-ground portions of the plant, which includes but is not limited to the leaves, reproductive structures, and stalks.

Conversely, rodents will interfere only with the ginseng's roots through excavation. Some rodents such as shrews are suspected to be predators of seeds and berries of the American ginseng. Insects such as stink bugs play a double role by preying on the ginseng's fruit and seeds and also being a pollinator (McGraw et al. 2013).

It is difficult for naturally occurring ginseng in the wild to mature for five years because there are many predators that consume this plant. Due to this and damage assisted by human-induced habitat destruction (Schmidt et al. 2019), it is essential that American ginseng farmers choose an area[4] away from constant foot travel that would disrupt the seed growth (Arnold 2016). For instance, in areas that support heavy deer populations, there is a visible reduction of ginseng in the following year (Hruska 2014). If over-harvested by deer and other small mammals, there is a strong possibility that the ginseng may not recover. Browsed plants, including the ginseng, do not support seeds[5] as they die off (Vaughan et al. 2011). However, the seed embryos are protected from harmful digestive enzymes and survive until they are excreted (Vaughan et al. 2011). Newly deposited seeds are found near topsoil in a nutrient-rich environment creating an ideal scenario for them to develop and mature. Not only does this diversify a forest's population of ginseng but it also protects ginseng from localized extinction.

4. Since the American ginseng requires specific light and soil requirements, it is ideal to grow it in either a wild-simulated or native environment.
5. Seeds of ginseng are three to five millimeters in length with a hard seed coat.

Conservation efforts

The delayed maturity of the seeds coupled with an extensive history of over-harvesting has put this species on the endangered list for many states. To combat over-harvesting of American ginseng, it is only legal to harvest during specific time periods and the ginseng must be five years or older (U.S. Fish and Wildlife Service 2021). Within Pennsylvania, ginseng has been historically documented to be found within each of the 67 counties from the early 1700s with protection measures implemented as early as the late 1800s. Pennsylvania allows American ginseng to be harvested from September 1st to November 30th. It is protected from April 1st to September 1st. This allows American ginseng to reach a mature stage where they are able to set seed for the next season.

The USFWS is hopeful that the plant could make a comeback with the positive promotion of ginseng cultivation and legal trade enforcement. American ginseng trade is regulated under the Convention on International Trade in Endangered Species (CITES). Many precautions have been taken to ensure proper harvesting of the American ginseng. When an American ginseng plant is harvested, it is done in a manner that will allow it to continue its growth and reproduction. The roots must be sold to a certified dealer within the state that they were harvested from. Dealers that make successful sales and purchases must keep a detailed history of their transaction records (Vaughan et al. 2011). American ginsengs are prone to poaching; thus, ginseng farmers have taken measures to protect their crops, such as surveillance cameras and guard dogs. Along with this, Appalachia is funding **agroforestry** to help maintain its species biodiversity, which includes the American ginseng (Hoffner 2019). The American ginseng appears to have the most successful growth in national forests, national parks, and state-owned land where it is best protected from poaching (Schmidt et al. 2019).

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9. Atlantic Cod: The Collapse of a Keystone Species and a New England Icon

Jennifer Brownell, Vivek Kandasamy, Peter Lam, Julia Naras, and Olivia Petropulos

Figure 1. Atlantic cod swimming towards the ocean floor in an attempt to escape a fisherman's net. "The bottom of the trap, no hope for these fish" by Derek Keats, CC BY 2.0

Atlantic Cod (*Gadus morhua*)

An Introduction

Cod has been integral to North American history and cultures since long before the arrival of European settlers. Indigenous Peoples of the East and West coasts have **angled**, **jigged**, spearfished, netted, and trapped the abundant fish for tens of thousands of years. The fish was nutritionally and culturally important in areas where the land could not support agriculture and is still recognized in Indigenous oral traditions as a fountainhead of life (Chaves 2014).

Figure 2. Image of a Massachusetts fishing operation in the early 1900s, "[Cod to haddock]" Courtesy of NOAA, [Public Domain]

In New England, the commercial fishing of Atlantic cod became the first American industry and supported the growth of the Colonies (Chaves 2014). Fishing towns that still exist today—Provincetown, Gloucester, New Bedford, Nantucket, et cetera—thrived because of the healthy Atlantic cod fishery and guidance from Indigenous Peoples (Figure 2) (Dybas 2006). The fish was a symbol of New England's economic prosperity and physically manifested in a five-foot-long Sacred Cod carved out of pine was hung in the Massachusetts State House. Three hundred and twenty years later, a replica still resides in the Massachusetts House of Representatives just west of Cape Cod Bay (Dietze 2017).

Now, however, this icon is fading away. As overexploited Atlantic cod stocks dwindle, New England fishing communities struggle with the loss of income (from commercial fishing and recreational guided fishing trips), food security, and regional culture. The ecosystems that once supported cod populations have changed irreversibly in their absence, and conservation efforts have had little to no success in recovering them.

Natural History and Significance

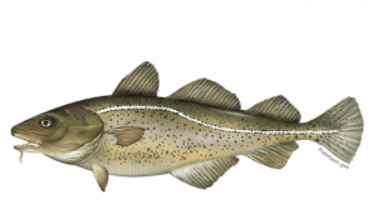

Figure 3. Illustration of Atlantic Cod [(Gadus morhua)], Courtesy of NOAA, [Public Domain]

Atlantic cod is a species as unique physically as it is culturally. Both females and males have three spineless **dorsal fins**, two **anal fins**, and a single **barbel** on the chin. They can change color based on their depth in the water column, often appearing greyish-green or reddish-brown with a light belly. A pale lateral line runs from above each **pectoral fin** to the squared **caudal fin** (Figure 3) (NOAA 2020). Females grow slightly heavier and longer than males but otherwise, they are indistinguishable (Jakobsen et al 2016). According to current government sources, within their 20-year lifespan, they can reach up to 77 pounds and 51 inches long (NOAA 2020). However, 19th-century **schooner** records show that Atlantic cod once exceeded 210 pounds (Dybas 2006).

Figure 4. [A map of the world with the range of the Atlantic Cod](). Courtesy of the Commonwealth of Massachusetts, [Copyright permission]()

This species' domain expands beyond New England's watersheds but is limited to the Atlantic and the Arctic Oceans. To the west, they can be found from off the shores of Greenland, all the way to North Carolina. To the east, they can be found from the Arctic Ocean to the Bay of Biscay. This includes other bodies of water like the North Sea, the Baltic Sea, the Barents Sea, as well as a few more. They are found in Europe all the way east to Scandinavia because of their seasonal migrations (Figure 4) (Commonwealth of Massachusetts 2021).

A **shoaling** species, Atlantic cod finds itself in rocky habitats, as well as down in the ocean along the continental shelf. Cod tend to prefer colder temperatures and deep water during the day. On the other hand, they enjoy the warmer and shallower water at night (Neubauer et al. 2013). Factors such as temperature, depth, and salinity can affect "growth rate, age of maturity, migration patterns, and timing of spawning" (Brander 2018). They **spawn** near the ocean floor from winter to early spring, beginning at age 2 or 3. Females can lay anywhere from 3 million-9 million eggs. A study on commercial fishing of Atlantic cod found that "total egg abundance is significantly higher in years with more old and large individuals in the spawning stock" (Stige 2017). They reproduce through broadcast spawning: a type of sexual reproduction where females release eggs into the water column where they meet up with sperms. This helps protect the eggs from egg predators (Stige 2017).

Cod is a generalist species with an **omnivorous** and **ontogenetic** diet. As they develop from "codlings" to medium-sized cod, their diet shifts from pelagic invertebrates to benthic invertebrates, small fish, and crustaceans. In ecosystems where populations of large cod are stable, they are the dominant **piscivore** and consume more fish (including smaller cod and other gadoids), crustaceans, and mollusks as they grow. Cod are opportunistic hunters and prefer the most abundant prey (Link and Garrison 2002). As a result, the species plays multiple roles throughout the trophic levels.

As a prey species, Atlantic cod links aquatic animals such as shrimp, crustaceans, and capelin, along with marine mammals such as harp seals and grey seals. Many types of fish prey on the Atlantic cod. Young and smaller cod are hunted by larger cod and pollock fish. Larger adults are hunted by sharks, spiny dogfish, and marine mammals (Link et al. 2009). Removal of cod will cause "an increase or decrease in abundance to every other species in the ecosystem in an alternating pattern" (Steele 2016) (Figure 5). As studied, a decline of the cod population has had an inverse effect for shrimp, crab, and foraging fish populations. However, this has led to large decreases in zooplankton which would be feasted on greatly from a now-unchecked predator (Bundy et al. 2009). While Atlantic cod plays a more predatory role in an ecosystem than prey, many species do still feed on cod "preying on the cod's early life stages (eggs, larvae or early juveniles) or by competing with those early life stages for food" (Link et al. 2009). Cod plays a vital role in the economy, but more so in the ecosystems that they reside in.

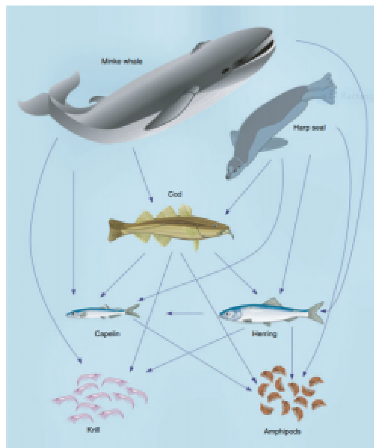

Figure 5. Diagram showing the trophic level and relationships of cod in an ecosystem. "[A simplified Barents Sea food web]" Courtesy of NOAA, Link et al. 2008

Stock Collapse

Figure 6. The decline in Atlantic cod stocks from 1850-2000. Courtesy of Millennium Ecosystem Assessment, Terms of Use

Over the past 150 years, the population of Atlantic cod experienced significant changes. Through the 19th and early 20th centuries, Atlantic cod was a staple for the fisheries in the Northern Atlantic Ocean. However, starting in the late 1950s, offshore bottom **trawlers** began to fish in deeper parts of the stock (Walter et al. 2005). This led to a dramatic increase in the number of fish landings. Since there was a decrease in the number of fish, especially the most mature fish with the highest rates of reproduction, the population was unable to replenish the stock. The mass number of fish caught from the 1950s onwards led to a decline in the **biomass** of the Atlantic cod (Figure 6). While overfishing played a large role, it is not the only reason for the collapse of the Atlantic cod population (Walter et al. 2005). Other reasons for the decline include pollution, climate change, and human activity, which all led Atlantic cod to be declared a **vulnerable** species by 1996. Today, they remain vulnerable to extinction with some populations now being labeled as endangered (Ono et al. 2019).

Management Policies

In response to the cod stock depletion and its staggering effect on the fishing industry, Congress passed the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), the first and principal marine conservation law, in 1976. The legislation protected U.S. waters from foreign fishing vessels and established eight management councils, appointing them by region to the nation's major marine fisheries (NOAA 2020).

The New England Fishery Management Council accounts for both Atlantic cod stocks in U.S. waters: the Gulf of Maine and Georges Bank. All eight U.S. Regional Fishery Management Councils collaborate with scientists and workers in the fishing industry as well as the National Oceanic and Atmospheric Administration (NOAA) to regulate commercial and recreational fishing, protect habitats, and develop new strategies to restore overfished species (NOAA 2020).

Nevertheless, overfishing persisted and cod was listed as a vulnerable species in 1996 (Wilmot 2005). Many amendments have been made to the MSFCMA to address this, most notably the Sustainable Fisheries Act (1996) and the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (2006), which further limited fishing access to vital habitats and enforced stricter catch limits (NOAA 2020). In 1986, the New England Fishery Management Council developed the Northeast Multispecies Fishery Management Plan to restore cod (and 12 other groundfish species) stocks (NEFMC 2021). Amendments and adjustments have also been made to the Northeast Multispecies FMP (and several are currently in progress); however, regulations have not reversed the decline of cod populations (Hayden et al. 2015; NEFMC 2021). New research analysis suggests that overharvested cod **shoals** group together, joining the once-fragmented populations. These **metapopulations** are easy targets for trawlers, making the fish vulnerable to overharvesting even when strict, traditional fishing regulations (e.g. landing limits) are in place (Hayden et al. 2015). This information is beneficial as organizations like the New England Fishery Management council work to develop new regulations to recover Atlantic cod.

With this new legislation, local fishermen had interesting opinions. At first, fishermen viewed the new restrictions as another barrier they must face. The restrictions also took away revenue. As time passed, the locals became better educated on the problems associated with the Atlantic cod collapse. Fishermen now recognize the importance of the government's efforts to intervene in the collapse of an iconic and ecologically essential species. Locals adhere to the new restrictions and hope that this change in behavior can recover the species. This is a great example of how powerful education is. Not only do the people in power need to be educated to make a change, but the general public does as well. This issue highlights the fact that education brings about the knowledge to advocate for change (Oceana 2018).

Recovery

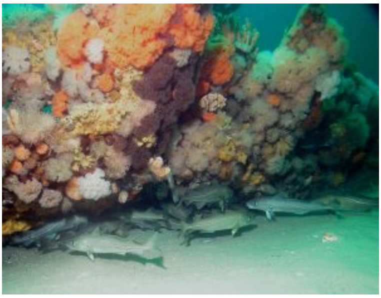

Figure 7. The natural habitat of the Atlantic Cod. Courtesy of NOAA, Public Domain

Despite the action taken by Congress, there have been no substantial results to show that the Atlantic Cod population has recovered at all. These actions seem like they are making large strides, yet there is a lot more work to be done. Most importantly, there is no set recovery plan in place for this species. Even though this species started to collapse many years ago, a true plan has yet to be made. This is an alarming reality because as quickly as a population can disappear, restoring it is extremely challenging and time and resource-consuming. This means that there needs to be more actions taken and effort exerted by those who can bring change (Hutchings and Kuparinen 2020).

Firstly, there needs to be support from the community and local fishermen to have these changes make a difference. Some of these restrictions make it difficult for fishermen to keep the cod they catch, as there is a limit to what they can catch in a day. This results in a large amount of dead cod that has been caught and thrown overboard. In 2018, one study found that it was not uncommon for there to be over 3,000 pounds of cod throw out per trip. Without knowledge of the current population and management compliance, it is not possible to fully know how the population of cod is doing. This makes it nearly impossible for scientists and government officials to set forth rules and a specific course of action. To fix this issue, all groundfish trips in New England would need to be monitored. As of late, people are starting to recognize how important complete monitoring can be. In addition, locals must recognize how detrimental recreational fishing of Atlantic cod can be. Recreational fishing creates additional challenges in properly monitoring the species (Hutchings and Kuparinen 2020).

Secondly, refuges should be set up for the Atlantic cod to protect their important habitat. Protecting the fish's habitat protects the fish. Actions like this would stop the fishing of cod in specific areas. One of the most important aspects of this effort is that it can protect young cod and highly productive females (Hutchings and Kuparinen 2020). This action poses a method to quickly increase populations in areas.

Another effort that could be made in the distant future is the creation of modified fishing gear to reduce the amount of cod caught by accident. It is very common for cod to be caught while other fish species are being targeted. The creation of new gear could minimize this issue. This would require help from scientists as well as major funding to make this gear commonplace (Hutchings and Kuparinen 2020).

Overall, we can see that Atlantic cod is a victim of human greed and lack of education. With the start of the Industrial Revolution came a wave of production, which also meant the consumption of resources faster than anyone could predict. Today, Atlantic cod habitat waters run 53 degrees Fahrenheit.

As humans warm up the planet, so do the oceans. The Gulf of Maine “is one of the fastest-warming bodies of water on Earth” (Lawson 2019) and the Atlantic cod’s range grows smaller and smaller.

These warmer waters are a challenge and a result of negligent human behavior within the environment, which has stunted the growth of the Atlantic cod population along with many others like it. Acidity levels are rising along with the temperature. Studies have found “that increasing acidification makes cod embryos more sensitive to higher and lower temperatures, effectively narrowing the optimal temperature range for reproduction” (Berwyn 2018). Factors such as these limit cod spawning areas, inevitably slashing future cod populations and their re-build.

The current COVID-19 pandemic has only made it harder on the fishing industry and the groups associated with conservation efforts of the threatened fish species. Now more than ever, the fishing industry needs financial support from the government as well as support from the community. Something the community can do is continually advocate for advancing rebuilding plans, promote education to those around, and follow the rules already set in place to protect Atlantic cod.

Conclusion

Like all living entities, the Atlantic cod has a complex natural history. What’s remarkable about this fish, however, is how its natural history is interwoven with human history. For millennia, the species was so important to human survival that entire cultures and technologies were developed around it (Dexter and Speck 1948). Initially, cod was a nutritional staple to Indigenous Peoples in New England. Following European settlement, it then became valued for its economic significance within the Colonies. Now, cod is an internationally sought-after commodity, a direct result of commercial demand and the advancement of fishing technologies since the Industrial Revolution (Dybas 2006). Serial overharvesting, especially of large cod in indiscriminating trawls, inevitably led to the collapse of the fishery. Despite continued government intervention since the 1970s, cod stocks continue to fall, fishing towns continue to struggle, and the **trophic levels** that healthy cod populations once supported are damaged without them (Steele 2016). Conservation success stories for Atlantic cod are rare, and climate change is an added challenge to recovery efforts. Although minimal, the Gulf of Maine has seen improvement in the cod fishery, which is attributed to strict landing limits, but more importantly, to strict area limitations and habitat preservation (Alexander et al. 2009). If we protect the habitat, then we protect the Atlantic cod.

Figure 8. A cod swimming towards the ocean floor after escaping from a net. "Cod escaped from a cod trap heading straight for the bottom." by Derek Keats, CC BY 2.0

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10. Managing the Overfishing of Atlantic Bluefin Tuna

Isaac Garry, Jaya Mills, and Joseph Peregrim

Chapter Summary

The Atlantic Bluefin Tuna is an important species to both the environment and the global economy. The largest threat that the species faces is overfishing. This chapter will discuss why the Atlantic Bluefin Tuna needs to be protected and will outline the status of the species throughout the Atlantic ocean. The policies that regulate fishing practices in the western Atlantic with those of the Mediterranean Sea will be compared and their effectiveness in protecting the Atlantic Bluefin Tuna species will be evaluated. Policy change recommendations will be made based on the findings of the research presented in this chapter.

“Roter Thun, Bluefin Tuna (Thunnus thynnus) in Thunfischmast” by Tom Puchner, CC BY-NC-ND 2.0.

Introduction

The Atlantic Bluefin Tuna, *Thunnus thynnus*, is a majestic creature. It is among the largest and fastest creatures in the ocean and its unique body is unlike other fish. Over the course of 65 million years, evolution has turned the Atlantic Bluefin Tuna into what David Attenborough calls “the ultimate fish” (Hourston, 2019). These fish can grow up to 15 feet in length and weigh over 2,000 pounds over the course of their 35-year lifespan (“Atlantic Bluefin Tuna,” n.d). Atlantic Bluefin Tuna are capable of reaching high speeds upwards of 43 miles per hour due to their hydrodynamic shape (National Geographic, 2018). In fact, the teardrop shape of the tuna’s body, with its widest point two-fifths of the distance from head to tail, is the most hydrodynamic shape physically possible to achieve (Hourston, 2019).

Additionally, Atlantic Bluefin Tuna have developed a specialized method of swimming—thunniform swimming—named after the tuna's **genus**. In order to maximize efficiency, the fish's tail is the only part of the body to move laterally. The tail, or caudal fin, is tall, slender, and stiff. Horizontal keels at its base slice through the water to minimize water resistance as the tail moves side to side (Hourston, 2019). Further minimizing water resistance, most of the fins on a tuna are retractable (National Geographic, 2018). The fins that do not retract, the second dorsal and anal fins, are all narrow and swept back. Retractable fins also allow Atlantic Bluefin Tuna to make more precise movements in the water, which increases the likelihood that a fish lands its prey (Hourston, 2019). Yellow finlets along the back of the tuna serve to break up turbulence and further enable the fish to torpedo through the water (Hourston, 2019; National Geographic, 2018).

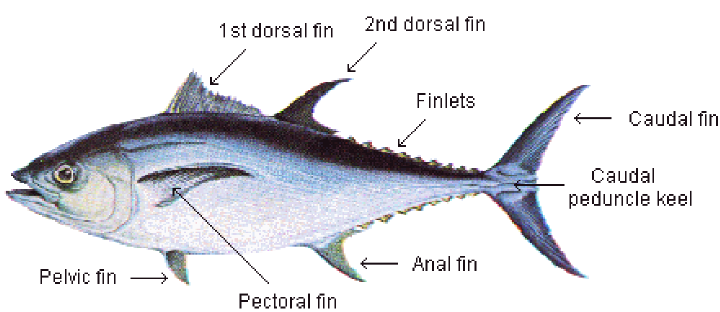

Figure 1. A fin diagram of the Atlantic Bluefin Tuna. Image from "Biological characteristics of tuna", FAO Fisheries & Aquaculture, CC BY 3.0 IGO

Inside the Atlantic Bluefin Tuna is just as significant as its exterior. The blood of the Atlantic Bluefin Tuna has 2-3 times more **hemoglobin** than the average fish, and its heart is several times larger (Hourston, 2019). This advantage allows individuals to swim faster, for longer distances, and at deeper depths than otherwise possible. Atlantic Bluefin Tuna also have more red muscle as a percent of body mass than any other fish (Hourston, 2019). Red muscle is used for endurance, which the species needs to migrate thousands of miles every year.

Potentially the most interesting attribute of the Atlantic Bluefin Tuna is the fish's ability to regulate its body temperature through a countercurrent heat-exchange system known as a rete mirabile. This system prevents metabolic heat produced by the tuna's muscles from escaping into the surrounding water. Instead, the heat is absorbed by the cool, oxygenated blood coming from the gills ("Atlantic Bluefin Tuna," n.d.). This ability allows the Atlantic Bluefin Tuna to maintain a body temperature between 77 and 91 degrees Fahrenheit, even in the frigid waters of the arctic circle (Hourston, 2019). Maintaining a high body temperature gives Atlantic Bluefin Tuna an advantage over other species in cool waters because it allows the fish's muscles to function with greater performance and the brain to function more intelligently.

The Atlantic Bluefin Tuna is truly magnificent. Unfortunately, it is best known as a food source. The Atlantic Bluefin Tuna fishing industry has a **dock value** of US $1.6 billion and an **end value** of US $5.4 billion each year, with the largest markets located in Japan where sushi and sashimi are consumed at high rates (The Pew Charitable Fund, 2020). The high value of the species makes it one of the most sought-after types of fish in the world ("Bluefin Tuna", n.d.). Because of this, the Atlantic Bluefin Tuna population is constantly under threat by fishermen.

Though it is not considered an overfished species by the International Commission for the Conservation of Atlantic

Tunas, or ICCAT, the Atlantic Bluefin Tuna's population is far less than it once was (ICCAT, n.d.). Furthermore, the illegal and undocumented fishing of Atlantic Bluefin Tuna pushes the total biomass of tuna caught past international **quotas** (European Union News, 2018). A decline in the Atlantic Bluefin Tuna population can directly affect entire ecosystems through a process called **top-down cascade**. In a top-down cascade, a predator at the top trophic level, such as the Atlantic Bluefin Tuna, controls the populations of the levels below it. A decrease in the population of Atlantic Bluefin Tuna would therefore cause an imbalance in the surrounding marine communities, causing fluctuations in the abundance and scarcity of all surrounding organisms (Gupta, 2017).

Methodology

To collect information with which to write this chapter, the team first did research on the topic using the online George C. Gordon library and other search engines to find articles. Resources used include species reports, articles, and scientific studies. To get information from a variety of perspectives, the team also conducted interviews with experts on the topic of research. Information about Atlantic Bluefin Tuna from its geographic range was collected so that status and policy could be compared in this research.

Distinct Populations

Early in the research process, it was found that Atlantic Bluefin Tuna could be divided into two populations: the eastern population and the western population (ICCAT, 2020). The distinction is made based on the location where the tuna breed. Western Atlantic Bluefin Tuna generally breed in the Gulf of Mexico and Eastern Atlantic Bluefin Tuna generally breed in the Mediterranean Sea (“Atlantic Bluefin Tuna,” n.d.). It is important to note that these populations are considered to be of the same species and that most of their geographic ranges overlap as shown in Figure 2 (“Atlantic Bluefin Tuna,” n.d.). Nevertheless, these populations are impacted differently by different policies in their respective breeding grounds.

ICCAT separates these two populations for management by the 45° meridian (Taylor et al., 2011). Much of the geographic range of the Western Atlantic Bluefin Tuna, including much of that in which they breed, is along the United States’ coastline. The Eastern Atlantic Bluefin Tuna range throughout the Mediterranean Sea and as far north as the North Sea. This means that the eastern Atlantic range is under the jurisdiction of more countries than the western Atlantic range. Historically, the eastern population of Atlantic Bluefin Tuna has been of greater concern than the western population. However, because of the vast overlap of the ranges of each population, each population inhabits fishing areas regulated by both western and eastern Atlantic countries (ICCAT, 2020). If one set of policies is poor in effect, both populations are harmed.

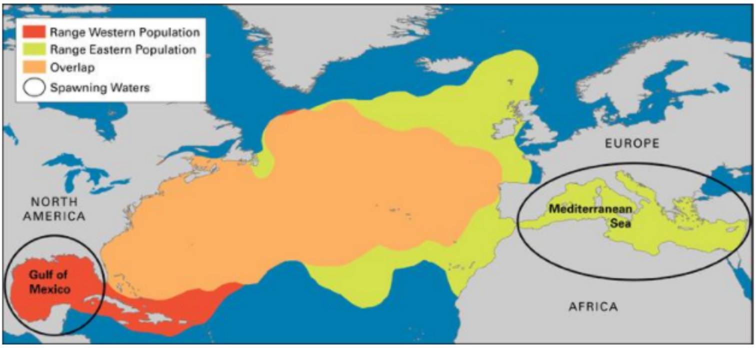

Figure 2. Using electronic tagging data taken from 1996 to 2007, this map shows the spawning grounds of two distinct populations of Atlantic Bluefin Tuna and where the ranges overlap. "Atlantic Bluefin Tuna Distribution Map", Courtesy of Smithsonian

International Regulation

The organization in charge of the international regulation of the Atlantic Bluefin Tuna is the International Commission for the Conservation of Atlantic Tunas (ICCAT). Established in 1966, ICCAT is described as an "intergovernmental" organization, responsible for conserving tunas and similar fish species. The region that ICCAT covers is the Atlantic Ocean and the seas that it borders (ICCAT, n.d.). The ICCAT makes regulations and develops management advice for all fish species across the Atlantic Ocean by using statistics from different fisheries. These statistics include those from research on coordinate locations of fish and stock assessments. Using recommendations from ICCAT, member countries make specific regulations for the regions within their jurisdictions based on population status.

Western Atlantic Status and Regulations

For a better understanding of the status of the Western Atlantic Bluefin Tuna, historical context is necessary. Western Atlantic Bluefin Tuna fisheries began in the middle of the twentieth century (Taylor et al., 2011). The historical range of the western population extended from Canada to Brazil, but in the twentieth century, the species seemingly disappeared from the southern part of its range (Taylor et al., 2011). This disappearance may be explained by the large amount of fish caught by the Japanese **longline fishery** in the region in the 1960s (ICCAT, 2020). The total catch of Atlantic Bluefin Tuna in the Western Atlantic peaked in 1964 with a total weight of 18,608 metric tons, most of which was caught by the Japanese longline fishery (ICCAT, 2020). The catch total decreased sharply after this with declines in catches along the Brazilian coast. The number of catches increased to over 5,000 metric tons in the 1970s as the Japanese longline fleet expanded into the Gulf of Mexico and the northwest Atlantic (ICCAT, 2020). ICCAT imposed a catch limit in 1982 and this caused total catches to decline again. There was another decline in total catches in the mid-2000s to 1,638 tons in 2007. In recent years, the total catches have steadily increased, reaching 2,305 tons in 2019 (ICCAT, 2020). In the last 6 years, the total allowable catch (TAC) has not been exceeded in the West Atlantic, and this is likely due to the market and operation conditions and not species decline, according to ICCAT. Currently, the Western Atlantic population is not considered to be overfished; however, the biomass of the population has decreased by an estimated 11.7% from 2017-2020 (ICCAT, 2020).

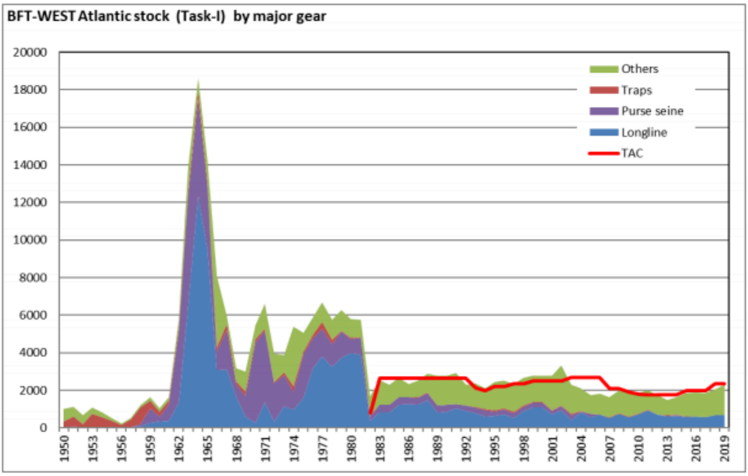

Figure 3. Graph of historical catches of Atlantic Bluefin Tuna by gear type with total allowable catch shown when instated. The y-axis represents the total catch in metric tons. Adapted from '2020 SCRS Advice to the Commission', 2020, International Commission for the Conservation of Atlantic Tunas, p. 46.

To learn more about regulation and policy in the western Atlantic, the team contacted and interviewed Raymond Kane from the Cape Cod Fishermen's Alliance. Kane has experience as a fisherman, a fisheries representative, and a lobbyist. He has been subject to regulations and has pushed for legislation regarding the Atlantic Bluefin Tuna fishery. It was found that he has extensive knowledge about the topic of this study. When asked about overfishing, Kane said that Western Atlantic Bluefin Tuna are not being overfished. This claim is backed up by the Standing Committee on Research and Statistics (SCRS), which states in their advice to ICCAT that Atlantic Bluefin Tuna are not overfished as of 2020. One of the reasons for this, according to Kane, is the high regulations on the fishery by the United States. Currently, regulations in the Western Atlantic are based on recommendations from ICCAT ("Western Atlantic

Bluefin Tuna," n.d.). In the United States, the National Oceanic and Atmospheric Administration (NOAA) enforces these regulations.

There are several management measures and regulations in place. First, commercial and recreational fishermen must have a permit to harvest bluefin tuna ("Western Atlantic Bluefin Tuna," n.d.). Other measures include annual fishing quotas, gear restrictions, time and area closures, and minimum size limits ("Western Atlantic Bluefin Tuna," n.d.). Kane stated that current regulations mandate that tuna caught using rod and reel must measure at least 73 inches in length, while fish caught with harpoons must measure at least 81 inches. Another important regulation is that targeted fishing of bluefin tuna in the Gulf of Mexico, a spawning ground, is not allowed ("Western Atlantic Bluefin Tuna," n.d.).

A specific example of a successful management program is the Individual Bluefin Quota (IBQ) program. The program was designed to incentivize fishermen targeting other species, such as Atlantic Swordfish or Yellowfin Tuna, to avoid interactions with bluefin tuna ("New Requirements Protect Bluefin," 2020). The program awards those who catch less bluefin tuna unintentionally with enhanced permissions to catch the fish that they desire. The program has had a substantial effect on the amount of Atlantic Bluefin Tuna bycatch. "Since it was implemented, the [IBQ] program has reduced the average annual bluefin bycatch by 65 percent compared to the three years before. That's about 330,000 pounds—or around four fully loaded semi trucks—less bycatch each year" ("New Requirements Protect Bluefin," 2020).

Recently, the Western Atlantic Bluefin Tuna population count has stabilized as fewer tuna have been caught in recent years as shown in Figure 3 (ICCAT, 2020). It is likely that this is not only because of regulations. According to Raymond Kane, there was a collapse in the bluefin tuna market in 2003. He said that this had a substantial effect on the selling price of the fish.

In the 1990s, Atlantic Bluefin Tuna were selling for around US $21 to $25 per pound, but now the same quality fish are selling for US $2 to $4 per pound. This, according to Kane, has made it impossible to make a living fishing for Atlantic Bluefin Tuna. The success of the fishery depends on the demand for the fish. Whether fishermen go fishing now depends on whether a person agrees to buy the fish, according to Kane. Low demand is bad for the fishermen and the economy but beneficial to Western Atlantic Bluefin Tuna.

Eastern Atlantic Status and Regulations

Eastern Atlantic Bluefin Tuna in the past have been severely overfished. From 1996 through 2007, catches are said to have been vastly unreported; the predicted correct stock numbers were 50,000 to 61,000 metric tons per year over that 11-year span (ICCAT, 2020). Since then, regulations made by ICCAT have been put in place around the Mediterranean, reducing the average catches over the last five years to 23,093 tons per year (ICCAT, 2020). Figure 4 below visualizes the sharp decline in the tons of fish caught once normal regulations were adapted into stricter plans for recovery, which were first put in place in 2006 according to European fisheries expert, Neil Ansell. Once these recovery plans took action, the Atlantic Bluefin Tuna stock eventually reached a status where today it is no longer considered to be overfished.

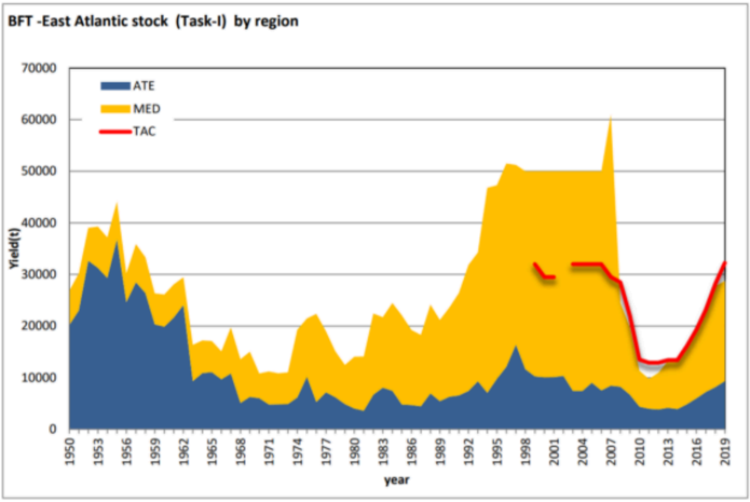

Figure 4. Graph of historical reported catches of Atlantic Bluefin Tuna by region. The y-axis represents the total catch in metric tons. TAC stands for total allowed catch. Adapted from '2020 SCRS Advice to the Commission', 2020, International Commission for the Conservation of Atlantic Tunas, p. 36.

Over the past few years, the stock has continued to improve; however, there is still more work to be done. In 2014, the implementation of stereo video cameras became part of regulation to help ensure that ICCAT was receiving true data that accurately represented how the Atlantic Bluefin Tuna was being fished. Unfortunately, there are still missing pieces for fully understanding how the population has changed since 2006 when recovery plans were put in place.

ICCAT's 2006 recovery plan changed a multitude of aspects of the previous regulations to ensure recovery of the Atlantic Bluefin Tuna. The recovery plan enforced closed fishing seasons. This meant that fishing of the Atlantic Bluefin Tuna was prohibited for different types of fishermen through different dates. Large long-line fishing vessels were prohibited from catching tuna from the start of June to the end of

December. **Purse seine** fishing for Atlantic Bluefin Tuna was prohibited from the beginning of July to the end of December. The last type of fishing to be given a closed season was fishing by **bait boat**, which was prohibited for the Atlantic Bluefin Tuna from the 15th of November to the 15th of May (ICCAT, 2006). Having these specific closed fishing seasons helped the tuna reproduce and grow their population without being constantly fished.

Another change that helped the Atlantic Bluefin Tuna population increase was the increase of the minimum size of tuna that could be legally caught. This change prohibited the sale of tuna weighing less than thirty kilograms (ICCAT, 2006). Another part of the recovery plan was the implementation of a maximum percent bycatch for Atlantic Bluefin Tuna. Authorized fishing vessels were allowed a maximum of 8% bycatch of Atlantic Bluefin Tuna that weighed between ten and thirty kilograms (ICCAT, 2006). This allowed fishermen to make unavoidable mistakes without repercussions but worked to limit those mistakes.

The recovery plan also required all fishing vessels to keep a logbook to record the quantities of Atlantic Bluefin Tuna that were caught and kept on board the vessel. Information such as the date, time, and specific location of a catch was to be recorded in these logbooks. Communication and reporting of catches were also required by the recovery plan (ICCAT, 2006). This made sure that as few catches as possible would go unreported, which was important when it came to gathering data to adapt the plan for the future. There were numerous other rules that this recovery plan enforced, but those mentioned above were the most important and most relevant to our research.

To learn even more about regulation and policy in the eastern Atlantic and Mediterranean Sea, the team contacted and interviewed Neil Ansell from the European Fisheries Control Agency (EFCA). Ansell has been with the EFCA for seven years and holds a position as a fisheries consultant. In his time with the EFCA, Ansell has worked mostly with tuna fisheries control. He was able to share with the team information regarding how ICCAT enforces its regulations and policies in the Mediterranean Sea. Because each participating country has its own government, ICCAT provides regulation recommendations. The mode of enforcement is entirely up to each country's own government, as long as regulations are in fact being enforced. In addition, the European Union, consisting of 27 countries, has to implement the rules and regulations as well. The most important information that we learned from Neil Ansell is that the Atlantic Bluefin Tuna is no longer considered to be overfished in the Mediterranean Sea. As of 2019, ICCAT's recovery plan has been changed to a management plan, which aims to maintain the now considered healthy Atlantic Bluefin Tuna population.

Black Market Trade

Because of the success of regulations across the Atlantic in recent years, overfishing is no longer a legal problem and has become an illegal problem, especially in the Mediterranean Sea. One example of a bluefin black market is the one that was suspended through Spanish Operation Tarantello in 2018 (*European Union News*, 2018). This illegal market was catching up to 2.5 million kg of tuna per year, which is double the estimated annual volume of the legal trade (*European Union News*, 2018). One of the reasons this market was so large is likely the amount of money it made. According to the article referenced previously, criminals earn at least €5 profit per kilogram of tuna. This means that the profit of this recently operating illegal market was approximately €12.5 million per year. With this information, it is evident that the potentially high value of Atlantic Bluefin Tuna is a driver of illegal fishing.

Illegal markets are not only a danger to the bluefin tuna population but also to the health of consumers. In Operation Tarantello, for example, fish were stored and transported in unsanitary conditions, causing several cases of food poisoning (*European Union News*, 2018). Tuna were sometimes hidden underwater after being fished and were in cases transported in false bottoms under the decks of boats (*European Union News*, 2018). These unhygienic conditions caused the degradation of proteins in the tuna, making them harmful to consume (*European Union News*, 2018).

Another example of an illegal bluefin tuna black market is that run by Colonel Moammar Gadhafi in Libya until 2011 (Lewis, 2020). Prior to the fall of Col. Gadhafi, "…Libya operated a fleet of at least 48 purse seiners, which resulted in a hefty percentage of the entire Mediterranean bluefin tuna production being caught in Libyan waters" (Lewis, 2020). He was accountable to no one and this resulted in the massive exploitation of bluefin tuna. Eastern Bluefin Tuna were being caught in the **Gulf of Sidra**, which is a spawning ground and a marine sanctuary (Lewis, 2020). According to figures from ICCAT, 12,000 metric tons of bluefin tuna were being harvested annually, and that is only the amount declared to them (Lewis, 2020). For this reason, the fall of Col. Gadhafi is considered to be one of the reasons for the resurgence of bluefin tuna in the Mediterranean in recent years (Lewis, 2020). Despite the fact that the population of Bluefin tuna is increasing, the task of management still remains for the future. Without proper management and cooperation, the black market could continue to be a problem and more people could start exploiting the Bluefin tuna in the future as their numbers increase.

Conclusion

The current global population of Atlantic Bluefin Tuna is in a state of recovery. Increasing populations in the east and west Atlantic indicate successful efforts made by ICCAT and the governments under its recommendation; however, in the western Atlantic, this could be a result of the changing Bluefin Tuna economy. Though the species is not fully recovered, current trends have brought the Atlantic Bluefin Tuna out of danger of extinction. While the species' population has greatly recovered, there are still management regulations in place to maintain the population's health. Unfortunately, the existence of the Atlantic Bluefin Tuna black market trade still threatens the species as of this writing.

Methods similar to those protecting the Atlantic Bluefin Tuna can be used in other regions with other species in the future. The black market trade, however, demands heavier enforcement. It is recommended that governments impose greater punishments for vessels and operations found guilty of illegal fishing. More effective methods of monitoring water for illegal fishing should also be put into place. This may look like an increase in government patrol vessels or increased monitoring of ports for fish sales. At the consumer level, customers should look to identify where their tuna comes from to ensure that they avoid tuna from regions that may be at risk of overfishing. The Western Atlantic Bluefin Tuna population is much more stable and healthy than the population of the Eastern Atlantic.

To expand on these findings, more research should be done on the behavior of Atlantic Bluefin Tuna in the west and the east. This research should focus on the interaction of individuals and possible cross-breeding of the two populations. More research should also be done on Atlantic Bluefin Tuna fishermen and their livelihoods to better understand policy regulation and overfishing as a whole from their perspective.

Finally, more population data would assist officials in making decisions relating to the management of Atlantic Bluefin Tuna.

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11. The Bigger Picture: Animal Trafficking and Poaching

Naomi Prevo, Mae Felkner, Davis Howland, and Luke Harrington

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Wildlife Crime – A Threat to our Health, Courtesy of UN Environment Programme, Terms & Conditions

Animal trafficking and poaching are two illegal methods in which humans capture and often kill exotic animals in return for animal products or the economic status that comes along with owning these animals. In this chapter, we will look at animal trafficking/poaching from a general and economic point of view, learn how animal trafficking and poaching negatively affects the ecosystems they occur in, and finally, we will show how to use this information to help contribute towards the battle against illegal wildlife trade.

Animal trafficking is in the top five most lucrative global crime enterprises. It is estimated that this trade accrues between $7-20 billion a year (Goyenechea & Indenbaum, 2015). In total, it is estimated that over 350 million animals are bought and sold on the black market each year (Carrington, 2013). There are many reasons why animal trafficking is still so prevalent, but one of the largest reasons is poverty. This industry provides some stability, and due to the high demand for these luxury goods, the hunters are expected to be well compensated. Another aspect that allows this industry to continue is the demand for specific "animal-based" products. The people who are supplying poachers with income are looking to purchase luxury items like animal skins, ivory, or even medicine obtained from certain animals. As mentioned earlier, over 350 million animals are estimated to be trafficked per year globally, but of that number, we decided the three most interesting animal species to research were the tiger, elephant, and rhino. Each of these species is sought after for their own specific product or attribute: tigers being sold for their pelts or as exotic pets, elephants being killed for their ivory or being sold as pets, and rhinos being killed for their ivory and sold as pets. All three of these species are constantly in danger in their natural environments due to poachers, and the decline in their populations severely affects not only them but every animal in their ecosystem. Locationally, these animals reside mainly in Southeast Asia, China, and Mexico.

With Asia being such a large continent, it has an extremely high amount of illegal trafficking. So much that researchers are now looking into Asia's recent exponential economic growth and whether it is due to the economic increase in animal trafficking which is raking in billions of dollars annually. It has also recently been revealed that Asia has played a huge part in the production and distribution of luxury goods obtained from these exotic animals. For example, in Indonesia, there are around 17,000 islands containing a large portion of the world's environmental **biodiversity**96; because of this biodiversity and the animal trafficking that occurs there, Indonesia has become one of the largest suppliers of these illegal products and has been recorded transferring up to $2 million worth of product annually (Linkie et al., 2018).

As well as Indonesia, China and Vietnam are other major countries that have made a significant impact on the global animal trafficking market. China has become well known for the distribution of elephants and their ivory as ornaments (Carrington, 2013), whereas Vietnam is well known for distributing mainly rhino ivory. Unfortunately, both of these species are facing extinction, and in fact, the Javan Rhino population is currently at 74 members globally due to poaching over time (Martin, 2019). Although this paper is focusing on the tiger, elephant, and rhino populations, there are thousands of other well-known species going into extinction due to animal trafficking and poaching annually. In Thailand, animals like frogs, snakes, leopards, and other animal species are all on the brink of endangerment or extinction due to human involvement (Carrington, 2013). Many of them are sold for their fur, medicinal purposes, or luxury goods, but as stated earlier, the removal of animals from their natural habitat on the large scale is not only detrimental to that species but to every other species in that ecosystem.

Although Asia is commonly accepted as the center of animal trafficking and poaching, it is not the only continent that is involved in this trade. North America, or more specifically the USA, has played a huge role as a consumer of animal-based goods. The estimated value of illegal trade within the U.S annually is currently $6 billion which is approximately 30% of the global income due to animal trafficking per year (Goyenechea & Indenbaum, 2015). People of higher income in the US have a high demand for luxury goods that come from small creatures like caiman, sea turtles, and exotic birds, whether that be as pets or clothing items. Although the rate at which people in the US purchase these animal products is high, it isn't necessarily the country's fault. At this point in time, the US is lacking financial support from the government to properly secure and enforce its borders to halt the flow of animal trafficking. One of the first main steps in solving this issue is obtaining the funds and support from governments around the world to help stop this issue from getting any worse.

At the moment, we as humans are constantly updated through the local news of our collective negative impact on the environment through things like littering, the burning of fossil fuels, and the use of pesticides; however, what most people don't understand is that animal trafficking is the most concerning problem to the health of our planet and our species. As mentioned earlier, when animal trafficking occurs in specific locations over long periods of time like with the tiger, elephant, and rhino, the ecosystems that they live in are negatively affected through a chain reaction of events. When an animal like an elephant is removed from its natural environment, its source of food (plantation) is allowed to overgrow. Although the slight increase in plantations in an environment may not seem like a significant problem, this new plant life often provides effective cover for smaller prey animals which are often food to predators like tigers. With the ability to catch prey becoming harder, the tiger and other predator populations suffer greatly and in extreme cases, they grow closer to extinction themselves. Although this still has no obvious negative effect on humans, the overall increase in loss of **biodiversity** across the planet is detrimental to the health of our planet, and the more we harm our planet, the less time we have to survive on it. When animals are shot in the wild for their produce, the bullets are often made of lead which is a metal that is known to be extremely poisonous. Keeping this in mind, it is estimated that over 4,000 tons of lead are shot into the environment per year due to poachers (Animal Matters, n.d.) . This lead not only kills the animal that has been shot, but it is estimated that 20 million animals each year die from lead poisoning due to the introduction of the metal into their habitat (Animal Matters, n.d.). This is just another example of how the effect of animal trafficking damages ecosystems in a “trickle-down” effect.

On top of the environmental issues that animal trafficking brings up, the industry has been heavily linked to the mass spread of infectious diseases. Currently, the world is in the middle of a global pandemic which is accepted to have originated out of Wuhan, China. The origins of the Covid-19 outbreak are still unknown, however on March 24, 2019, nearly 8 months before the first reported case of the outbreak, 21 live Sunda pangolins were taken into the Guangdong Wildlife Rescue Center, in Guangzhou. Although these 21 pangolins seem insignificant to the current global pandemic, when 11 of these creatures were tested for infectious diseases, fragments of coronavirus strains were found that were considered “a family high on the watch list of viruses potentially dangerous to humans” (Quammen, 2020). Although this doesn’t directly tie the connection between pangolins and the Covid-19 outbreak, it isn’t unlikely that illegal animal markets in Asian countries may have played a role at the beginning of this pandemic. It is also well known that many viruses like SARS, Nipah, and even Ebola were all found in groups of bats which are commonly distributed animals globally (Kessler, 2018). Reports from EcoHealth Alliance show that thousands of bats are transported from Asia to the Americas yearly. Additionally, back in 2002-2003, the SARS pandemic was a huge disaster that affected more than 8,000 people globally (Kessler, 2018). The virus was later traced back to a live animal market and proved that one animal being transported illegally around the world has a serious potential of doing serious harm to humans. On top of the detrimental effect that animal trafficking has on the environment, it is more than clear to see that it has the potential to harm the well-being of humans which should encourage people to support the battle against it.

The first interview that was conducted was with Dr. Samantha Russak of the Department of Education at Southwick Zoo. We asked her a variety of questions about the wildlife trade and her zoo's involvement in educating the community about this problem. She told us about the programs the zoo offered to visitors and about the animals they protected at the zoo. Russak informed us that sometimes preserves from other countries would send their animals to the US to protect them. For example, the rhinos at the Southwick Zoo were imported from Africa from a preserve. This seemed odd because the whole purpose of a preserve was so that the animals were protected, but she told us that sometimes these organizations cannot keep poachers off the whole preserve so it's safer in those cases for the animals to be sent to the United States where they can be looked after more closely.

Our interview with Joe Fontain, professor of ecology at Murdoch University in Australia, brought about many insights into the impact trafficking and poaching have on various ecosystems. Fontain spoke of the destructive chain effect brought about by the removal of animals from their ecosystem. He explained how every animal has its purpose in balancing the ecosystem and this balance as we know it has been refined over millions of years. But we are actively disrupting this balance. Another important topic brought up in the interview was how most animals that are being trafficked or poached have long pregnancy periods compared to many rapidly reproducing animals that can easily recover from population change. The example he used was elephants, which have an 18-22 month pregnancy period, and it is estimated that 70 elephants are poached per day, therefore making it impossible to repopulate at the rate that they are being removed (National Geographic Television, 2013). This goes for all of the animals that are most commonly being poached and traded towards extinction. Once extinct, these great creatures will become things of the past, lost forever in history. Joe Fontain believes the fact that for whatever reason, selfish motives or not, we must come together to save this planet from the current path of ecological destruction.

As humanity continues to both combat and feed the changing climate's earthly wrath, we often hyper-focus on day-to-day life. The most effective way to open your mind to the scale of destruction going on every day around us is to educate and be educated. There is no end-all answer to this oncoming **cataclysm**, the answer lies in numerous plans set in motion to rebuild our planet. Constant efforts are made to increase the use of alternate energy, as it is equally as important we learn to protect the wildlife we share the planet with. The removal of animals through poaching or trafficking can rapidly lead to ecological imbalances that will aid the path of climate disaster coming our way. Removing even a single animal from its local habitat can have a remarkably dangerous effect on the ecosystem, but what often goes unsaid is how even one conscious act towards protection can make a difference far greater than you may think. Knowing the potentially positive impacts of our often effortless actions should be enough incentive for even the most unmotivated people. This project, alongside many organizations and programs, aims to raise awareness of the severity of our often-overlooked consequences. Passing time while combined with an awareness of behavior will gradually lead to a decrease in the negative qualities of that behavior. It is our duty as humans to become aware of our impacts so the necessary changes can be made. It is time for us to take these steps, as no amount of guilt can change the past and no amount of anxiety can change the future—the time for change is now.

Ways that we would recommend helping this global issue are, most importantly, educating yourself and others. Through research and interviews, we have found that by educating yourself you can help spread the word about animal trafficking and poaching even when it does not seem to directly affect you. For example, if you have free time you could read more about this topic from reputable sources or if you see something on social media trying to spread awareness you can send that information to your friends or even post it yourself. There are so many other ways you can educate yourself and others too. If you are not a casual reader, you can take a trip to a zoo with your family or even watch an informative documentary. Donating to foundations is a wonderful way to support this cause, but it is important to do your research to ensure that the money you are donating is providing service directly to the communities and wildlife in need. Oftentimes you will find some larger organizations working with larger overhead costs, so less of your money will go directly towards the cause. The active foundations are ever-expanding and new ones are appearing all the time, but a few that we have found to be effective uses of money are places like the International Anti-Poaching Foundation and the Southwick Zoo.

The Southwick Zoo has many charities on their website for people to browse that are verified through the zoo as places that effectively use the money towards the cause. The possibilities and opportunities for change are seemingly endless if you're willing to put in just a fraction of your time and money. The scope of possibilities on how to help spans far past ecological needs. Looking at the economic instabilities of countries harboring this precious wildlife could be the origin of these issues. Actions to help these countries with alternative sources of work, or acquiring essential needs can, in turn, save the lives of numerous wildlife species that sustain our global ecosystems. Humans have constructed a culture based on material value, and to restore balance to the natural world we have to understand that killing animals is never worth the fur coat or ivory jewelry often sought after. Pursuing alternate materials such as synthetic versions of products like ivory, reptile skin, or even fur coats, will prevent much of the active poaching. These eco-friendly solutions will protect wildlife, and in turn, protect the very world we live in.

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PART III

CLIMATE CHANGE AND POLLUTION

Unlike the localized approaches to environmental problems that dominated the environmental policy arena from most of the 20th century, today's challenges regarding climate change and pollution require a more complex understanding of its multi-scale causes and consequences. Threatening around 13% of the world's biodiversity combined (WWF Living Planet Report 2020), climate change and pollution are thus prime examples of our contemporary challenges. Our responses need attention to human and ecological processes and both biogeochemical changes at a planetary scale and socio-political and economic decisions at a local and national scale.

Focusing on critical issues impacting aquatic and coastal ecosystems such as the sea-level rise and plastic pollution, the chapters in this section embrace these difficulties across scales and actors.

Considering mangroves as a cornerstone of life for coastal ecosystems and communities, the following two chapters examine the impacts of changes in this aqua-terrestrial ecosystem on biodiversity and coastal communities in less developed countries. Both chapters, "Mangroves: The Roots of an Ecosystem" and "Flooding Forests and Farmland: Sea Level Rise in Bangladesh," remind us of how human actions combinedly impact non-human species and the livelihoods, food security, and economies of the most vulnerable communities around the world.

Addressing the problem from the perspective of two paradigmatic species, Sperm Whales and the Laysan Albatross, these chapters recenter the question about human-induced global environmental change on plastic pollution. Plastic has become a transboundary socio-ecological problem and a marker of human presence on Earth. However, by focusing on what plastic does in these species' bodies, life cycles, and behavior, these two chapters highlight that the impacts of human presence are today embodied in the biological and life cycles of species.

All the chapters in this section remind us that the answers to environmental change and pollution are processes entangled on local and planetary dimensions and involve existential threats to human and non-human communities. Our ability to understand and face them from various perspectives and scales will be essential for our future on Earth.

Bleached staghorn coral on the Great Barrier Reef between Townsville and Cairns, March 2017. "[Bleached staghorn coral March 2017](#)", by Bette Willis. [CC BY-ND 2.0](#)

12. Mangroves: The Roots of an Ecosystem

Jacqueline Aaron, Lauren Abraham, Gelila Hailemariam, Sophie Loree, and Jackson Lundberg

A View of a Mangrove Ecosystem. Photo by Caroline Rogers, National Park Service, Public Domain.

The Aqua-Terrestrial Life of the Mangroves

Mangroves are plants that thrive in salty coastal marine habitats. In the United States, mangrove shrubs and trees can range from 6.5 feet (2 meters) to 33 feet (10 meters) in height with oval-shaped leaves (Conservation International 2020). Mangrove species can produce flowers that are yellow, white, green, or red (Selvam 2007). In the tropics, red mangroves can grow to 80 feet (24 meters; NWF 2020). Mangroves can grow bigger in the tropics due to more water and sunlight. Salt from the seawater is excreted in different methods depending on the species of mangrove; it may be excreted through the glands in the leaves, the root system, or the bark on the roots (AMNH 2020). The leaves also function to retain water within the plant. They have a waxy coating to capture water and have small hairs which are used to reduce water loss during photosynthesis. However, out of all the tree's characteristics, its unique root system sets mangrove tree species apart from tree species around the world. The exposed arched root system either projects out from the trunk like stilts or extends in wide and curved plank-like formations. The roots act to stabilize the mangrove shrub or tree's shallow root system within the soil and sediment. The exposed root system also functions as the conduit for oxygen for respiration. Thousands of raised pores called lenticels on the exposed roots (also known as pneumatophores) allow for oxygen intake and then close during high tide (AMNH 2020). The method by which mangroves reproduce is just as fascinating as to how mangroves take in oxygen.

A mangrove reproduces by producing small flowers in late winter or early spring. The flowers produce a bud, or propagule, which then has a further growth period. The propagule then splits off from the parent plant and is sent into the water for further embryonic development. The amount of time that the propagule will float in the water depends on the species;

embryonic development for the red mangrove is up to 40 days, for the black mangrove it is up to 14 days, and at least 5 days for the white mangrove (Booker et al. 1998). Once the propagule becomes waterlogged, it sinks to the bottom of the water, germinates into the mud and sediment, and grows plant roots and leaves, a process varying between 5 -15 days. The new mangrove plants produce propagules of their own, and the life cycle continues (NHMI 2021). Another adaptation mangrove shrubs and trees have developed is being able to store carbon from the atmosphere in the soil (MOW 2020). The process starts as carbon is taken in from carbon dioxide for the development of a mangrove's leaves, branches, and roots. Carbon is captured in the leaves and when dead leaves settle in the mud and sediment, the carbon is stored in the soil. This organic matter is called "blue carbon" because it is fixed in ocean ecosystems (MOW 2020). These unique methods of sprouting new growth and storing carbon dioxide explain how mangrove forests have been able to grow along coastlines all over the world.

Figure 1: The map shows the global distribution of mangroves. "World map mangrove distribution.png" by Pinpin, CC BY-SA 2.5

As of 2010, mangroves covered an estimated 137,760 square kilometers (53,190 square miles) of the Earth's surface (Figure 1). Mangrove forests are found in over 118 countries, however, almost 75% of mangrove forests are in only 15 countries (NASA Earth Observatory 2010). As shown in Figure 2, the top 5 countries with the most area of mangrove forests are Indonesia, Brazil, Malaysia, Papua New Guinea, and Australia (Hamilton and Casey 2016). Mangroves are usually located around the equator between 25° North and South latitude covering five continents, mangrove forests are located as follows: 42% in Asia, 21 % in Africa, 15 % in North and Central America, 12 % in Australia, and 11 % percent in South America (NASA Earth Observatory 2010). Due to their wide distribution, as shown in Figure 1, mangroves provide a variety of economic and ecological benefits for coastal communities around the world.

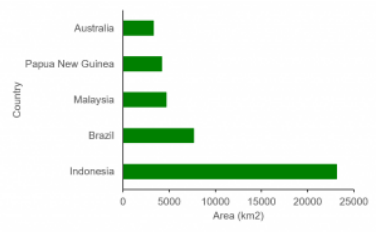

Figure 2: Top 5 countries with the most area of mangrove forest. Graph is drawn with 2014 data from Hamilton and Casey (2016), CC BY 4.0

The Economic and Ecological Importance of Mangroves

The global estimate for all the ecosystem services mangrove forests provide (coastal protection, carbon sequestration, harvestable wood, tourism, and fisheries) comes to a total of $25 trillion USD (zu Ermgassen et al. 2021). The global mapping of carbon sequestration (the process of capturing and storing carbon dioxide) is shown in Figure 3. The greatest impact of mangrove forests on human communities is observed in near-shore fishing communities in less developed countries, where they help to support the economies and food security of these high poverty areas (zu Ermgassen et al. 2021). For local communities around mangrove forests, mangroves provide valuable wood to build houses because the wood is insect and rot resistant and they provide fish populations as a food source. Mangrove forests can also be used as "nursery habitats for (commercially important) crab, prawn and fish species, and support offshore fish populations and fisheries" (Nagelkerken et al. 2008).

Data collected from the French overseas territories was used to calculate the annual service of water purification to be about 109 million euros/year, which would be about 130 million USD/year (Trégarot et al. 2021). Other service sums include coastal protection, which was between 202 million and 688 million euros/year, carbon sequestration was about 938 million euros/year, and supporting fish biomass production summed up to about 88 million euros/year (Trégarot et al. 2021). Mangroves cover only 0.1% of Earth's land surface and store more carbon per hectare than any other type of forest (Marcus 2018) and occupy one-quarter of the tropical coastline on Earth (Acharya 2002).

Mangroves and fish populations are so intertwined that the loss of one square mile of mangrove forest will cause a loss of about 124 metric tons of fish per year (Feller 2018). The aerial roots help create habitats for sponges, meiofauna, macrofauna, prawns, insects, elasmobranchs, bony fish, as well as amphibians, reptiles, and birds (Nagelkerken 2008). Even microorganisms rely on the mangrove's roots and in turn provide for their ecosystem by filtering out nitrates and phosphates from rivers and streams before reaching the sea (AMNH 2019). Mangrove forests also provide a canopy for other non-aquatic species such as birds, insects, mammals, and reptiles (Nagelkerken et al. 2008). Due to the dependence of many organisms on mangrove forests in coastal ecosystems, mangroves are considered a keystone species and are vital to the biodiversity of coastal ecosystems (AMNH 2019).

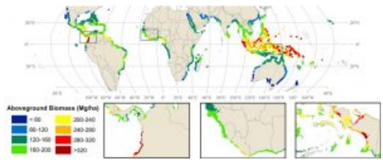

Figure 3: A global map showing the global distribution of carbon stored in mangrove forests. "Figure 2. Global mangrove map showing modeled patterns of above-ground biomass per unit area." by Hutchinson et al. 2013, CC BY-NC-ND 3.0

One of the most important aspects of how mangrove forests contain such biodiversity is through the leaves of the mangrove. When the leaves of a mangrove tree fall, they fall to the floor where they are broken down and decomposed to form detritus. This process cycles nutrients back into the ecosystem where microorganisms such as algae and plankton are able to prosper, creating food for the rest of the food web. Many organisms such as crabs, small fish, and prawns eat the decaying detritus directly. This combination of nutrient-rich detritus and the complex root structure of the mangrove trees provides an ideal habitat for many aquatic organisms. These organisms then become food for the top consumers in the ecosystem- crocodiles, sharks, ospreys, and humans (Shaw 2013).

The marine life that thrives in these estuarine ecosystems supports the needs of residents in the surrounding areas. With around 4.1 million fisheries associated with mangrove forests worldwide, the effects of climate change on mangrove habitats permeate far beyond the devastating ecological impact (zu Ermgassen et al. 2021). As mentioned previously, the coastal communities that rely on food and other resources from these mangrove forests have been forced to adapt their lifestyles to the changing mangrove ecosystems. Mangroves prevent erosion, provide coastal and wind protection, and help with water purification (Trégarot et al. 2021). These ecosystem services are vital to the survival of coastal communities, putting them at risk as mangroves continue to be affected by climate change, pollution, and coastal/urban development and, for some, being on the brink of extinction.

The Loss of Mangroves

There are 70 known species of mangroves, 11 of which are at a higher risk of extinction (Polidoro et al. 2010). Based on data from IUCN the two mangrove species *Sonneratia griffithii* and *Bruguiera hainesii* are critically endangered. The species Camptostemon *philippinense, Heritiera fomes*, and *Heritiera globosa* are endangered. *Heritiera globosa*, a rare species with less than 250 known adult trees, and *Sonneratia griffithii*, which lost 80% of the population over the past 60 years, have the largest global loss percentage (Polidoro et al. 2010). The red mangrove species is not threatened, but the overall population is declining (Ellison et al. 2015). It is difficult to determine the number of individual *Rhizophora* mangle trees in the world as they grow in large tangles, often with other species of mangrove trees. However, according to a 2011 study, there are about 55,000 km2 of mangrove forests that are found within *Rhizophora* mangle's native range (Giri et al. 2011). Although it is difficult to estimate the number of individuals of mangrove trees, there is an observed downward trend in population numbers.

Fifty percent of the world's mangroves have disappeared in the past half-century, due to two major factors. The first is due to very low genetic variability between mangroves which are almost identical to their neighbors. Without genetic diversity, species are not able to adapt to a change in their environment, increasing the probability of populations with similar genetics becoming extinct. The lack of genetic variability indicates a past change in sea level, caused by a retreat of the glaciers, that killed most of the mangrove population causing a genetic drift (Candy 2018). After this occurrence, the mangrove species had less genetic variation.

The second major factor of the mangrove population decrease is the human environmental impact. The populations of all mangroves have decreased due to agriculture, coastal development, low rates of reproduction, pollution, and climate change (ELAW 2021). Mangroves are removed to make space for "artificial ponds that are densely stocked with shrimp" (AMNH 2020). The chemical soup, containing copper and organic tin compounds, must be poured into the water supply to keep the shrimp alive. This contaminates the seawater by creating toxic residues and sediments, and the mangroves are essentially poisoned (Gräslund and Bengtsson 2001). Mangrove forests are removed for other agriculture such as rice paddies, rubber trees, and palm oil plantations that replace the coastal areas. The extensive exploitation of mangrove forests may lead to the potential loss of these species. Government actions to enforce management practices and protection of mangroves are needed to discontinue the downward population trend.

Conservation efforts and Mangrove Management Practices

As mangrove populations decrease, with some being critically endangered, it is important to make conservation efforts to help save the populations. Data collected in the French overseas territories estimates that 70.6 % of the mangroves in the area are legally protected but only 25.5% of those mangroves are effectively managed (Trégarot et al. 2021). On a global scale, efforts are being made by conservation groups such as the World Wildlife Foundation (WWF). One conservation project established by WWF for mangroves includes Tun Mustapha Park, the largest marine protected area in Malaysia, which encompasses more than 2.2 million acres of coral reefs, mangroves, seagrasses, and productive fishing grounds (Marcus 2018). Another protected area established by WWF and local communities is Sanquianga National Park in Colombia. The park consists of a 197,000-acre protected area that includes 105,700 acres of mangroves and is a crucial source of income for more than 125 communities along Colombia's Pacific coast (Marcus 2018). Both of these examples, National park reserves and the fact that they both support local communities economically, is a prime example of agroforestry, which is the land management method of integrating forests with crops and pasture land in order to protect the ecosystem diversity and nutrients of the soil (Gold 2017). If the mangroves were removed, there would be space for greater nearshore fishing endeavors, but since fish populations rely on the mangroves the benefit is greater to conserve mangrove forest populations, resulting in greater fish populations and diversity. A global issue is that mangrove forests have been cleared and now need the contributions of conservation organizations and government aid.

With the appropriate government aid in place, mangrove forests can recover. An example of this is seen in Singapore. Singapore has lost more than 90% of its mangrove forest extent since becoming an independent state in 1965 as land has been reclaimed for industrial development and aquaculture, freshwater reservoirs have been constructed in previously mangrove-fringed estuaries, and the shoreline has eroded and been increasingly polluted. In 2018, there were only 0.81 km2 of mangrove coverage in Singapore (Ellison et al. 2020). Mangrove rehabilitation efforts in Singapore started because the government made climate change and preparing the country for rising sea levels a key priority. The Singaporean government has included programs like ecological engineering, monoculture plantations, and Ecological Mangrove Restoration (EMR) approaches (Ellison et al. 2020).

Ecological engineering was used on Pulau Tekong, an island off Singapore's northeast coast, where mangrove saplings have been planted within new and existing hard coastal defense structures due to the coastline being severely damaged from shoreline erosion (Ellison et al. 2020). The mangrove population increases on the coast and it is considered ecological engineering because nature is being used to help the human population by preventing erosion.

Monoculture plantations were used on Pulau Semakau to plant 1,900 propagules (segments of mangrove trees) per hectare to replace the loss of habitat from clearing the original forest to make way for a landfill (Ellison et al. 2020). Monocultures are typically regarded as bad for the environment, but because this monoculture was made up of multiple species of mangroves, it helped the biodiversity in the area. This density was required to account for the ≈ 94% mortality rate of the planted propagules that is common with monoculture rehabilitation projects globally (Ellison et al. 2020). Despite the high possible mortality rate, the monoculture was created to combat the large loss of habitat from creating the landfill. The high mortality rate of monocultures typically comes from nutrient competition, a farm of many different plants would require many different nutrients, so competition is low. In a monoculture of mangroves, all of the trees are competing for the same nutrients.

One of the first EMR approaches in Singapore was observed in Pasir Ris, and was designed to allow mangrove seedlings to naturally colonize a 1-ha area that had been reclaimed previously. The goal was to create corridors between other mangrove patches along the coastline of Pasir Ris (Ellison et al. 2020).

A second, and most recent, EMR project was the recolonization of the abandoned agricultural ponds on Pulau Ubin. The community-based rehabilitation effort in the 8.8 ha area required extensive mapping of the local mangroves and examination of the biophysical conditions in the area. The purpose was to match the conditions for successful mangrove growth with the new mangrove species that were planted during the EMR project (Ellison et al. 2020). After 20 years, more mangrove species had grown than what was originally planted, mollusks, crustacea, and snakes had established in the area, and a higher amount of fish diversity has been observed compared to areas with constructed shorelines (Ellison et al. 2020).

The success of these three methods shows the importance of recreating the correct biophysical conditions for seedlings, offering artificial protection for seedlings, planting numerous species of mangroves, planting enough to overcome the high seedling mortality rate, and increasing the area of mangrove rehabilitation in order to restore mangrove forests in urbanized coastal settings (Ellison et al. 2020). By following the methods used by Singapore, coastal cities around the world would be able to drastically increase the populations of mangrove forests. Despite the enormous number of benefits mangrove forests provide, there is an overall decline in the populations of Mangrove tree species and conservation organizations are stepping up.

As climate change continues to alter coastal ecosystems, overall mangrove conservation efforts have become more widespread, as shown in Figure 4. The Global Mangrove Alliance (GMA) is a community of activists and scientists who are committed to "comprehensive mangrove conservation and landscape restoration that help the world mitigate and adapt to climate change, safeguard biodiversity, and enhance the well-being of the most vulnerable coastal people" (Knowledge Hub 2018).

Figure 4: A group of individuals in Jakarta, Indonesia planting mangrove propagules. "Planting mangrove" by Ikhlasul Amal, CC BY-NC 2.0

The GMA has many current conservation initiatives including one in the Philippines to sponsor community activism and engagement in local ecosystems. The World Wildlife Foundation (WWF) works with the GMA and together they work to conserve mangroves in Malaysia. Tun Mustapha Park, the largest marine protected area in Malaysia, was founded with community help and encompasses more than 2.2 million acres of coral reefs, mangroves, seagrasses, and productive fishing grounds. The park allows for agroforestry to occur because of the positive relationship mangroves have with fish populations and in turn the fishing industry of local communities (Marcus 2018). As a result of these management practices, the rate of mangrove decline has stabilized. In the late 20th century, the mangrove rate of decline was 1% to 3% per year (Lo 2020). As of September 2020, the rate of decline has ameliorated from 0.3% to 0.6% (Lo 2020). This statistic shows the hard work that has been poured into mangrove conservation, but also shows that there is still a great amount of work to be done in terms of conservation. Mangrove conservation and management are very different across the varying regions where mangrove forests grow leading to differing rates of habitat loss by region.

Case Study: Florida's Fight for Mangrove Preservation

In looking at mangrove protecting policies in Florida, it is important to first understand the history of mangrove populations in the region and how urbanization has affected these populations. Tampa Bay, located on Florida's southwest coast, is one of the ten largest coastal ports in the nation. Over the past 100 years, this part of the state has seen a rapid influx in population and subsequent urbanization. As a result of new development since the 1920s, "Tampa Bay has lost over 44 percent of its coastal wetlands acreage; this includes both mangroves and salt marshes" (FDEP 2021). This loss in mangrove habitats has resulted in an overall loss in biodiversity and the decay of the local estuarine ecosystem.

Similar effects on mangrove populations are evident elsewhere in the state. On Florida's southeast coast is a lake known as Lake Worth that naturally evolved from a saltwater lagoon to a freshwater lake. It has since been changed back to an estuarine lagoon as the result of human modification. Due to these changes, Lake Worth has seen an 87% decrease in the overall mangrove acreage over the past 40 years (FDEP 2021). What used to be vast mangrove forests have been replaced with invasive Australian pines as they are more desirable in the newly developed suburban neighborhoods. In this area of Lake

Worth, the 276 remaining acres of mangrove forests are strictly protected by state regulation.

To combat the rapid loss of mangrove ecosystems, regulations have been put in place and enforced to ensure the survival of these vital native estuarine species. In 1996, the Mangrove Trimming and Preservation Act was enacted with the intent to “protect and preserve mangrove resources valuable to our environment and economy from unregulated removal, defoliation, and destruction”(FDEP 2021). This act outlines exactly how mangrove populations can be altered by private citizens in the state of Florida. The main points focus on ensuring that professional mangrove trimmers and certified arborists are the sole persons trimming and altering mangrove forests of a specific size. On private property, “trimming must be conducted in stages so that no more than 25 percent of the foliage is removed annually” (FDEP 2021). This is to ensure the longevity of localized mangrove populations. It is also stated that there can be no use of chemicals or herbicides to remove leaves from a mangrove tree (FDEP 2021).

Despite the enactment of this policy in 1996, the population of mangroves has continued to decrease in Florida. This is largely due to the continued coastal development and overall urbanization of the state. With the imminent threat of more species loss, further legislation and personal action are necessary to protect these keystone species. Mangroves contribute immensely to both aquatic and inland ecosystems and with their continued depletion comes a great risk for these environments. Governmental-mandated management practices have proven minimally effective as states often prioritize development for monetary gain over the environmental needs of the local ecosystems. For this reason, it is necessary that individual action must be taken to help protect mangrove species.

What Can You Do To Help the Mangroves?

In regions where mangroves present are in forests, many environmental groups work to protect these vital natural resources. These groups and nongovernmental agencies are always looking for funding and volunteers to aid in the fight to defend mangrove populations. Efforts can also be made to protect mangrove ecosystems by those who do not live near these keystone species. People can choose to stay away from vacation spots built on mangrove forests as tourism has led to the destruction of mangrove forests. These forests have been removed to expand land development in tropical locations. Mangrove forests are also being destroyed to make room for agriculture such as seafood, palm oil, rice, and rubber. One way to contribute to helping mangrove forests is by refraining from purchasing any seafood or other products that use palm oil, rice, or rubber that was grown in a former mangrove forest. Limiting personal waste and production helps reduce pollutants that threaten the livelihood of mangrove forests.

Summary

Mangroves are the cornerstone of life for coastal ecosystems and communities. Found in over 118 countries located near the equator, mangroves serve as ecological and economic giants for the estuarine and human communities that they serve. The greatest impact of mangrove forests on human communities is observed in near-shore fishing communities in less developed countries, where they help to support the economies and food security of these high-poverty areas. Mangroves are the most carbon absorbent forests on earth and provide many ecosystem services including the prevention of erosion, coastal wind protection, and water purification. Mangroves are the roots of estuarine ecosystems and must be protected to ensure future coastal prosperity.

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13. Flooding Forests and Farmland: Sea Level Rise in Bangladesh

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Abstract

As the global climate continues to shift, many different environmental changes are being experienced far and wide. One of the most widely known effects of climate change is the global rise of sea levels, which has a large potential to affect biodiversity and extinction rates. Bangladesh is experiencing the challenges many countries have begun to face, like increased groundwater **salinity** , and erosion. This chapter focuses on three areas: the expansion of the **aquaculture** industry, the damage being done to the **Sundarbans** mangrove forest, and the effect that these issues have on the people of Bangladesh.

Figure 1. The result of a mangrove tree being cut down. "[Mangrove tree in Kuakata Sea Beach Patuakhali Bangladesh](#)" by Shahnoor Habib Munmun, [CC BY 3.0](#)

All around the world, countries like Bangladesh are being impacted by sea-level rise in various ways, especially in coastal regions. Rising sea levels in combination with the increasing frequency of extreme weather patterns have greatly increased the rates and levels of flooding in Bangladesh. Among other effects, this has led to increased groundwater salinity and erosion. When beginning our research into this topic, our group sought to learn both how the biodiversity of wild species and the people of Bangladesh are being and could be affected by sea-level rise. As we continued our research, we began to recognize the sheer scope of the issue, even confined to one country, and narrowed our focus to examine the impacts on Bangladesh's agricultural industry and on the Sundarbans mangrove forest. By focusing on these two areas, we were able to connect the effects on humans with the effects on other wild plants and animals. Understanding specific relationships between humans and ecosystems such as this may prove to be beneficial in helping humans adapt to a changing environment in conjunction with a rising population.

Our Research Process and Methodology

Our methodology consisted of three main steps. At the start of this project, our goal was to gather as much research on the general topic of sea-level rise in Bangladesh as possible. By doing this, we were then able to start narrowing down which subtopics we wanted to focus on, without having to scramble for more information. The next step we took was to reach out to different experts in the field to gather even more information. We took this opportunity to fill in the gaps in our thought process and to clarify which areas we wanted to focus more on. We also wanted to hear the personal experiences of a person in these areas. Our group was fortunate enough to interview Dr. Stuart Hamilton from Salisbury University. Dr. Hamilton provided us with great information about mangrove conservation that helped solidify the direction we wanted to go in. The last step was the analysis. At this stage in our research, we took a step back to look at all of the information we had and finalized which smaller topics we wanted to explore.

Figure 2: Bangladeshi woman standing next to an aquaculture pond. "Feeding the fish in pond, Bangladesh" by WorldFish, 2008, CC BY-NC-ND 2.0

The Expansion of Aquaculture

The Bangladeshi economy is primarily agriculturally based, having marine produce as one of their largest and most valuable products, second only to rice (FAO, 2005). Seafood accounts for about 63% of animal protein intake in Bangladesh (Jahan et al., 2009), and is also their second-largest export industry (FAO, 2005). Due to the rising sea levels, seawater **inundation** has increased soil salinity throughout much of the region (Chen & Mueller, 2018). The increases in salinity are shown to have negative effects on a range of crops with rice being greatly affected (Zeng & Shannon, 2000). Due to the increase in salinity, land-based agriculture is becoming increasingly difficult to profit from in places like Bangladesh as sea levels continue to rise. One way that many Bangladeshi are adapting to this is by diversifying and shifting their focus to aquaculture, a controlled cultivation of aquatic organisms. From 1990 to 2010, aquaculture in Bangladesh exhibited an average annual growth in production of 10 percent (Jahan et al., 2009).

The Possible Negative Effects of Aquaculture

While aquaculture is capable of providing a highly efficient and adaptable food source for growing countries like Bangladesh, it is also known to have negative effects on surrounding aquatic ecosystems. In countries such as China that have exhibited a similar expansion of aquaculture, negative side effects have been observed (Cao et al., 2007). It is well known that the solid waste products produced from aquaculture can dramatically increase the levels of nutrients such as nitrogen and phosphorus in bodies of water. This build-up of nutrients can lead to **eutrophication**, which can, in turn, cause algal blooms and reduce the oxygen levels of the water (Mancuso, 2015). One source of this pollution is the wastewater produced from aquaculture. If discharged untreated, the large concentrations of phosphorus and nitrogen increase levels in surrounding bodies of water, making it much easier for algae to reproduce, causing algal blooms and eutrophication. This is made worse by solid waste such as uneaten feed and fecal matter which also contains these same nutrients. As well as this, untreated wastewater can dramatically decrease levels of oxygen due to the decomposition of organic matter (Cao et al., 2007). Open-water cage aquaculture systems are particularly harmful for these reasons due to their high level of exposure and interaction with their surrounding environment.

Another source of environmental harm caused by aquaculture is the use of disinfectants and antibiotics.

According to (Burridge et al., 2010), antibiotics used in aquaculture have the potential to affect the local biodiversity of phytoplankton and zooplankton even after being digested, which could have extended consequences possibly affecting land animals and humans. As well as this, the widespread use of antibiotics can lead to the proliferation of antibiotic-resistant strains of various bacteria. This also has the potential to affect myriad animals as well as humans.

The Effects of Aquaculture on Coastal Communities

Growing every year by about 6.1% from 2002 to 2012, aquaculture is one of the fastest-growing animal food-producing sectors worldwide (Abdullah et al., 2017). Increasing sea level rise and salinity levels and reduced freshwater availability have been the main reason for the transition from rice culture to shrimp aquaculture practices. The industry of aquaculture is funded by foreign companies and industries that benefit from the low cost of the land and work in Bangladesh and most of the products are exported for a profit. A study from 264 households in Mongla examining how shrimp aquaculture has affected the livelihoods of people living beside the Sundarbans mangrove forest in Bangladesh found that shrimp income represents about forty-six percent of the total household income for the higher-income households, but just twenty-six percent for middle-income households and eight percent for lower-income households (Abdullah et al., 2017).

The increase in aquaculture will mainly benefit those who come from higher-income households. The lower-income households are being bought out by the higher-income households who already have large plots of land and will benefit from this industry. The people from lower-income families end up in poorly paid jobs working in the aquaculture industry. More than 90 % of those in aquaculture-related jobs either collected shrimp fry for the farms or worked as laborers. Income from shrimp aquaculture in Bangladesh is and has been, beneficial only to the rich. Fifteen years ago, around 84% of the very poor received no income at all from shrimp aquaculture, where the very rich earned around 58% of their total income from shrimp aquaculture (Abdullah et al., 2017). Shrimp income forms an integral part of the higher-income and some middle-income households. As a result, economic growth due to shrimp aquaculture has had a positive outcome for middle- and high-income households that own shrimp farms due to the shrimp aquaculture increasing their income-earning opportunities, but a negative outcome for low-income households.

The Ecosystem Services that Mangroves Provide

Figure 3: Sundarbans mangrove forest in Bangladesh. "Sundarbans – high tide" by juggadery, CC BY-SA 2.0

The Sundarbans is a mangrove forest spanning 4,000 square miles of both India and Bangladesh. It is the world's largest continuous mangrove forest and is home to a wide variety of species. Due to its large size, it serves as a natural barrier against tides and cyclones and absorbs storm surges. Unfortunately, due to climate change and human activity, the forest has been exponentially shrinking over the years. There are multiple reasons why it is shrinking, including the salinity of the water and illicit logging. The increase in salinity comes from both the rising seas and upstream dams that are reducing the freshwater flow into the Sundarbans. Another downfall in the rise in salinity is that it kills off higher value, storm-stopping tree species like the Sundari. This is very important because this species and multiple other tree species contribute to the coastal protection of Bangladesh. Mashfiqus Salehin is a professor at Bangladesh University of Engineering and Technology's Institute of Water and Flood Management and commented that "The salinity front is just going up and up and up. New areas will salinize, and moderately salinized areas might become unlivable. It's becoming a big problem" (Schwartzstein & Datto, 2019). Illicit logging is the process of cutting down trees and using wood for building materials to house the population. This depletes the mangrove population drastically.

Due to these reasons leading to a depleted mangrove population, the stabilization of the coastal land is now compromised. With the absence of the tangled roots of the mangroves giving structure to the land, it erodes into the sea. In addition, the land is not replenished as it once was due to the upstream dams blocking the river flow. An example of how much the land has eroded due to the depleted mangrove population is three islands in India's Hugli River: Lohachahara, Suparibhanga, and Bedford. A century ago, these islands were covered in mangroves but they have since vanished. Another island that has been affected is Sagar Island, which is an island in India that lies on the Bay of Bengal. Since the mid-20th century, the size of Sagar Island has shrunk by 20 square miles (Schwartzstein & Datto, 2019). Another issue this island is facing is the drastic increase in population due to new arrivals coming from disappearing neighboring islands. This ties into how the local communities are drastically affected by the lack of coastal protection from the mangroves and the sea levels rising as a whole.

The Changing Biodiversity of the Sundarbans

The Sundarbans of Bangladesh contain some of the most diverse ecosystems in the world. As a biodiversity hotspot, it is home to 334 plant species, 49 mammalian species, 59 reptilian species, 210 whitefish species, 24 shrimp species, 14 crab species, 43 mollusks species, and around 260 bird species (Uddin et al., 2018). It is also home to many endangered species including the Royal Bengal tiger, the only tiger known to reside in mangrove forests. These species are in danger, as deforestation and salinification destroy sources of food and shelter for both plants and animals. The rising sea levels are causing seawater to have a higher salt content. When temperature increases, water is evaporated at a higher rate, leaving behind a very high salt concentration in the remaining water (Uddin et al., 2018). The seawater containing a very high concentration of salts destroys vegetation and soil fertility in the region. It also creates a lack of drinking water. These species have little to no access to drinking water and are left with increasing rates of dehydration. Habitats are also being destroyed, especially those of marine life as conditions become unlivable.

Silvo-Aquaculture, a Sustainable Aquaculture Alternative

Shrimp farming is expected to contribute to the local economy, but export-oriented production in the hands of big corporations can have damaging effects on the surrounding environment and ecosystems. Over 50% of the global shrimp for consumption is still obtained through shrimp farming, which is a key cause of mangrove destruction. A sustainable form of aquaculture is needed in order to protect the ecosystems of the Sundarbans in Bangladesh. Sustainable **silvo-aquaculture** is when mangrove trees are planted alongside shrimp ponds or shrimp ponds are placed alongside certain mangrove species. It replicates a more natural habitat and allows for profitable net income from shrimp farming. This type of aquaculture is considered organic farming and it increases the mangrove area, maintaining biodiversity by providing a nursing ground for many aquatic and animal species.

It is important to select mangrove species that will be useful and locally acceptable to be used in transitioning the current non-mangrove shrimp culture practice towards a more sustainable shrimp silvo-aquaculture in the coastal regions of the country. There are thirteen mangrove species in Bangladesh that are documented as suitable for use in silvo-aquaculture systems (Rahman et al., 2020). In Vietnam, "The net return from the mangrove-based shrimp farming system was three times higher than the extensive traditional systems due to higher shrimp yields as well as yields from other aquatic products and the timber" (Rahman et al., 2020). Traditional shrimp farming is considered unsustainable in the area because the Total Economic Value of the mangrove ecosystem is substantially higher than the income derived from the harvest of shrimp. The size of shrimp aquaculture plants has expanded, but a decreasing trend of shrimp production over the time period from 1995–2015 has been reported. The decrease in shrimp production is mainly due to the degradation of the local coastal ecosystem including biodiversity loss, an increase in pollutants, and the degradation of water and soil quality (Rahman et al., 2020). In many areas of Bangladesh, coastal erosion is getting rid of natural habitats and natural mangrove nursery areas.

A total of 13 species of mangrove trees are commonly used in the silvo-aquaculture practice in different tropical countries.

The four genera of mangroves represented by more than one species are Avicennia, Rhizophora, Sonneratia, and Xylocarpus (Hossain, 2015). Avicennia alba is established due to its high tolerance of salinity and its use for timber, fuelwood, and house construction materials. It is found in the low to mid-intertidal levels of the mangrove forest under full sunlight in silt deposited muddy soils. The leaves are 6–15 cm in length and are used as fish feed and fodder (Hossain, 2015). Another species, *Rhizophora apiculata*, is an evergreen light-demanding species with a slow growth rate. It is a lower-mid intertidal species with a preference for deep muddy soils. Leaf length varies from 8 to 19 cm and the wood has an economic value in the form of timber, fuelwood, charcoal, and poles. (Hossain, 2015). *Sonneratia apetala* is an evergreen fast-growing pioneer that grows up to 20 m in height and has a leaf length of 6–13 cm. This species possesses pneumatophores and is very salt tolerant. Because of these qualities, *S. apetala* was intentionally planted in the coastal areas of Bangladesh (Hossain, 2015). Lastly, *Xylocarpus granatum* reaches a medium height of around 20 m and develops a narrow crown. It is a mid to upper mangrove forest species typical of low salinity areas and produces edible fruits. The species provides fuelwood, timber for furniture and building materials, raw materials for pencil, and veneer production (Hossain, 2015). The research on these specific mangrove species aims to help identify and select mangrove species that are most likely to be useful and acceptable for use in more sustainable shrimp-based silvo-aquaculture in the mangroves of coastal Bangladesh. The use of these species in silvo-aquaculture depends on a variety of factors that include species suitability, species characteristics, species availability, local farmers' knowledge about the ecological services, and the economic importance of mangrove species (Rahman et al., 2020). The roots of these specific mangroves serve as anchorage and aeration and are also classified as stilt, buttress, or pneumatophore root. Mangrove roots reduce wave energy and abrasion, but only the pencil and knee root types, pneumatophores, really accelerate sediment retention.

Impacts of Sea Level Rise on Bangladeshi Communities

Besides the ecological impacts on Bangladesh, the people in these areas are also affected. The Sundarbans mangrove forest provides many assets to the people of Bangladesh, but most importantly, it provides livelihoods. The loss of the Sundarbans will have countless negative impacts on the people involved with it. Tuhin Ghosh, an associate professor at Jadavpur University in Kolkata, shared that, “the people around the Sundarbans will lose a lot” (Schwartzstein & Datto, 2019). The mangrove forest is a source of honey and its waters are a source of fish. This is a source of sustenance for the people of Bangladesh. Joydev Sardar, the secretary of the Fisherman’s Association in Harinagar, Bangladesh, commented that “The Sundarbans is our mother. She protects, feeds, and employs us” (Schwarzstein et al., 2019). Besides the food that the Sundarbans mangrove forest provides, the forest also provides jobs for the people of Bangladesh. But because the mangrove forest has been shrinking over time, jobs are being lost and people need to find new sources of labor. For example, Sagar Island’s crop-growing conditions have worsened so much that the residents have to find seasonal labor in other locations. Bimol Sardar, a farmer from Bangladesh, shared that, “Because of the water damage, it sometimes seems like only the carpenters have work” (Shwarzstein et al., 2019). But, the communities that are not close to the Sundarbans are also feeling this impact. Ghosh said that cities a far distance away from the mangroves, like Dhaka, Bangladesh, and Kolkata, India, will find themselves, "...extremely exposed to cyclones and storm surges" (Schwarzstein et al., 2019). The people of Bangladesh have also experienced hardships due to sea-level rise in areas other than the Sundarbans. In February 2018, a part of an embankment that holds back the Chunar River west of East Dhangmari, Bangladesh collapsed for the third time in one year. During this event, 16 houses were swept away, devastating each of those families. But, unfortunately, this became a routine tragedy for the locals.

Aquaculture itself is a somewhat new practice around the world so it was initially a fairly unregulated area especially in Bangladesh. The actions that have been taken in the past were nonexistent for the most part with a large amount of freedom placed in the hands of the organizations that work in the field (S. Hamilton, personal communication, December 2, 2020). The unfortunate truth of this matter is that the companies are only looking to profit and not necessarily looking for the most environmentally stable opportunities. This forced the government of Bangladesh to create the Bangladesh Biological Diversity Act of 2012. Here it was detailed that the government would focus on creating plans to "use its biological resources in a sustainable manner"(Alam & Ahammad, 2017). The issue that arises with this is that there are no specific guidelines that were created just simply the promise that they would in the future. The act also stated that it would use the participation of its people to achieve the goals that it had laid out but again, a large amount was promised with little to no actual action. There have been many agricultural farmers along the coastal region of Bangladesh that were forced to move into cities due to the fact that they were not receiving any of the environmental aid from their own government. There were clear missteps of the Bangladeshi government in how they applied the Bangladesh Biological Diversity Act of 2012, but it is also important to note the notable impacts that they are making in recent times.

Aquaculture in Bangladesh has a clear positive future if the same momentum in policies can be continued. One, in particular, is the incentivizing and disincentivizing of adopting new and more ecologically sustainable practices in the realm of aquaculture. This can be done through numerous means such as subsidies, taxation, and fines (Alam & Ahammad, 2017). It is through actions such as these that the government can finally put pressure on the corporations that have been actively damaging the ecosystems of Bangladesh. In addition to these legislative actions, there have been programs put in place to aid in the creation and stability of smaller and locally owned aquaculture businesses (Alam & Ahammad, 2017). The programs have made it far easier for the smaller businesses to obtain loans in order to expand their businesses to the newer standard that they hope to see throughout all of aquaculture. It is with steps such as these that the government is making a positive impact on the area that it controls.

Conclusion

The research that our team has done on a set of specific issues in Bangladesh stemming from sea level rise shows a specific chain of impacts. This causal relationship of sea-level rise affecting the agricultural industry, which in turn affects the environment in negative ways is a series of connected impacts that could occur in many locations as the effects of climate change continue to worsen. The solutions and mitigation strategies that we have compiled may be used in similar situations that are likely to be encountered more frequently in the future as society and corporations continue to utilize aquaculture to meet growing food demand and make a profit for shareholders. The purpose of our research is not to discourage the development of the aquaculture industry, but to shed light on how aquaculture could be implemented while causing minimal damage. Aquaculture demonstrates great potential to fill a gap in food security globally and may prove to be a valuable tool as humans are forced to adapt to climate change.

When researching, the main objective is to solve the initial problem that was laid out at the start. In this case, there are several possible actions to be taken that could aid in the protection of the mangrove environments around the world. One of these solutions would be for the government of Bangladesh to create more protected areas within the Sundarbans. By doing this, the population of mangroves is protected and is more likely to remain at their normal levels as long as the laws are truly enforced by the government. Some actions that the government should take, specifically the Ministry of Aquaculture and Livestock, are to create regulations surrounding how the waste products of aquaculture should be dealt with via treatment and filtration methods. As well as this, regulations need to be put in place limiting the usage of pesticides and antibiotics. Lastly, there need to be recommendations directed towards aquaculture corporations. Based on what we have learned, we believe that it is in the best interest of the surrounding environment that the aquaculture ponds are converted into silvo-aquaculture. In this situation, it may be costly for companies to change their ways. In order to encourage growth in this more ecologically friendly sector, the government of Bangladesh could offer subsidies or benefits to these companies. These recommendations are important for the future of aquaculture as a whole. It is a new and blossoming industry that has a lot of promise in helping the world's food supply keep up with the ever-growing population.

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14. The Great Pacific Garbage Patch's Hindrance on the Albatross Population

Aidan Bryar, Anna Cox, Nathalie Martin-Nucatola, and Patrick McKenna

Abstract

Around one million seabirds are affected each year by the plastic in the Great Pacific Garbage Patch; especially the Laysan Albatross due to their close proximity. The Laysan Albatross enriches the nutrients of the soil improving the island ecosystem. This bird is at a higher risk for plastic consumption and is already on the near-threatened list. We examined different conservation techniques to determine the best method. These range from juvenile relocation, ocean current examination, river clean-up, and even a surgical attempt. This chapter argues the importance of cleaning rivers as the best approach to preserve the Laysan Albatross.

Figure 1: A Laysan Albatross was found with plastic in its stomach. The plastic was then removed and sorted to the right of the image. "Post-mortem examination of dead Laysan Albatross showing the huge amount of ingested plastic which caused death" by Claire Fackler (2019), NOAA, Public Domain.

A Deep Dive into the Great Pacific Garbage Patch

The Great Pacific Garbage Patch, a swirling vortex of trash that spans from Hawaii to Japan, is getting larger by the day. The Great Pacific Garbage Patch is approximately 1.6 million square kilometers, and for context, that is twice the size of Texas and three times the size of France. Why is this garbage patch so large? Part of the problem is that plastic items do not break down in a timely manner. For example, plastic bottles, an extremely common household object, can take up to 450 years to decompose. Some other plastic items, such as plastic bags, another common-use item, can take up to 1,000 years to break down. Needless to say, plastic is not going away on its own, and oftentimes it finds its way into the ocean to be picked up by currents that then deposit the plastic in the swirling gyres that make up the Great Pacific Garbage Patch (Lowe, 2019). What exactly is the Great Pacific Garbage Patch? Garbage patches are formed when gyres, which are rotating ocean currents, pick up trash and gather the trash to a central location. This does not form an “island” of trash like many would assume when they imagine a garbage patch. The debris instead is found from the surface of the ocean, all the way to the ocean floor (Marine Debris Program, 2020).

The Great Pacific Garbage Patch has deep effects on the environment. Especially on marine life. One such effect is ghost fishing, where abandoned fishing equipment continues to catch animals and then causes serious damage and even death. Another effect is the transportation of invasive species. The debris can transport barnacles and crabs and transport them to another area and hinder the native species in that new area. One effect of the Great Pacific Garbage Patch that can cause serious damage to seabirds is the act of ingestion. Many seabirds fly over the Pacific Ocean to gather food for themselves, and their chicks. The Laysan Albatross, a bird that resides on the Midway Atoll, found in the middle of the Great Pacific Garbage Patch, is one such victim of ingestion. The Albatross mistakes the brightly colored pieces of plastic as food and ingests them without realizing that what they are eating is not, in fact, food. This can lead to starvation, blockage, and even death (Jones, 2019).

As previously stated, the Great Pacific Garbage Patch is growing every day. Each year, about 1.15 to 2.41 million tonnes of trash enter the ocean. By 2050, in just 30 short years, it is estimated that there will be more trash in the ocean than fish. It is also estimated that by 2050 99% of all seabirds will have ingested plastic. Trash does not just affect the animals of the ocean, it also affects humans. Microplastics have been found in sea salt, shellfish, and even 94% of tap water (Lowe, 2019). It has even been found in beer and honey. Currently, researchers do not know how these microplastics will affect humans in the long run but it is definitely not beneficial in any way. The trash can also be a real hazard to marine vessels. Nets can become wrapped up in propellers and trash can hit the actual vessel causing damage. Needless to say, the Great Pacific Garbage Patch is a serious environmental issue that not only affects marine life, but also navigation, marine vessels, and even the economy (Marine Debris Program, 2020).

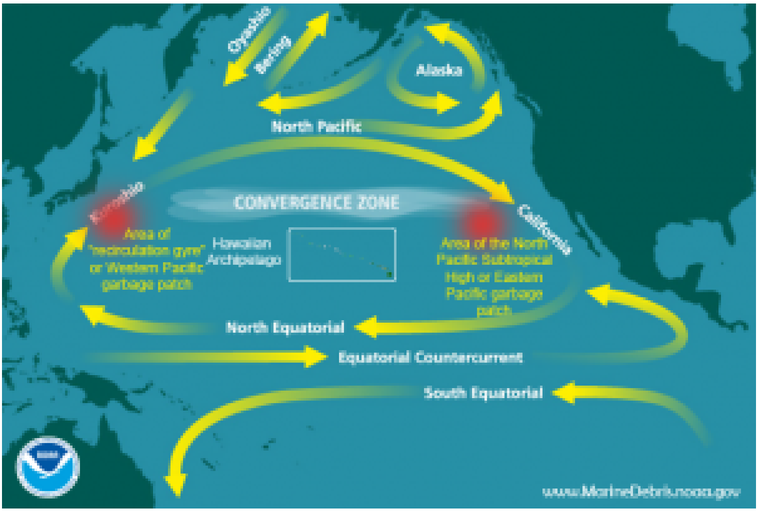

Figure 2: [This map](#) showcases the location of the Great Pacific Garbage Patch as well as the location of the Midway Atoll (in the Hawaiian Archipelago) where the largest colony of Laysan Albatross is found. [National Oceanic and Atmospheric Administration, Marine Debris Program](#), [Public Domain](#).

The Bird-un of the Albatross

Figure 3: A Laysan Albatross and its chick in their nest, by Kevin Rolle, Smithsonian, Terms of Use

The Laysan Albatross (*Phoebastria immutabilis*) faces minimal natural obstacles; however, some of their biggest problems originate from human invention. As of 2018, the Laysan Albatross is considered near threatened by the IUCN Red List (BirdLife International, 2018). Some of their biggest threats of survival come from "fisheries bycatch, predation by alien species at nesting colonies, bioaccumulation of contaminants, and ingestion of plastic" (VanderWerf & Young, 2011). In this chapter, we will be examining the direct threat that plastic consumption has on the Laysan Albatross population.

The largest breeding colony of the Laysan Albatross resides on the Midway Atoll, which is part of the Northwestern Hawaiian Islands (BirdLife International, 2018). They are long-lived seabirds, with a lifespan of 60 years, nearly 20 times longer than the average bird's (Bakermans, M., personal communication, 2020). However, their population is at risk as plastic pollution becomes an increasing issue. Their diet consists

Figure 4: A red bottle cap found in the body of a dead Laysan Albatross. Plastic like this is often mistaken for food by these birds. "Laysan Albatrosses' Plastic Problem" by Chris Jordan, Smithsonian, Terms of Use.

mostly of crustaceans, cephalopods, and fish (Petry et al., 2007), and often, they mistake plastic of similar size, color, and shape as their prey (Pierce et al., 2004). For example, the well-known red coca-cola bottle cap resembles closely to a squid, and so it is consumed without a second thought (CNN, 2016). The ingested plastic is then transferred to fledglings through regurgitation. Regurgitation is the action of casting up incompletely digested food, and the way in which birds feed their young (Merriam-Webster, n.d.). A study has shown that the ingestion of plastic is harmful to the weight gain and survival of Laysan chicks, which is detrimental to their population growth (Lavers & Bond, 2016). Laysan Albatross only produce one egg per clutch, and so the survival of the egg is of the utmost importance (Marine Debris Program, 2020).

The Laysan Albatross catch their food by plunging their necks under the surface of the water. This technique provides many chances for them to pick up plastic in accidental bycatch as well. While plastic can not fully disintegrate, it does break down into smaller and smaller pieces, called microplastics and nanoplastics (CNN, 2016). These small particles release their toxins into the ocean, while also attracting other chemicals such as pesticides to them. Not only can marine life consume these plastics, but nanoplastics are so small that they can pass through tissue membranes, furthering the spread of plastic consumption. A study has shown that “high levels of ingested plastic were correlated with increased concentrations of chlorine, iron, lead, manganese, and rubidium in feathers” (Lavers & Bond, 2016). These high chemical concentrations in the Laysan Albatross can “indirectly contribute to [their] mortality or morbidity” and lower reproduction success.

We talked with Mark Pokras, a professor at Tufts Cummings School of Veterinary Medicine, who said that plastic consumption has not always been as big of a problem as it has become. Oftentimes, the Albatross can either eliminate the small plastic particles or regurgitate them back up. It is when the plastic gets lodged in an important pathway that the bird can die of starvation, dehydration, or a corrupt digestive system (Pierce et al., 2004). As plastic consumption and pollution grow, the Laysan Albatross population continues to be at risk.

Quacking the Case: Prevention and Conservation Methods

The Laysan Albatross has many programs that look out for their well-being, such as Papahanaumokuakea Marine National Monument's prohibition of longline fishing, or eradication efforts of introduced invasive species (Awkerman et al., 2020, Kaiser, 2017). However, these programs do not combat the issue of plastic pollution and consumption, and with the increase of plastic production due to the Covid-19 pandemic, an addendum to these methods that focuses on the issue of plastic pollution is greatly needed. There are multiple ways in which plastic pollution can be combated. Some methods include the relocation of the juvenile Laysan population, cleaning up plastic before it enters the oceans, i.e. from the rivers, researching the Great Pacific Garbage Patch gyres and currents, or surgical removal of plastic.

Juvenile Relocation

Juvenile Relocation looks to be one of the most promising ways to help these birds, yet this is not quite the case. We reached out to Mark Pokras to ask him if this would in fact be a viable solution, to which he replied with a concern about the Albatross feeding flight and the locations the Albatross feed from. After all, almost all seabirds are eating plastic coming from the ocean and as plastic production inevitably increases location will not be as big of a factor. Even if efforts were made to relocate the Laysan Albatross it would be costly and take up a lot of time. It would also be hard to find an island that would meet the requirements they need to survive when they are young. They need a lack of natural predators like rats who would eat their eggs, as they build their nests upon the ground (Kaiser, 2017). The Albatross can fly up to 500 miles in a single day staying in the air for much of that time (Chu, 2017). During their flights, it is likely that an Albatross picks up plastic and feeds it to their young or keeps it for themselves. We have come to the conclusion that the rate at which these birds are consuming plastic in a relocated area vs their original habitat is not sufficient enough for a prevention method.

Cleaning the Rivers

Figure 5: This is the Interceptor made by the Ocean Cleanup which collects the trash in rivers through the currents. "Interceptor 001, first generation, in Jakarta, Indonesia", by The Ocean Cleanup, Terms of Use.

Plastic consumption is continuously growing and is not going to stop anytime soon. It reached just over 320 million metric tons in 2018 (Lebreton et al., 2018). With a number this large, it is inevitable that at least a fragment of the trash will end up in the ocean. Once in the ocean, different gyres pick up the trash and a considerable amount finds its way to the Great Pacific Great Patch. An example of one of these gyres is the Kuroshio Extension. This gyre takes a large amount of plastic from Asia and feeds it into the Pacific where it eventually reaches the Great Pacific Garbage Patch (Lebreton et al., 2018). Studies have shown that one thousand rivers contribute to 80% of ocean plastic pollution (The Ocean Cleanup, 2020). Some rivers contribute more to the Great Pacific Garbage Patch than others due to their location. The Ocean Cleanup has discovered a way to prevent the trash from reaching the ocean. CEO Boyan Slat has stated that they created a device known as the Interceptor that will patrol the rivers and catch trash before it leaves (Kavanaugh, 2019). The device has promise, but there are more than 1,000 rivers that contribute to the Great Pacific Garbage Patch (Kavanaugh, 2019). It is not very realistic for this nonprofit organization to make this many Interceptors without a substantial amount of funding. By funding any type of cleanup or any projects with the Great Pacific Garbage Patch, governments would be admitting that they are accountable for it and the cost of cleaning it would bankrupt any country. This is one reason why implanting the Interceptor could prove to be troublesome. Another is that these Interceptors would be all over the globe and convincing each country that is responsible to take part in this cause is also very unrealistic. However, compared to other options, this is the most cost-effective and helpful.

Ocean Currents

The reason the Great Pacific Garbage Patch is an actual occurrence is because of the gyres that gather pollution from all across the ocean and collect it. The gyres themselves are caused by large-scale wind patterns and thermohaline circulation. Thermohaline circulation is caused by differences in the density of the water in relation to the temperature of the water and the salinity (Sundermeyer, M.,

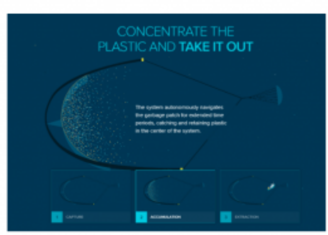

Figure 6: This diagram showcases how the [System 001/B] works while in the ocean. The three steps are capture, accumulation, and extraction. Photograph by [The Ocean Cleanup], [Terms of Use].

personal communication, 2020). Now the question is, can we somehow use currents in the ocean to prevent Albatross from consuming plastic? Potentially there is a solution that utilizes natural forces such as ocean currents and wind patterns currently in development. The Ocean Cleanup, one of the main combatants of the Great Pacific Garbage Patch, has developed System 001/B. This invention utilizes a floater system at the top and then a long hanging net/skirt to catch any debris that may reside just below the surface of the water. In its year-long trial period in 2019, it minimally interfered with marine life and measures have been taken to ensure no marine vessels would come close to System 001/B (The Ocean Cleanup, 2020). System 001/B has proven that understanding the currents of the ocean could be the next big step in cleaning up the pollution of the Great Pacific Garbage Patch. The Ocean Cleanup's research even shows that if large-scale use of this system was put into place, 50% of the pollution in the ocean could be removed in just 5 years (The Ocean Cleanup, 2020).

While this invention has a lot of upsides to it, in terms of the Albatross this might not be overly helpful in preventing them from mistaking the plastic for food. System 001/B collects the debris in the nets but Albatross and other seabirds could still see brightly colored plastic within the net, and mistake it for food. System 001/B's focus is to collect the pollution and keep it there until it reaches a certain accumulation point for workers to then empty the nets (The Ocean Cleanup, 2020). There is nothing stopping the Albatross from swooping in to eat the trash. So while this invention is extremely helpful in the long run in reducing the size of the Great Garbage Patch, it is not necessarily helpful in preventing the immediate threat to the Albatross. However, the Ocean Cleanup might make alterations to their System 001/B in the next version, which should be debuted in 2021, that may prevent wildlife like the Albatross from accessing the plastic.

Surgery… Fatal or Lifesaving?

As severe as it may seem, surgery is an option for removing the trash from birds. It is considered rare and does not happen that often. Mark Pokras said that it starts with x rays of the birds being taken, as well as an endoscope, and if trash is found, then the people examining the bird will try to get the said bird to regurgitate. If this fails and the trash found inside the bird will eventually kill it, then surgery is considered. The surgery method provides an abundance of problems. Many of these birds are too weak to undergo the anesthesia and will die during the surgery, x rays do not show everything inside of the bird so there could be surprises once the bird is open, and it is not realistic for this to be a go-to option for every bird. There are too many birds that have trash in their organs for this to be considered as a solution. The amount of money it would take to fund an experiment like this is far too great and the odds of success are very low. This being said, every now and then surgery can be a viable option for a select few birds that are deemed strong enough to survive and if there are no other ways.

Munching on Microplastics

Plastic is a huge problem in the Great Pacific Garbage Patch because the buildup contributes to the gyres that make up the patch. The microplastic waste sits on the ocean surface, invisible to the human eye, providing a shield to the other trash. Microplastics are also a huge danger to the Albatross who ingest microplastics and even macroplastics unknowingly which causes harm to their bodies over time. Only 0.2% of Shearwater birds were found to have not ingested plastic according to expert Mark Porkras who conducted a field study on plastic found in dead Shearwater birds. This concern is only growing as the Garbage Patch grows near the Albatross' habitat. Even if these birds were relocated, they would still consume plastic during their feeding flight which aligns with the Great Pacific Garbage Patch. Microplastics are small, almost invisible plastic particles that can rest inside living beings as well as the ocean and everything else we know. Macroplastics are more visible conventional plastic waste that we see more commonly. Microplastics are just the near-end result of the decay of Macroplastics which go through a life cycle of their own (Lucas, 2018). Looking more in-depth into the chemical makeup of plastics in general we may have a hard time finding a solution even among professionals who are still researching microplastics as a relatively new concept (Liittschwager, 2020). Emerging studies on bio-plastics that break down over time could be the key to future environmental health.

We have looked at methods such as taking trash from the source; rivers, streams, and lakes. This is ideal because most plastic pollution starts in these areas and feeds into the larger bodies of water. We have also looked into the production aspect of plastic which plays a big role in today's society especially because of covid-19. Mask production has severely impacted the albatross species as professionals advise people to cut their mask straps after use to save the birds from death by suffocation. With an increasing rate of plastic production, there is a greater need for ecologically friendly solutions related to plastics for our daily use.

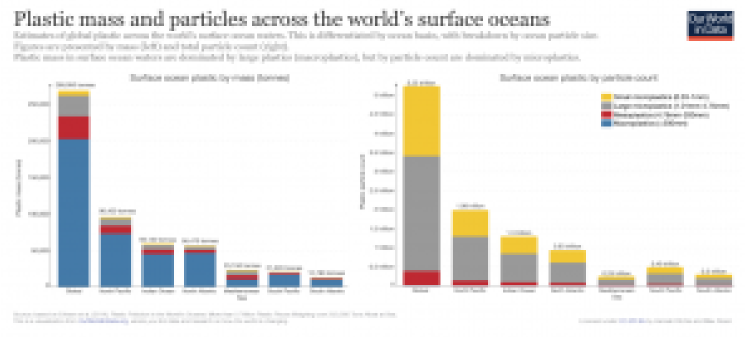

Figure 7: This chart shows the surface area of plastic, but also of the amount of each type of microplastic."Plastic mass and particles across the world's surface oceans", Our World in Data, CC BY 4.0

Final Thoughts

The loss of the Laysan Albatross population would be harmful to the wellbeing of island wildlife and flora (Kaiser, 2017). Their impact on their surrounding ecosystem is often overlooked because of how little they directly affect human life. However, their contribution of nutrients to the island's soil and habitats provides a healthy environment for all. With the ongoing pandemic, plastic usage and production have increased significantly due to sanitation concerns, and in turn, plastic pollution has increased (Silva et al., 2021). Therefore, the need for conservation methods, targeting the Laysan Albatross' consumption of plastic, is in dire need of implantation and enforcement. After much research, we believe that the best conservation method is collecting plastic in rivers before it reaches the Great Pacific Garbage Patch and the Laysan Albatross population. We believe that this is a necessary step because it is hard to bail out a boat if the hole is not fixed. Investment and implantation of devices such as the Interceptor will hinder the amount of plastic entering the ocean. Additionally, the $777,000 cost of the Interceptor is a significant cost reduction compared to the +$30 billion needed to clean up the Great Pacific Garbage Patch (The Ocean Cleanup, 2020, Dautel, 2009).

While the solution we are proposing may seem too broad and does not directly combat the Albatross issue, we are taking into consideration that they are long-distance fliers which means just getting rid of plastic around their breeding colony will not stop their consumption. To truly help the Laysan Albatross, the growth of the Great Pacific Garbage Patch needs to be addressed. That means stopping the trash from reaching the ocean in the first place and controlling the flow of this process in the future is important. Overall, the Great Pacific Garbage patch is an extreme threat to the human population as well as the Laysan Albatross. The Laysan Albatross' accidental consumption of microplastics is a continual issue, and while there are many potential solutions to this plastic threat, we have found that prevention is the best solution.

Flying Forward

In the future, governments are going to have to take accountability for the Great Pacific Garbage Patch. Allotting taxes or funds to invest in devices such as the Interceptor is the first step towards helping the Laysan Albatross. These devices have proven to be effective on the rivers in which they operate. In addition, we need to track the Laysan Albatross' flight patterns to best determine areas in which they might feed. By doing this, we can focus on those areas of the Great Pacific Garbage Patch and use devices such as System 001/B most efficiently. We would also suggest further research in the production of bio-based plastics and how to implement them into the greater society. Bio-based plastics would be beneficial because if recycling efforts do not improve, plastics that fully break down once they reach the ocean will no longer not harm the Laysan Albatross.

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15. Physeter macrocephalus and the Battle for Plastic-Free Seas

Ally Breen, Dana Littlefield, Corey Logan, Iris Morin, and Katie Quinn-Cyr

Abstract

Sperm whales are a staple of marine life, known for their intellect and impressive size. However, like all animals, they have been negatively affected by modern human interference. One example of this would be the Great Pacific Garbage Patch, a large mass of plastic floating in the Pacific Ocean as a result of ocean currents and unsustainable recycling methods. This chapter will dive into greater detail on sperm whales, the threats they face, and the ways that their populations can be protected and maintained.

"A pod of sperm whales off the coast of Mauritius" by Gabriel Barathieu is licensed under CC-BY-SA 2.0

Natural History and Physical Description

With their intelligence and affinity to exist in a life-long family, sperm whales (*Physeter macrocephalus*) are goliath marine mammals that have affectionately gained the reputation as the "elephants of the sea." As seen in Figure 1, their gray bodies, with relatively small, white sections on their underside, waxy skin, and slight wrinkles on their heads uniquely characterize this species. Their blowhole, located on the left side of their head, adds to their unique features. Their small, paddle-shaped fins are located halfway back on their bodies, and their dorsal fins are low, wide, and rounded. Their heads are extremely large and make up an astounding one-third of their body length. Their thin, long jaws contain between 10 and 26 teeth on each side (NOAA 2021). A sperm whale will use its teeth to prey on deep-sea organisms such as squid, sharks, skates, and other fish, diving up to 10,000 feet below the surface for an average range of 45-60 minutes. Sperm whale's, typically weighing 15 tons to 45 tons, consume about 3.5% of their body weight each day (NOAA 2021).

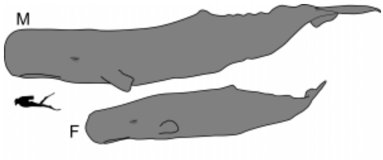

Figure 1: “Size comparison of a male and female sperm whale with a human (16m, 11m, 1.75m respectively)” by Kurzon licensed under CC BY-SA 3.0

These creatures may be an impressive sight, but they are not immune to threats within their ecosystem. The main factors that lead to the premature demise of these ‘elephants of the sea’ are unfortunately all too common for these majestic creatures. These threats include but are not limited to, vessel strikes, ocean noise, **marine debris**, climate change, and oil spills, and contaminants (NOAA 2021). For a population historically depleted by whaling, these threats are detrimental. The National Oceanic and Atmospheric Agency (NOAA) estimates that, since the whaling **moratorium** went into effect in 1986, the sperm whale population has only grown about four percent per year (Alaska Fish and Game). This slow growth rate makes any loss to the already small population devastating.

The small growth rate of sperm whales is primarily due to their life cycle and survivorship behavior. Sperm whales exhibit **sexual dimorphism**, meaning that males and females exhibit different physical characteristics. A female will grow to 40 feet in length and weigh up to 15 tons, whereas a fully grown male can be around 52 feet in length and up to 45 tons in weight. The female begins her life cycle in rapid growth for the first 9 years of age, at which point she will reach sexual maturity and see slowed growth. She may be ready to produce a calf at 9 years old, yet a single calf is only produced every 5-7 years. This slow rate of reproduction, along with a **gestation** period of 14 to 16 months, contributes to the slow growth rate (NOAA 2021).

In comparison to their female counterparts, the male sperm whale's growth and puberty period last much longer. In fact, male sperm whales may experience puberty up until the age of 20. Even in the case of a male reaching sexual maturity, he may not participate in breeding until his late 20's regardless. However, the differences after this age are relatively minute. Both females and males form social units or pods called **stocks**, and as males get older they will depart the pod and typically travel alone toward the poles while the females stay in their pods near the equator at a common breeding ground (NOAA 2021).

Sperm Whale Distribution

With the exception of the poles, sperm whales can be found all across the world's oceans. This wide distribution is shown as blue in Figure 2. Scientists were able to use biochemical markers, such as the gene CYP1A1, nitrogen and carbon isotope ratios, latitude, and whale blubber contaminants to determine areas of the Pacific Ocean where sperm whale populations were highly concentrated (Godard-Codding et al. 2011).

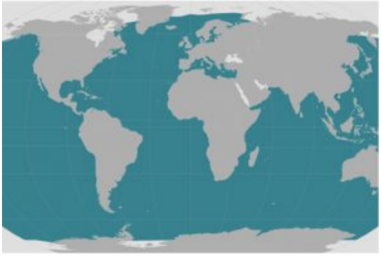

Figure 2: Sperm Whale distribution in blue. "Sperm whale range map" by NOAA (2021), Public Domain.

Sperm whales are typically found in deep waters, usually avoiding the coastal shelf but staying within a few hundred kilometers of the coastline (Purdon et al. 2020). This concentration pattern can be seen in the heat map displayed in Figure 3.

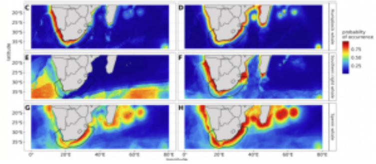

Figure 3: Coastal heat map of sperm whales in summer (G) and winter (H) shown in the bottom panels. "Ensemble model projection using the mean probabilities for each season for the Bryde's whale, humpback whale, southern right whale and sperm whale" by Purdon et al. 2020, CC BY 4.0

Despite its widespread distribution, sperm whales tend to stay with their stocks. This affects the population's genetic characteristics as well as behavioral patterns, which influences conservation efforts for different stocks of sperm whales (Begg and Waldman 1999). Stocks tend to contain anywhere from 10 to 14 whales that, depending on the stage of the life cycle they are in, will have a similar age range or family structure. The unique patterns exhibited by different stocks or populations, depending on the region in which they live, create very different migration patterns that are not easily or well understood. Food sources, breeding grounds, and water temperature all contribute to the specific behaviors of individual populations, as well as the global distribution of sperm whales on a yearly basis. Due to their extreme diving behavior, the seasonal migration of the sperm whale is also difficult to track in comparison to most other species.

Sperm Whale Ecological and Social Impact

As a keystone species, sperm whales play monumental roles in ocean health and greatly impact the overall stability of marine ecosystems. The diet of a sperm whale consists of large fish and invertebrates, which places their species high on marine trophic levels, below only orca whales and the largest of sharks (Safina 2016). Their ability to contribute to carbon and nutrient cycling in the ocean through natural behaviors makes all whales excellent **ecosystem engineers**. Each time a sperm whale dives at depths of up to 10,000 feet, they are actively mixing the marine water columns and agitating nutrients and minerals to enrich the entire ocean ecosystem around them (Animal Welfare Institute 2017). Sperm whales encourage **carbon sequestration** by aiding the growth of phytoplankton populations, which absorb atmospheric carbon dioxide. Sperm whales do this via the nutrient release from their fecal matter, which enhances the productivity of the phytoplankton at the ocean surface. As the carbon dioxide-rich matter sinks to the ocean floor, it will successfully trap 20 to 40% of the carbon for millennia. The remaining carbon will continue to circulate marine life at the ocean's surface. This sperm whale-driven system successfully removes 240,000 tons of carbon from the atmosphere per year and provides a significant **ecosystem service** (Animal Welfare Institute 2017). Even after death, whales facilitate marine life with a biological event called a "**whale fall**", in which a whale dies and its body sinks to the ocean floor to decompose. A single whale fall event can provide food and nutrients for over 400 deep ocean species in the vicinity for up to a decade, as well as sequester massive amounts of carbon (Safina 2016).

The sperm whale has even provided intellectual services in areas such as religion, the arts, cultural unity, identity, and modern education (Cook et al. 2020). Whales have had a growing impact on art and music since 1970 and have been the center of important media throughout the years, such as in the book Moby Dick (Cook et al. 2020). In certain regions, whales have been cemented in the founding culture of modern civilization. Whales can be found throughout the myths, legends, and religions of older civilizations, such as the indigenous people of Canada, New Zealand, and Hawaii (Cook et al. 2020). In Polynesian culture, sperm whales are sacred, and their teeth and bones are believed to be a symbol of good luck. As a result, their artifacts are sold and traded for valuable art and jewelry, but the materials are only collected from the sperm whales after they have already died and washed ashore. A treaty developed in Tonga has made it illegal to kill whales or even trade goods that have come from whales (Van der Grijp 2007). Sperm whales are a key factor to maintaining **biodiversity** and **species richness** in their marine ecosystem and contribute to our understanding of ethics from an educational standpoint in modern times.

The modern whaling industry, both commercial and subsistence, has societal and ethical implications and consequences. The commercial needs have grown in recent years to unsustainable demands, with countries such as Norway and Japan ravaging the whale populations (Scheiber 1998). This is agreed upon as unethical by the standards of modern environmentalism, as these industries favor profit over the well-being of whale populations and the biodiversity of ocean ecosystems. While wasteful commercial industries ravage the whale population, indigenous people take only as much as needed and utilize the whole whale through subsistence practices (Scheiber 1998). The ethical implications carry more weight when applied to larger companies. While indigenous communities with deeply rooted ties to whaling in their cultural practices take advantage of the entire whale so as to avoid being wasteful, industries typically only use some of the whales and discard the rest as it is considered to be worthless (Scheiber 1998). The ethical implications are important considering humanity's large-animal bias. If sperm whales are recognized as having dignity, then that thinking may extend to other smaller or overlooked organisms in the future. The intelligence of sperm whales has sparked important moral and ethical debates. Their ability to communicate and echolocate has supported their sympathetic appeal, which attracts society to supporting conservation efforts (Kalland 1991).

In the 19th century, sperm whales were hunted for their **spermaceti** organ which was used for illumination oils. As demand for illumination oils increased, more whaling occurred (Kaiser 2013). However, the opportunity cost rose quickly because it became harder to find whales as populations dwindled, which in theory was accounted for by a drastic increase in the price of spermaceti oil. The economics of whaling eventually transferred from over-predation to popularizing conservation efforts (Kaiser 2013).

Sperm whale depredation has also had socio-economic consequences for fisheries. Longline fisheries in particular have suffered direct costs, such as catch losses, and indirect costs, such as increased fishing time or fuel consumption, as a result of depredation by sperm whales (Janc et al. 2018). Depredation has caused a need for fishing industries to reevaluate fishing equipment and conditions of fishing operations. Although fishing industries are looking to implement technological solutions to deter depredation and lessen the economic consequences they face. One important factor of sperm whale conservation is the overexploitation of fish populations. This raises the question of how we should manage natural resources and to what extent we should utilize these resources for ourselves versus wildlife populations.

Impacts of Plastic Pollution on Sperm Whales

Possibly the most unlikely, yet deadly predator of marine life in today's world is ocean plastic pollution (Johnson 2021). These bits and pieces of garbage can be found in every part of the world's oceans at all depths, and the marine ecosystem is feeling its effects. The current estimate of surface plastic pollution is 269,000 tons, while the annual global input is between 8 and 11 million tons (Ritchie 2018). One might not expect a creature as large and powerful as a sperm whale to be affected by ocean plastic, yet ocean pollution is becoming their greatest threat. The two main ways ocean pollution harms marine life are through ingestion and entanglement, and for sperm whales, there is no exception.

Ingestion of plastic is a very serious problem for all whale species. Plastic pollution ranges from large fishing nets to tiny particles called microplastics. Sperm whales will typically ingest larger marine debris, mistaking it for the larger prey they feed on. While sperm whales do ingest microplastics, the effects from the released chemicals are small compared to impacts from larger debris. A whale can survive after ingesting a few pounds of plastic but will be constantly experiencing the effects of starvation and stomach unrest (Johnson 2021). It is hypothesized that large amounts of ingested plastic could be causing whale species to intentionally beach themselves to escape inevitable starvation. Sperm whales have been found all over the world beached with pounds of marine debris in their stomachs. Two sperm whales were found on the northern coast of California with 53 lbs and 162 lbs of plastic, rope, and net debris in their systems, as seen in figure 4. It was suspected that both animals died from **gastric rupture** as a direct result of the ingested pollution (Jacobsen et al. 2010).

Figure 4: "Dead sperm whale found with pounds of garbage in its stomach, including rope, plastic and fishing nets". Used with permission from The Scottish Marine Animal Stranding Scheme

It is possible that these poor creatures had encountered most of this trash while in the **Great Pacific Garbage Patch** (GPGP) located off the coast of California, and some whale sightings in this region can be seen in Figure 5. The GPGP is the largest **ocean pollution gyre** in the world with an estimated surface area of 617,763 square miles (The Ocean Cleanup 2019). Due to the abnormally high percentage, 46%, of the GPGP being discarded fishing nets, commonly known as "**ghost nets**," entanglement is a huge concern for sperm whales moving through that area of the ocean (The Ocean Cleanup 2019). This is considerably concerning, as ghost nets **engender** 300,000 cases of whale, dolphin, and porpoise deaths by means of starvation, exhaustion, or suffocation every year (Johnson 2021).

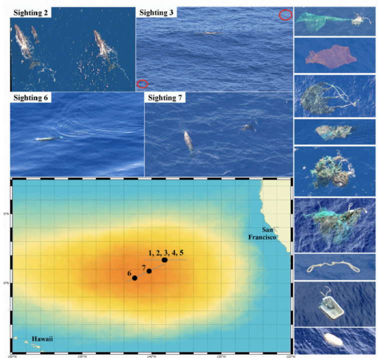

Figure 5: "[Cetacean sightings within the Great Pacific Garbage Patch]" by Gibbs et al. 2019, [CC BY 4.0]

Current Conservation

Right now, sperm whales are not a globally protected species, but they are protected by various conservation efforts and protective methods. Sperm whales are active on two lists of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) and have been categorized as "in danger of extinction" throughout all or most of their range. The species' poor conservation status might be improved if an international co-operation agreement could be organized (DSWP 2021).

In the Caribbean, sperm whales are protected by the Specially Protected Areas and Wildlife Protocols (SPAW). There are current regulations in place for whale-watch tours to ensure proper guidelines are being followed, as well as efforts to enforce a protected marine area (DSWP 2021). In the Mediterranean Sea, there is also the 'Protocol for the Protection of the Mediterranean Sea against Pollution from Land-Based Sources and Activities', and the 'Protocol for the Protection of the Mediterranean Sea against Pollution Resulting from Exploration and Exploitation of the Continental Shelf and the Seabed and its Subsoil' that protect sperm whales and other marine species from pollution (Notarbartolo-di-Sciara 2013). Finally, the International Whaling Commission has implemented regulations for the management of sperm whale populations (IUCN 2008). The unique and poorly understood qualities and patterns of sperm whale populations around the globe require several specified protection efforts in different locations for maximum effectiveness. However, the current conservation efforts aim to protect a historically overexploited species with natural barriers that prevent the population numbers from increasing significantly. Plastic pollution, especially in the case of the GPGP, has come to a point where conservation efforts are aimed toward fixing a human-made problem, and their effectiveness has not proved to be very significant so far.

Furthermore, recent data suggests that the Great Pacific Garbage Patch is growing exponentially in size, currently weighing an estimated 79,000 tons (Fossi 2020). There has been some success with partnerships between private-owned companies funding nonprofit organizations' cleanup efforts. For example, Project Kaisei is a nonprofit organization working to clean up the Great Pacific Garbage Patch, with an annual goal of removing 50 tons of plastic from the ocean to be converted into renewable energy (Sesini 2011).

Sperm Whale Status

Even after every conservation effort to date, the sperm whale's current status is listed as vulnerable on the global IUCN Red List of Threatened Species, while The United States Endangered Species Act has sperm whales listed as 'Endangered" (DSWP 2021). This low rating shows how greatly the whaling industry has impacted sperm whale populations for decades, even after whaling was banned. Current populations collected from a series of surveys ranging from 1996-2007 show an estimate of 30,000 individuals in the Northeast Atlantic. However, as there is limited overlap in the key survey areas and there is likely a negative bias due to sperm whale diving behavior, this estimate is most likely quite conservative (Pike et al. 2019). This is compared to an estimated total population of 300,000 sperm whales worldwide (Shirihai and Jarrett 2006).

Future conservation

Sperm whales have established their importance in marine ecosystems, and we are responsible for maintaining that role and protecting vulnerable species. So how do we continue to manage sperm whale populations? To combat the threats posed to sperm whales by the fishing industry, we would need to implement and monitor fishing regulations and establish swift and effective prosecution against illegal fishing practices. But we should not stop there; we can also go straight to the source itself. Establishing protocols to avoid plastic pollution in marine ecosystems in the first place can lower the risk of the species contacting or ingesting micro and macro plastics. Working toward economically viable recycling practices, while a difficult task, may aid in reducing plastic pollution in the oceans. A more difficult problem to address, however, is incidents of sperm whale collisions with vessels. Restricting maritime travel to designated shipping lanes, limiting the speed at which vessels can travel in areas with a high density of sperm whales, and spreading awareness to captains to have caution when traveling through these populated regions can contribute to a decline in incidents of whale collision with vessels. Broadcasting cautionary messages through VHF radio or including warnings in nautical charts can bring awareness and hopefully save sperm whale lives (Notarbartolo-di-Sciara 2013). Increasing the number of specified protected areas can help to mitigate many of the problems mentioned previously as well, but mostly in the case of protecting critical habitats.

Prey depletion and climate change are more difficult ecological threats to address, especially given the species' slow growth rate (Notarbartolo-di-Sciara 2013). Yet we must also consider the restrictions we face to implement such conservation and management efforts. Large-scale stock assessments in the deep seas need to be completed to better address, and potentially combat, biological and ecological factors in the decline of sperm whale populations. However, many of these assessments are financially and technologically beyond the reach of many countries, which introduces a limiting factor that we cannot quickly or easily overcome (Notarbartolo-di-Sciara 2013).

Figure 6: "Sperm whale mother and calf. Observed on System 001's first mission" by The Ocean Cleanup, permissions

Is Tourism Funding Conservation Efforts?

As of 2008, 13 million people had participated in whale watching tours across 119 countries nationwide. There has been specific growth in the whale watching industry in Asia, the Pacific, South America, the Caribbean, and Europe, which have surpassed global tourism rates over the course of a decade. In combination with the global shift away from whaling practices, the growing whale watching industry has not only contributed to better sperm whale population maintenance and protection but has also generated $2.1 billion in revenue and has created jobs for an estimated 18,500 people in the 119 countries associated with this report (IFAW 2020).

The International Fund for Animal Welfare (IFAW) is an incredibly important conservation corporation leading the global protection of large marine mammals. They work with whale watching companies all over the world to make sure the health and safety of each species are at the forefront of everyone's minds. They also maintain strong working partnerships with governments and facilitate public awareness for the benefit of whales (International Fund for Animal Welfare 2020). In 2008, the Australian organization, *Economists at Large*, used IFAW's collected data to complete an economic and expenditure report called "Whale Watching Worldwide". The study reported the total expenditure for whale watching tourists be $2.1 billion US dollars, with 41.4% from ticket sales and the remaining 58.6% attributed to other indirect expenses (O'Connor et al. 2009). While the report by *Economists at Large* does not explicitly say how much compensation the IFAW received, the fact that they are a nonprofit organization implies that any amount they accumulated over the years was used to fund their work, completing the idea that tourism is helping to finance whale conservation efforts (IFAW 2020). Continuing to promote safe and respectful whale watching practices can fund further conservation efforts, introduce a meaningful relationship between society and the sperm whale, and push for the continued protection of the species.

The Importance of Protecting Sperm Whales

This majestic and impressive marine species holds a key role in maintaining biodiversity and upholding a stable ecosystem. As a keystone species, the need to protect sperm whales on a global scale is significant. As the depleted global populations face a modern, man-made issue of marine plastic pollution, it becomes clear that we hold an important role in managing sperm whale populations. Current conservation efforts are limited by the slow growth of the global population size, as well as technological and financial barriers that make it difficult to fully understand the needs of the species with its wide range and extreme diving behaviors. Recognizing our role in reducing and cleaning plastic pollution to manage sperm whale populations and other marine life is an important step to take. Continued conservation will take time, effort, money, and respect toward the species. For all they provide, this species certainly deserves it.

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PART IV
CONSERVATION AND MANAGEMENT

Environmental conservation and management challenges sit at the intersections of human decisions (e.g., policymaking and consumer demands) and ecological changes—many of them influenced by human actions. Decisions to better manage and conserve ecosystems and species require thus close attention to both dimensions (human and environmental) and the impacts of individual and collective efforts at multiple scales.

The chapters in this section examine many environmental conservation and management challenges from both a human and ecological perspective. Several chapters study the problems in managing invasive species, including eradication efforts of the Asian Longhorned Beetle in New England, the Red Lionfish in the Gulf of Mexico, the Caribbean, and the Atlantic, and the extensive distribution of Red Foxes in Europe and North America. These chapters remind us that although public debates on invasive species tend to blame and focus on the "invasive" species, the processes leading to these population changes are rooted in a combination of human and ecological factors.

In addition, the chapter on "Gentle" Giants, The Goliath Grouper, highlights the importance of international conservation policies in reversing population declines and protecting vulnerable species. As the chapter's authors remind us, it is crucial to understand that although management systems are imperfect, they are incredibly necessary. Finally, the chapter on the Arctic Fox offers a cautionary tale of an extinction process *in the making*. The chapter examines the impacts of habitat loss, human interference, and climate change in the Arctic to point out the need for preventive protection to **keystone species** that are and will be critical as we continue facing the impacts of climate change and human actions.

A CIP (Conservation Internship Program) youth pulling invasive water chestnut at the Long Island National Wildlife Refuge Complex. "Pulling invasive species" U.S. Fish and Wildlife Service – Northeast Region. Public Domain

16. The Invasive Asian Longhorned Beetle: A Threat to Northeastern Forests

Spencer Whitford, Christopher Langevin, Janelly Torres, and Allison Burke

Abstract

In 2008, the Asian Longhorned Beetle (ALB) outbreak in Worcester, MA led to an eradication effort that left the local area barren, as trees were cut down. The ALB is an invasive insect originally from Asia that has spread throughout the world through infected wood packaging material. This burrowing beetle causes stress to forest ecosystems and the only effective eradication method can lead to the loss of thousands of trees. This chapter examines the dangers ALB poses, the damaging effects of the eradication effort, and the potential for a new outbreak leading to ecological and economic problems.

A YouTube element has been excluded from this version of the text. You can view it online here: https://extinctionstories.pressbooks.com/?p=39

"Inspectors checking NY trees for Asian Longhorned Beetle", CBSNewYork.com, Terms of use

Introduction

What is an Invasive Species?

Invasive species are the second leading cause of endangerment and extinction in the United States (Doherty, 2016). An alien-invasive species can be considered any non-native species in an ecosystem that successfully reproduces, reaches high density, and spreads further (Devin & Beisel, 2006). Alien-invasive species can disturb the natural balance of an ecosystem and lead to many problems, such as a loss of biodiversity and an imbalance of naturally occurring resources.

What is the Asian Longhorned Beetle?

The Asian Longhorned Beetle (Anoplophora Glabripennis) (ALB) is an invasive beetle native to China and Southeast Asia (Dodds, 2011). This invasive insect spends nine months of its year-long lifespan in the pupa stages buried in the trunks of hardwood trees. Upon reaching adulthood, the beetle tunnels to the surface and continues to feed on the trees. The ALB consumes essential portions of a host tree including the phloem, cambial tissue, xylem, and bark. This weakens the physical structure of the tree, as well as its essential cardiovascular system, and can result in its death (Stefan et al., 2014). After the local ALB population has depleted its host tree of resources and the tree dies, the ALB moves on to find a new host (Teng et al. 2013). Eradication efforts aimed at preventing the ALB from spreading further have resulted in the culling of many host trees by humans. This has led to a dramatic shift in the make up of forests in which the ALB has been present (Dodds, 2011). The ALB has appeared across the globe including multiple European countries such as Austria and France as well as several outbreaks across North America, more specifically the Northeast area (Dodds, 2011).

Figure 1: Asian Longhorned Beetle sitting next to a bored hole. "Asian longhorned beetle and "egg site." by R. Anson Eaglin, USDA-APHIS, Public Domain

The Guiding Issue

Using a 2008 outbreak of ALB in Worcester, Massachusetts as our guiding case study, this project examines and lays out the problems associated with this invasive pest and suggests potentially improved eradication methods. Our guiding research questions for this project are: How is ALB spreading and why is it still a concern after eradication? What are the direct and indirect impacts of the insect on surrounding forests in the Northeast of the United States? This includes the damage the beetle incurs on trees directly as well as the loss of trees due to the eradication efforts. When ALB is found within a stand of trees, the most effective eradication method involves cutting down all current and potential host trees, this leads to the loss of thousands of trees. If the beetle is left alone, however, the same result occurs except the beetle remains and continues to be destructive. This loss of trees, particularly maple trees, has a drastic effect on the ecosystem, the maple industry, and the local human populations. All of these consequences will be discussed in further detail later in this chapter.

Research Methods

We began this project with a focus on the detrimental impacts of invasive land species on biodiversity and natural resources. Our research began by looking into scholarly sources and articles acquired through the WPI Gordon Library and it was quickly realized we needed to narrow down our scope. A team member familiar with the Worcester Area, Christopher Langevin, assisted with his personal experience dealing with ALB to re re-define our research scope. As a group, we began using scholarly articles and journal entries related to ALB within the Northeast as well as ALB in its native habitat. In addition to compiling data from these journal articles, we reached out to various professionals in the field. We were able to interview Dr. Kevin Dodds, a key researcher on the Worcester outbreak in 2008. Dr. Kevin J. Dodds is a member of the USDA Forest Service who has also co-authored a paper on the invasive nature of ALB within Northeastern Forests and its impact in the Worcester Area between 2011 and 2012. Although Dr. Dodds has not worked specifically with ALB since the publication of these papers, his insights into the problem were invaluable to our research. We used local news reports to supplement our research and supply first hands accounts on how local areas were handling ALB outbreaks. Using all of the information gathered from scholarly sources, interviews, and firsthand news accounts, we compiled our findings in this chapter.

Intellectual Merit

This research considers and uses multiple disciplines to examine our research questions. Our research can potentially contribute to disciplines such as forestry, ecology, agricultural sciences, biology, and chemistry. Our research will contribute to each of these fields as it consolidates a significant portion of information regarding the impacts of the Asian Longhorned Beetle into a singular location to be referenced by multiple fields of study.

ALB in Worcester

While the entire Northeast is at risk due to this invasive species, one of the most notable outbreaks was in Worcester, Massachusetts. This 2008 outbreak was the first where the insect had spread out of the urban area and into the surrounding forest areas of the city. This in itself caused stress to the local ecosystem in the area on a bigger scale (Dodds, 2011).

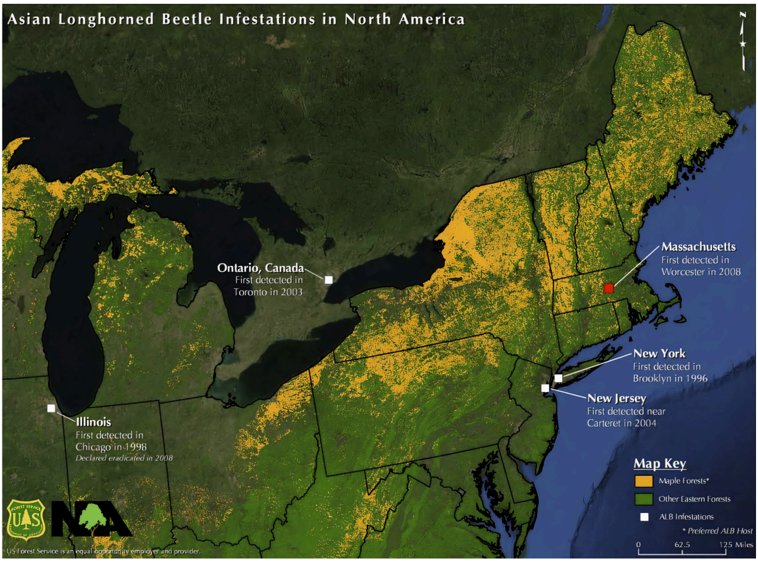

Figure 2: Map of the Northeast showing the distribution of maple forests, the most affected genus of trees, and outbreak locations of ALB as of 2012. "[Asian Longhorned Beetle infestations in North America]" by [USDA Forest Service], [Public Domain].

During our interview with Dr. Kevin J. Dodds, we learned that it would be difficult to assess the spread of the ALB in the northeast over the near future (5 years). The researched populations of the 2008 Worcester outbreak, have been effectively eradicated making the spread from these populations unlikely. Worcester had an ideal ecosystem for the ALB to inhabit, as it had a large tree population. Places such as New York or New Jersey would not have sufficed as livable areas for the beetle. Should the ALB make a return to the Northeast, it would be difficult to detect it immediately, allowing it to spread. While losing a large population of maple trees was not ideal for the Worcester Area ecosystem, it did allow other species of plants and vegetation to flourish with the newfound space.

Before the Asian Longhorned Beetle was introduced to the Massachusetts forest, in the 1860's there was a release of gypsy moths that spread through much of the Northeastern forests (Dodds, 2011). Looking back at this occurrence it acted almost the same as how the ALB spread in Worcester in 2008. Both of these species have changed how the forest looks, killing much of the same species of tree for each infestation. With the loss of these species of trees comes a large effect on the economy and the residential areas in the city of Worcester.

Twelve years after the initial outbreak of ALB in the Worcester area, the outbreak is no longer a persistent problem, however, it has had a lasting effect on the local area. According to Dr. Dodds, the Worcester area has seen a massive decrease in maple trees which has led to a shift in the balance of the ecosystem. This loss is mostly due to the currently most effective method of eradication involving cutting down thousands of trees. Many parts of the city are left lacking trees (Doyle, 2020). As will be discussed later in this chapter, the potential for reintroduction remains a problem, even if ALB is currently eradicated in the Worcester area. As a result it is a problem that must be addressed.

Figure 3: ALB awareness sign found in Green Hill Park. Credit: Samantha Grillo

Current Eradication Methods

As the Asian Longhorned Beetle has been around in Worcester for over 10 years there have been multiple eradication methods and steps to ensure the demolition of the beetle. The beetle is known for "killing trees it lives in" by laying its eggs inside the tree (USDA APHIS, 2020). The larva eventually tunnels through the tree spending most of their life eating the tissue of the tree, specifically the maple tree. In order to stop the invasive insect, cities began to take action by cutting down the trees that host the ALB.

The ALB made it to places along the northeast region of the United States, specifically places like New York, Worcester, Mass, and New Jersey. It is said to have the potential to cause more damage than chestnut blight and gypsy moths destroying millions of trees in America's national forest and even backyards (USDA APHIS, 2020). Due to the outbreak of the ALB many cities that have found signs of the beetle take part in eradication efforts in order to get rid of the insect. These places have decided to cut down trees infected with the beetle following a specific procedure that ensures the beetle is gone. The eradication strategy includes establishing a quarantine zone that keeps the beetle from spreading any further. Then the stressed host trees are cut down and removed. Even though this eradication strategy was one of the most effective to date, the removal of the trees is expensive, which leads to serious economic threats for cities (Nowak et al., 2001). Cutting down these trees also decreases the land value.

Although costly, these eradication efforts have been successful in many cities along the northeastern coast. Places like Illinois and New Jersey have seen massive decreases in the ALB population (Stefan et al., 2014). In order for the eradication of the beetle to work there needs to be strong stakeholder support and sufficient resources that will help carry out the eradication efforts (Stefan et al., 2014).

Programs used to eradicate the beetle are also set in place to help fight the invasive insect. The USDA APHIS has created two goals for the program, to prevent more outbreaks of the ALB and to eradicate current ALB outbreaks. Without these eradication efforts, it is estimated that 45% of trees in the eastern parts of the U.S will be at risk for ALB infestation (Stefan et al., 2014). Proving the eradication efforts to be important and beneficial in saving the trees of the national forest. Although some can be costly and destructive it is the currently most effective way to eradicate the beetle as soon as possible.

Threat to the Maple Industry

Although eradication efforts have been very successful in multiple areas in the Northeast, it is extremely costly and destructive to the forest. The beetle itself poses economic threats to major cities, attacking and killing host trees impacting the people and industries. The ALB infestation has caused 30.3% tree mortality (1.2 billion trees) and a value loss of $669 billion (Nowak et al., 2001). The maple tree, being the most common host for the ALB, has caused maple industries to lose profit.

For years people have been tapping maple trees for sap to make syrup, which is now being threatened by the spread of the ALB. Through eradication efforts, many maple trees are being cut down, impacting property owners and posing a huge threat to the maple syrup industries (Greenwood, PR Newswire 2012). The beetle infestation has occurred in multiple maple-syrup-producing states, causing many industries to have economic issues. Along with the loss in property value, industries will lose around $1 to $10 million 30 years after the introduction of the pest (USDA APHIS, 2020). The ALB has caused there to be a drastic change in profit for maple syrup industries due to the infestation of maple trees.

Since the pest can't move on its own, industries have found that the best way to stop the spread would be to not move any firewood from its original area. Not only are industries encouraging the "Don't Move Firewood" campaign. They also believe a good way to stop the spread of the beetle is to educate people unaware of the issue and bring awareness to the problem (Chapeskie, PR Newswire 2012). Many people may not know what's going on in their surrounding area. By educating them it can push them to buy locally harvested wood and contribute to the protection of the trees (Greenwood, PR Newswire 2012). Although eradication efforts can be expensive, industries have realized that the potential loss from the ALB will exceed the cost of prevention (Chapeskie, PR Newswire 2012).

Figure 4: Tree affected by the ALB in Green Hill Park Worcester, MA. Credit: Samantha Grillo

Potential for Reintroduction

In most major outbreaks of ALB, the eradication methods of quarantining and felling trees is effective in preventing further spread from the host stand. This, however, does not prevent the potential reintroduction of ALB into an ecosystem from new Solid Wood Packaging Material or the transversal of ALB through accidental human movement (Macleod, 2002). In a study examining the potential threat of ALB to European communities, A. Macleod establishes a very clear fact that ALB can and will be introduced in multiple locations throughout the world. The wood-boring nature of this pest allows it to travel undetected across oceans contained within palettes and other transported wood. The ability for ALB to travel in this manner is what has allowed it to become an invasive species throughout Europe and North America (Macleod, 2002).

The risk assessment conducted by Macleod analyzed weather and climate data regarding the native ranges of ALB and compared this distribution of climate with potential invasive zones. The study assigned various locations an Ecoclimatic Index (EI). This value assesses how well ALB is predicted to survive in these locations, the higher the value, the better ALB will survive.

Within the figure, larger circles represent higher EIs and a cross represents an EI of zero. Although the risk assessment focuses on the European Community, the software was also run in New York and Chicago, which had EIs of 45 and 47 respectively (Macleod, 2002). These values are higher than the mean value of the native range of 32.1 +/- 6.9. The risk assessment concludes that the invasion of ALB into the

European Community is a potential risk that should be taken seriously. Based on the similar trade tendencies China has with the United States and Europe, consisting of billions of dollars of trade and goods shipped in SWPM that has the potential to transfer ALB, and the high EI values of Northeastern cities such as New York suggests the Northeast is also at risk of consistent introduction of ALB (Macleod, 2002). The high risk of ALB introduction is still prevalent and this leads to multiple distinct outbreaks unrelated to one another. This pattern of reintroduction can be observed in the presence of outbreaks all across the Northeast, such as Worcester, Boston, New York City, Long Island, Ontario, and New Jersey (Dodds, 2012).

According to Dr. Kevin Dodds in the interview we conducted with him throughout our research process, this potential for reintroduction is one of the hardest problems to combat and track since “it really only takes one shipment that gets through inspection and has solid wood packing material that was not treated properly to start an infestation.” This becomes a problem when, even after a local area has been quarantined and properly eradicated, such as the outbreak in the Worcester area, there is still the potential for ALB to begin its invasion nearby with no relation to the current outbreak. Most recently, the USDA has begun an eradication effort in South Carolina (USDA APHIS, 2020). This outbreak is clearly not connected to the various outbreaks found across Massachusetts and is a prime example of how ALB can be introduced to a multitude of locations and wreak havoc on ecosystems as independent populations.

There is also a danger of accidental transfer of ALB through firewood. Just as it would burrow into SWPM, ALB can just as easily pass undetected within firewood across county and state lines. Organizations such as the Don’t Move Firewood Organization in Massachusetts attempt to bring awareness to this issue and how easily ALB and other pests can be hidden. With the movement of firewood, ALB can easily establish a new population many miles away from the initial host tree and create a new distinct problem (Campbell, 2020).

Potential New Eradication Methods

Our group has explored a multitude of new solutions to solve the eradication of the Asian Longhorned Beetle. The two central solutions we focused on are 1) the introduction of predatory species into ALB affected areas, and 2) the introduction of insecticides to ALB affected areas.

Predators of the beetle include toads, wasps, and woodpeckers. Introducing a new species into an environment may limit the growth and spread of the ALB, but there will also be some negative side effects. Introducing a new species to an environment may negatively affect some of the other (non-ALB) species, similar to what the Asian Longhorned Beetle did to tree species in the northeast.

Rather than targeting adult ALB's, our group researched methods on how to eradicate the beetle during its larvae stages. Nematodes have been discovered to prey on larvae stage ALB. These nematodes were used in China during the original ALB outbreak, prior to its spread to North America. For this specific predator, we suggest following in the footsteps of the Chinese environmental agencies, by stapling the nematode (which will sit on a moist sponge) to trees throughout the area. The nematodes are then able to locate and attack the host larvae within 30 centimeters of the initial entry point of the tree (Solter, 2017).

Our other targeted solution is the introduction of insecticides. Insecticides can decrease the number of beetles in an area and help trees from becoming infected. Insecticides might help contain the spread of the beetle in currently infested areas and will kill off the beetle so that it is not able to infest new areas. Insecticides are used only on trees that are not known to be infested. The insecticide itself can be applied either directly into the trunk of the tree or directly into the soil beneath it. The tree's vascular system will then pull the insecticide up and throughout the tree so that all parts receive the insecticide.

Imidacloprid is a tested insecticide. Historically, imidacloprid has been shown to be effective against other insects such as termites, cockroaches, and flies (USDA, 2017). Imidacloprid is also used for tick and flea prevention in domestic pets and has been sold commercially in the US for over 25 years.

Our team suggests treating only specific types of trees with the Imidacloprid insecticide. These types of trees include -but are not limited to- maple, birch, buckeye, willow, and boxelder. In order to maximize the effectiveness we suggest treating all host trees in an area, so that we are able to see the effectiveness of the insecticide of an entire area. The application of the Imidacloprid insecticide should take place only during specific seasons. Ideally, the insecticide will be applied during the spring or the early summer, which will be prior to the adult emergence of the Asian Longhorned Beetle. The aforementioned tree injection can take 1-3 weeks to be fully effective throughout the tree, and the soil injection can take up to 3 months. These time frames are dependent on the size, age, and overall health of the tree.

While our group has high expectations for the effectiveness of the insecticide, we recognize that it will not rid any tree entirely of the Asian Longhorned Beetle, only limit the spread. The entire removal of trees remains the only effective method of entirely ridding a stand of the ALB.

Conclusion

Ultimately our findings show ALB is never going to be a contained problem. Even after the eradication of a local population ALB can still be introduced to a location and cause harm to the local ecosystem. Our findings have shown the detriment this and the accompanied eradication methods can have on local ecosystems and humans. Our research found that it is almost always human intervention that spreads ALB. As a result, we, as humans, have an ethical duty to attempt to correct this impact we have had on ecosystems. This duty has come with eradication methods which often have just as much effect on the ecosystem. This is why our research has made an effort to develop and suggest new eradication methods, such as insecticides, that will not be damaging to the ecosystem while still solving the problem. Our findings can also be felt economically. ALB's specific targeting of maple trees has the potential to be devastating to the maple industry. In order to not experience a greater drop in this industry, ALB must be monitored and effectively eradicated when present. In addition to the ethical and economic implications, socially our research has also shown the effects of ALB on urban forests.

The loss of trees throughout cities has led to an imbalance of access to trees and nature within underprivileged neighborhoods throughout Worcester and other cities. Preventing the spread of ALB will prevent these losses from becoming greater than they already are. Our research has led us to suggest the usage of safe insecticides in place of the current eradication method, a better monitoring of the movement of SWPM as well as firewood that could contain ALB, and the continued monitoring of Northeastern forests for potential reintroduction. We believe it is essential to continue to monitor forests and recognize an infestation early and eradicate the local population in the least harmful way possible. We also recognize research into other potential eradication methods or preventative measures can be beneficial for the future of our forests.

The Asian Longhorned Beetle has had a major impact on Worcester forests and their surrounding areas. The species has impacted Worcester County for the past twelve years and the lasting results show even after eradication in the lack of trees. In the hope to stop the spread of this invasive species, the eradication methods that were mentioned above have started to become implemented to help stop the spread in order to save the forest. With this being said, there is a high chance for the maple industry in the surrounding area to economically be saved and for the maple industry to begin to rebuild itself. With the current eradication method in place, even if this is successful, however, there is a chance that there can be a reintroduction of the Asian Longhorned Beetle. With this, there has been more research of the current eradication methods being executed in the locations with the most substantial outbreaks, and new methods of eradication are being implemented into this current outbreak. Overall, if the new eradication methods are successful, the forests will begin to flourish once again, saving the oak and maple trees that have been affected for over ten years, and the maple industry will become positively economically impacted.

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17. The Red Lionfish and their Effect on Native Fish Populations and the Well-Being of the Coral Reefs

Kayla Carpenter, Cat Garcia, and Cameron Norton

Abstract

The lionfish have threatened the population of Atlantic native fish and the well-being of coral reefs in the area since their introduction in the 1980s. This chapter assesses causes, consequences, and solutions to help mitigate the negative effects caused by the lionfish to restore Atlantic waters.

Figure 1: Lionfish in a Caribbean coral reef. pic_0270 by Greg Grimes, CC BY-SA 2.0

Framing of the Problem

The population of Atlantic native fish and the health of the coral reefs are seeing a rapid decline due to an alien invader: The lionfish. This majestic fish, which is native to Pacific ecosystems, was introduced into the Atlantic by irresponsible pet owners who released them into the ocean. The lionfish first appeared off the coast of Florida in the mid-1980s but quickly spread all across the east coast, the Gulf of Mexico, and the Caribbean (Hixon, 2011). Due to the aggressive nature of the lionfish, they are able to rapidly eat the majority of reef fish that likewise belong to the diets of native fish, leaving them no food to prey on. This huge appetite has caused many fish to become harder to spot, causing fisheries in the area to suffer economically. This inability to catch and sell fish in return for money has threatened the comfort as well as the security of those living near the affected areas. Lionfish also feed on herbivorous fish that keep the algal growth on coral reefs at bay which has caused the reefs to rot, destroying the shelter for many other marine creatures.

The lionfish in the Atlantic area are causing a severe negative downfall in their ecosystem. They are indirectly causing one of the most dangerous situations the Atlantic waters have ever experienced and driving native fish and plants to local extinction. In just a 5 week span, lionfish are said to reduce the population of native sea creatures by 80% to 90% (Lionfish Central, 2020), which in turn is destroying the coral reefs. They are consuming more reef fish than any other predator in the Atlantic due to their large stomach capacity, causing a decrease in the population of small reef fish and larger native fish who feed on these smaller prey fish. Without the range of algae-eating fish, coral reefs are also starting to crumble. Atlantic native fish and coral reefs are already in danger due to overfishing and climate change, but soon enough the lionfish will drive them to extinction in the Atlantic and rid the area of biodiversity.

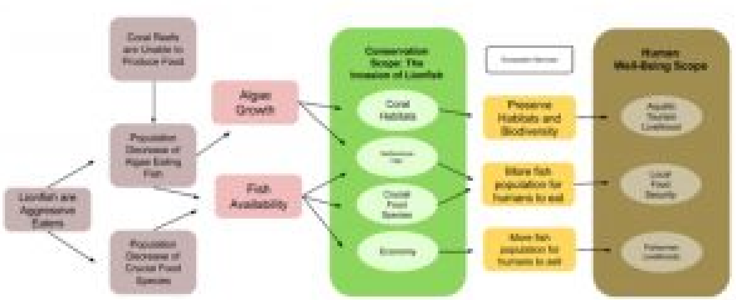

Figure 2: A situation model to demonstrate the effects of lionfish invasion and its impacts on various trophic levels. Created by chapter authors.

Background

The Lionfish

Pterois volitans, better known by the name Red Lionfish, is a venomous predatory coral reef fish of the family *Scorpaenidae*. It is characterized by its most dominant features, red and white stripes covering its body, long extravagant fins, and large mouths. These fish can grow to be between twelve and fifteen inches long at maturity and can weigh around one to two kilograms. The Red Lionfish is adorned with many venomous spines on its back and fins. A "sting from the red lionfish constitutes a serious health emergency," which in many cases can require hospitalization (Robins, 2017). Many symptoms of the venomous sting include headache, nausea, and swelling, but can escalate to more severe issues such as pulmonary edema, muscle paralysis, and loss of consciousness. Lionfish are known to be aggressive and can charge at their prey with their spines revealed, often cornering them against a part of the reef. In humans, they "rank second only to stingrays in the total number of envenomations, with an estimated occurrence of approximately 40,000 – 50,000 cases annually" (Robins, 2017).

Lionfish are highly predatory and will typically consume small species of fish, but have been reported to consume larger fish and crustaceans as well. They are effective predators, chasing their prey into a corner before snapping them up with incredible speed. In addition, these fish are very intelligent and use their coloration to blend in with their surroundings. Most notably, lionfish "prefer living near rocky coral areas where they can hunt small fish and invertebrates, and then retreat into crevasses" and are masters at hiding, where they are practically undetectable by other fish (Robins, 2017).

Species Introduction

The lionfish originated in Pacific reef ecosystems, but since their introduction to the Atlantic, they have spread quickly. The primary reason behind the introduction of the lionfish to the Atlantic was caused by “human-mediated introduction through the ornamental fish trade” which has led to extreme ecological damage (Bariche et al., 2017). Since the introduction of the species, the Indo-Pacific lionfish has been sighted in numerous Atlantic regions, primarily thriving in the southeastern region including the Floridian coast and the Bahamas. The survival of the lionfish is dependent on multiple factors such as temperature and predation or lack thereof. Lionfish are commonly observed in the southeastern United States continental shelf, spanning from southern North Carolina to the south tip of Florida. The waters in this region are “relatively saline (34 to 36 salinity) and warm (12 to 16 C winter minimum), which can allow for temperate marine fauna to survive and reproduce (Whitfield, 2002). They have also colonized large areas of the Caribbean and Western Atlantic,” (Bariche et al., 2017). Many theories lead to the introduction of these fish in the Caribbean, but the most likely theory is “an arrival through the Suez Canal” caused by larva transport through a current (Bariche et al., 2017). With the fish present in the majority of the Atlantic, many species of flora and fauna are now in danger.

Figure 3: A map demonstrating how quickly lionfish have populated the Atlantic. "[Reported lionfish sightings: Animated Map (1985-2020)]" U.S. Geological Survey, [Nonindigenous Aquatic Species Database], [Public domain]

Many early efforts to assess the population of lionfish "suggested that lionfish populations were rapidly increasing, with trophic interactions with native reef fishes a concern" (Morris & Akins, 2009). With the lionfish now residing in Atlantic reef ecosystems, many species of Atlantic fish have faced a severe decline. Unfortunately, because lionfish are non-native to Atlantic ecosystems, Atlantic fish lack an understanding of the predation that lionfish inflict on ecosystems (PBS

NewsHour, 2016). The lionfish is a sustainable hunter in the Pacific since fish in surrounding habitats know to avoid it, but in the Atlantic, it gorges itself and consumes far too much since surrounding prey have no instinct to avoid the fish. Many lionfish, upon gastrointestinal examination, were known to prey upon crustaceans but also prey upon many species of fish that aid in reef health and maintenance. The lionfish invasion has "increased swiftly between 2004 and 2010" in the Bahamas and between 2008 and 2010, "lionfish increased from 23% to nearly 40% of the total biomass of predators" which demonstrates the rapid rate of decline in native species (Green et al., 2012). Many small species of fish are consumed by lionfish, but often larger species are consumed as juveniles as well and these larger species could include predators or larger algae eating fish. An example of a smaller fish preyed upon by the lionfish is a critically endangered fish known as the social wrasse, which is a planktivore that is one of five coral reef fish species in immediate danger of extinction (Rocha et al., 2015).

Detriment to Coral Reefs

Coral reefs are suffering due to the immense predation that lionfish inflict upon their ecosystems as well. In the Bahamas, "lionfish have extended their habitat range into mesophotic depths down to 91 meters where they have reduced the diversity of several important fish" who are important to maintaining algae growth on the corals (Lesser & Slattery, 2011). In addition, there has been a significant loss of coral diversity due to algae growth, and because the herbivorous fish responsible for cleaning the corals are becoming endangered and declining at a fast rate, the growth is becoming unmanageable.

Many reefs, specifically mesophotic reefs, are high-density sheltered hubs for a variety of species of the flora and fauna biota. In the Bahamas specifically, mesophotic reefs are known for their algal-dominated coral formations and the presence of the herbivores that keep the growth at bay. Lionfish have been spotted at depths up to 300 feet below the surface, where reefs with a “>50% benthic cover” are common (Lesser & Slattery, 2011). This high density of lionfish has resulted in the decline of herbivorous fish and sponges, causing algal growth to dominate the reef. According to an article by Michael P. Lesser, the phase shift between coral and algal dominance is prevalent and, “the timeframe of that shift depends on the level of coral recruitment in the system, as well as the intensity of herbivory and the structure of the herbivore guild” and due to the abnormal rate of predation by the lionfish, coral recruitment is at an extreme low.

A study conducted in Bock Wall from the year 2003, when lionfish first began moving to the region, to 2009 was performed by observing the structure of the coral reef ecosystem. By the end of the study, it was concluded that “percent algal cover at 46 m was 27% in 2003, 31% in 2005 and 94% in 2009,” demonstrating the impact that lionfish had on the reef since their arrival (Lesser & Slattery, 2011).

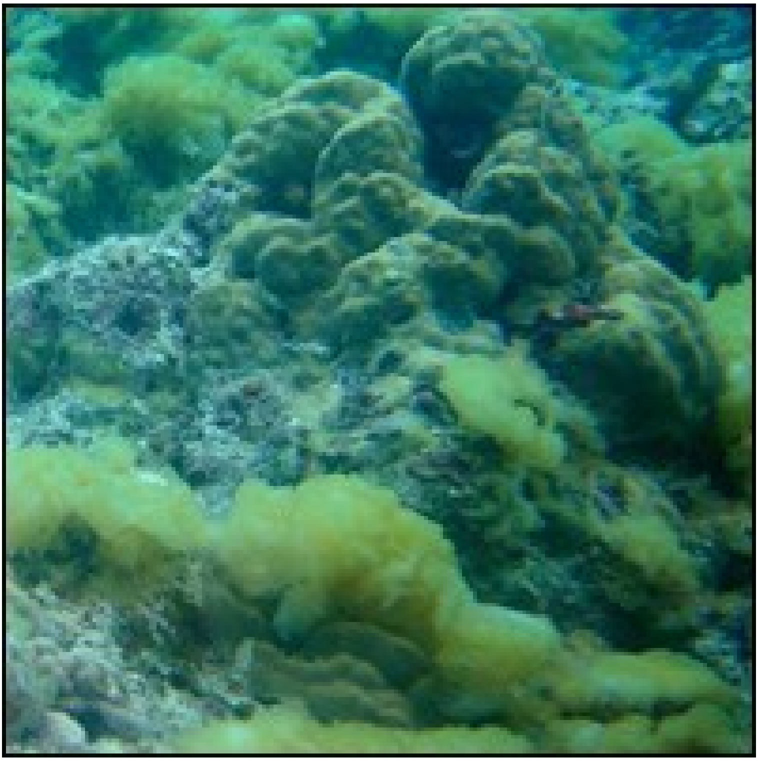

Figure 4. An increase of lionfish in an area can result in the overgrowth of algae. Photo by CORE, Public Domain.

Economic Impact

From these invasions, other problems have arisen in areas that rely on fishing. In areas, like the Bahamas, the spiny lobster is important to sustain the economy. However, since lionfish have started to appear in that area, the productivity of some of these lobster fisheries has gone down from at least 7% to some estimates of around 13% (Henderson, 2012). This trend has been caused by the abundance of lionfish in certain fisheries, which requires individuals to take them out or kill them. This has caused major concern for certain fisheries, as it shows that lionfish have the power to economically impact businesses, especially on islands. (Henderson, 2012).

Intellectual Merit

Our research examines the negative effects that lionfish are indirectly causing in the Atlantic and assesses effective solutions to help mitigate these issues. The main question that guided our research into this problem was: What measures need to take place to ensure the safety of the native fish populations and coral reefs in the Atlantic? This research could become crucial in saving certain populations of native fish that live in coral reefs as well as improve the financial stability of the Atlantic fisheries. Ecological sciences play a vital role in this research due to the fact that the lionfish are destroying coral reefs and have the potential to cause native fish to become extinct. A better understanding of the relationship between lionfish and its surrounding provides insight into their aggressive nature and their effect on other organisms. With this decrease in the native fish population, there are fewer fish for humans to hunt and sell. Local fisheries are not catching as many fish due to complications between the native fish and the lionfish, which is causing the financial stability of the communities in the area to be at risk, which ties in the role of economics. When studying how the economy relates to the situation with the lionfish, those studying in this field have a better understanding of how the financial standpoint of the communities in the area is declining. Without the abundance of fish for people to eat, social sciences will be involved because the comfort and security of those living near these affected areas will no longer be stable. Different social sciences will have the opportunity to come together in order to research this issue in more depth in order to help the community thrive.

Methodology

In order to execute this research, the group reviewed scholarly, peer-reviewed materials that are related to the topic. This included papers written by professors, maps and models of the situation, legal documents, and other scholarly sources that help the group get a greater picture of how the lionfish are causing species to go extinct. In addition, part of the research was done by interviewing experts in lionfish, conserving species affected by these invasive creatures, and limiting their impact. The interviews were done mostly through email, though other alternatives were available if they agreed. This does not include, however, experiments that could have been done by the group, as COVID-19 has hindered the ability to perform such tasks. Once the data was all collected, the group wrote a paper with all the details in it, a poster that easily shows the findings to the public, and a presentation that is a combination of both the previously stated creations.

Findings and Results

While it is true that the lionfish invasion has no perfect solution, there are a variety of current and future approaches that could aid in the restoration of the Atlantic ecosystems. A prominent solution that is currently being used is the targeted killing and removal of lionfish in Atlantic reef ecosystems. This method is performed in many regions along the Caribbean including the Floridian coast, the Bahamas, and the Gulf of Mexico. Many events take place in these regions to curb the effects of invasive lionfish which include diver-led targeting practices and lionfish derbies. Lionfish derbies are competitive events that encourage dive teams to hunt and kill as many lionfish as they can in one day. These events are an effective way to encourage the community to get involved in the eradication of this dangerously invasive species. According to the NOAA, “recent efforts to focus collections by divers has resulted in over 1400 lionfish collected in one day during derby-style events” especially in areas where lionfish are highly concentrated on reefs (Morris & Whitfield, 2009).

One possible solution is the introduction of traps to contain lionfish for removal. However, according to Dr. Exton, this method comes with numerous ethical concerns due to the possibility of trapping and killing species other than the Red Lionfish. In order to not contribute to the decline of native species, a fish trap must exclusively capture lionfish, which is nearly impossible. Though they are not quite feasible, lionfish traps could be a cost-effective solution to the issue. They can cover wide areas of the seafloor and can collect numerous lionfish at once. Research is underway to determine a more effective lionfish trap, such as an option to allow small fish to swim out of the trap if caught, and an option to tangle the lionfish’s venomous spines to prevent harm to other fish as well as divers.

Guardian LS-1

Dr. Dan Exton, a marine biologist at Operation Wallacea, participated in many dive expeditions and targeted killing on the coast of Honduras, where lionfish are very prevalent. In an interview, he addressed the concern that lionfish now exist at depths of up to 1200 feet. These individuals have adapted reproductively to lay as many as 2 million eggs per year. Because of the prevalence of lionfish in such deep waters, lionfish derbies and diver-facilitated killings become increasingly difficult and not feasible due to a variety of reasons. For one, the gas emitted at that depth can be harmful to divers, and the pressure from the water can impact the well-being of the divers involved as well. To combat this, Dr. Exton and his team have explored a variety of solutions to combat the recent invasion of the species in such deep water.

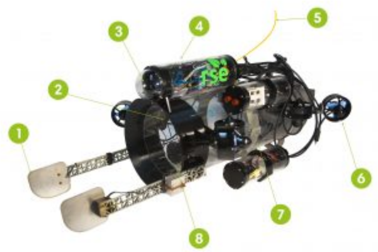

Figure 5: RSE lionfish targeting robot, Guardian LS1, with labeled parts. Courtesy of RSE.

Due to concerns about traps designed to capture lionfish, Dr. Exton and his team are collaborating to form a new type of solution. At a chapter of iRobot near Boston, researchers and engineers alike are collaborating on the invention of a robot that can capture lionfish with ease. This robot is currently being developed by researchers at Robots in Service to the Environment (RSE), an organization founded by Colin Angle of iRobot. The robot, known as the Guardian LS1, has many different parts that contribute to capturing and securing lionfish for capture. As shown in the figure, part one consists of stunning panels with "low controlled voltage" that "temporarily stuns the lionfish long enough to be captured" (RSE, 2019). To pair with the stunning panels, a thruster mechanism is mounted to quickly capture the lionfish and place them in a chamber fitted with a retention feature. It is mounted with a number of additional features for added stability such as, "8 thruster array for total motion control, allowing complex hunting maneuvers and stabilization of undersea currents" along with pressure safe containment of electronics to amplify the effectiveness of the device (RSE, 2019). According to the RSE, the critical breeding depth is 150-500 feet. The Guardian LS1 is capable of achieving depths of up to 700 feet, able to capture the majority of the lionfish present in this critical area.

Culinary Applications

Though there is no perfect answer to the lionfish problem, a solution exists that includes fisheries, restaurants, and members of the general public alike. Consuming lionfish for culinary purposes was found to have significant economic and ecological benefits regarding the issue. Often, at the end of a day-long lionfish derby in the Caribbean, local restaurants along the coast gather together to cook a variety of recipes using lionfish as a way to come together and celebrate the end of a hard day's work.

Lionfish is described to have a light flavor and a flaky texture. Because it is mild, it can be prepared in many different ways and is suitable for many recipes. Besides its great taste, lionfish meat is known to have numerous health benefits when consumed. Compared to other fish such as grouper and tilapia, the lionfish is very high in n-3 fatty acids which are known to greatly improve heart health and lower the risk for heart attack or other heart diseases. The primary fatty acids found within lionfish are n-6 and n-3 polyunsaturated fatty acids, with a mean fillet yield of, "30.5% of the total body wet weight, a value that is similar to that of some grouper and porgy species" (Morris et al., 2011).

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18. Misunderstood "Gentle" Giants - The Goliath Grouper

Ryan Polansky, Kathryn Rodriguez, Neilie Fromhein, and Jeffrey Compere

"Goliath Grouper" by Tom, CC BY-NC 2.0

Introduction

The goliath grouper, *Epinephelus itajara*, is a long-lived large-bodied fish found within warmer Atlantic waters (Koenig et al.

2019). Like much of the grouper species, goliath groupers are **protogynous hermaphrodites**, meaning they initially mature as females and later as males (Koenig et al. 2019). This, combined with their lifespan and predictable mating routines left the grouper vulnerable to overfishing, leading to their near extinction in the 1990's. While currently protected by a fishing moratorium, there has been recent pushback from fisheries hoping to yet again fish the still-vulnerable species. We hope to address misconceptions and establish the benefits of continued conservation.

Species Introduction

The goliath grouper is the Atlantic's largest grouper, and when mature, can grow up to 800 pounds in weight and 8 feet in length (Fisheries NOAA n.d.). They are relatively long-lived, given that the maximum recorded age of a goliath grouper is 37 years old; however, scientists have predicted that they have the ability to live to the range of 50-100 years (Florida Fish and Wildlife Conservation Commission n.d.). Adults typically are a mottled brown-yellow or green-grey color with spots or faint vertical bars. Younger groupers exhibit similar coloration but are often more muted. Characteristic features that allow them to be distinguished from other large-bodied grouper species are their broad head, rounded tail, short dorsal spine, and small eyes (Robins 2021). Additionally, the grouper has between three and five rows of teeth, including short underdeveloped canine teeth, allowing it to be distinguished from other Atlantic grouper species. While this can make the grouper appear more dangerous to undereducated fishers and divers, the grouper is an ambush predator that primarily feeds on crabs and other slow-moving fish species, which humans are not. It captures prey by expanding its mouth and sucking in the prey whole, meaning that its actual bite is weak, and wouldn't pose a danger to humans (Robins 2021). Some of its natural predators include barracudas, king mackerel and moray eels, and Sandbar sharks; however, its populations are mainly threatened by fishing and habitat destruction.

The goliath grouper has been found in the Gulf of Mexico, off the coast of Florida, in the South Atlantic, off the coast of Africa, and as far north as New England (Fisheries NOAA n.d.; Figure 1). Its primary habitat, as one of the only groupers to inhabit **brackish water**, is shallow, only as deep as 46 meters, and consists mainly of coral, rock, and mud bottoms (Robins 2021). Young goliath groupers live in mangrove habitats, most commonly off southwest Florida, and move to shallow reefs as they grow. The destruction of mangrove habitats is another contributing factor to species vulnerability, which will be explored later. Adults are usually solitary when they're not forming aggregates during mating season and remaining in the same area for large periods of time (Robins 2021). During mating season, aggregates form primarily around shipwrecks, isolated reefs, and rock ledges as these are spawning sites. In order to form these aggregates, they use a specialized bladder to create rumbling sounds with which to locate other members of their species. Groupers are known to be nocturnal spawners, preferring to spawn under the new moon, meaning that aggregates normally form at night or during the early morning hours (Koenig et al. 2019). Aggregates have been recorded to involve around 10 groupers in the past, however, due to successful conservation efforts over the last 30 years, aggregates of the species often see groups of 20-40. Once the eggs are fertilized, they are distributed by ocean currents, resulting in spawning during the late summer months, July-September (Fisheries NOAA n.d.).

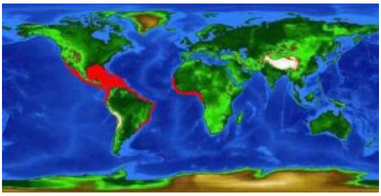

Figure 1. Range map of the goliath grouper. "World distribution map for the goliath grouper" by RH Robins, Florida Museum, with permission

Goliath groupers generally do not exhibit **sexual dimorphism** as they are protogynous hermaphrodites; they spend the first 1-6 years of their lives begin females and eventually mature into males. The males often have a much slower growth rate. Groupers in the transitional state are hard to find, however, the notion of protogynous hermaphrodism is supported by similarities to other species of groupers. In a study executed by SEDAR (SouthEast Data, Assessment, and Review) the sex ratio was seen as 1:1; however, later in the article, they concluded that more long term monitoring was needed to draw conclusions as to life traits such as reproductive habits, gender ration, and sexual maturity, as well as more studies are needed to understand genetic variation (SEDAR 2011, SEDAR 2016). This lack of data and general knowledge of the species is largely due to the fishing moratorium on goliath groupers, as there is little to no data being brought in by fishers in the Atlantic.

Current Species Management

Due to its long lifespan, late sexual development, slow maturity, protogyny, and spatially predictable mating routine, the goliath grouper is exceptionally vulnerable to overfishing. As the fish is incredibly large it was often sought after by anglers looking to fish for sport and trophies or by fishing companies for a perceived value in its large amounts of flesh. From the 1970's to the 1980's the goliath grouper was fished to near extinction in US waters, as a culmination of half a century of overfishing (Koenig et al. 2019) (McClenachan 2009). In 1990 goliath groupers were placed under federal and state fishing bans closing them to harvesting and possession within the United States. Many of these bans are still in place today (SAFMC 2021). Later in 1991 the species was listed as part of the Endangered Species Act and labeled as a species of concern; this label has since been removed in 2006, but the fishing bans still remain in place by fishery management councils (Fisheries NOAA n.d.). It was expected for the species to have high enough populations to be fished again by the mid 2000's, however, in 2004 it was concluded by SEDAR that populations would not reach their targets until 2020 or later. A secondary petition to get the grouper listed as endangered or threatened was filed in 2011; however, it was concluded that there was not enough scientific or commercial data to once again put the species under review (Barnett et al. 2011).

The current Policy within US waters is if the goliath grouper is caught it must be returned to open waters unharmed and alive. Smaller goliath grouper can be removed from the water to remove the hook properly however large goliath grouper should not be removed from the water due to the fact that their skeletal structure can not adequately support their weight without causing internal damages. As such fishers that fish within the areas populated by goliath groupers should be prepared to release larger fish by cutting the lines rather than pulling them out of the water and should be prepared adequately to do so (Florida Fish and Wildlife Conservation Commission n.d.). These conservation efforts have been successful with the current population increasing year by year. The increased abundance of goliath grouper is noticed in

Tampa Bay, Charlotte Harbor, and the Ten Thousand Islands. Increasing perceived abundance in these areas and among fishermen is encouraging, however, the species remains incredibly at risk.

Other countries within the goliath grouper’s range have not instituted enough measures to fully protect the species. In Mexico, there is little to no policy on the fishing of goliath groupers, especially in the southeast where US and Gulf of Mexico protections are no longer in effect. This general lack of regulation has put the grouper species even more at risk (Aguilar-Perera et al. 2009). Additionally, there have been instances of poaching off the coast of Brazil, even though a fishing moratorium has been instituted there since 2002, nine years after the ban was placed over US and Caribbean waters. This increased poaching has been due to limited enforcement of the moratorium which was granted the ability to stay in place until 2023. A small subsection of the grouper also lives to the west coast of Africa where there is no legislation passed to currently protect the species. These populations are generally less in danger, as they are mostly caught by local spearfishers rather than members of the fishing industry or for sport (Bertoncini et al. 2018).

The main targets for conservation in these areas are the spawning aggregates as they are easy targets for poachers, and any tampering with the sites can cause drastic effects on resulting grouper populations. A recent study concluded that even though these management systems are imperfect they are incredibly necessary as the loss of these systems would cause an estimated population decline of 85% in just under 2 generations (Bueno et al. 2016).

Threats to the Species

As mentioned previously, the threat of overfishing is obviously very real and imminent to the species, however, there are some other threats that also bear being addressed. These threats include loss of mangrove coverage, red tides, cold temperature events, and increasing mercury levels (Bertoncini et al. 2018). These elements of different threats to the populations also do not act alone as humans, ever a part of the ecosphere, continue to present increasing negative pressures on the species.

Mangroves provide an important location for the development of juvenile goliath groupers. This is especially important as the grouper has such a long development time. Their time spent within the mangroves is determined by the amount of dissolved oxygen and salinity of the waters and normally last around 6 years. The mangroves are necessary for maintaining very specific conditions necessary to the development of the juvenile groupers (Bertoncini et al. 2018). This developmental phase is crucial to the accumulation of goliath grouper **biomass** and as such the destruction of these habitats presents an imminent threat to the long-lived slow-developing species. Mangrove habitats have seen a reduction by at least a third since the 1990's, relatively similar to the population decline of the grouper themselves. Humans have also created some anthropogenic factors that make this habitat largely unsuitable for the juvenile groupers as well as additional challenges caused by eutrophication.

Algal blooms are often preceded by the **eutrophication** of an ecosystem. A particularly devastating example of a large-scale algal bloom is the red tide (Bertoncini et al. 2018). This bloom is comprised of *Karenia Brevis*, a dinoflagellate that produces toxins that are harmful to developing juvenile goliath groupers especially as it continues to be a problem in the southeast of Florida. 2018 presented another red tide year to challenge south Florida's ecosystems, and the extent of the damage caused by that bloom has not yet fully been interpreted in regards to goliath grouper populations (Koenig et al. 2019).

Juvenile goliath groupers also saw a very large population in

2008 within Florida waters as there was an extreme cold time event. Groupers being a tropical species, especially as juveniles are highly susceptible to be impacted by cold weather patterns. The cold event that occurred in 2008 caused a juvenile goliath grouper population reduction of around 90% (SEDAR 2016) and recovery efforts still have not been able to confirm if the species has yet recovered from that one event. These cold time events, much like the red tide events are rare, but due to human interference in different forms have become more prominent in recent years, causing extreme setbacks in the recovery of the grouper species (Koenig et al. 2019).

While the high mercury content found within goliath grouper species may at first seem beneficial as it may have the effect of dissuading potential fishers, the mercury has also had potential negative effects on the fish themselves. As mercury is a toxin that occurs with bioaccumulation, while the effects of eating the grouper may be lethal to humans, there are several sub-lethal effects that may cause groupers to be less fit for their environment. These effects are lesions, decreased immune response, reduced liver capabilities, and problems maintaining osmolarity (Koenig et al. 2019). While these effects will not directly cause a population decline they have several implications to reproductive viability where they could negatively affect groupers longevity as a species the most, as female egg viability may be compromised (Bertoncini et al. 2018). All of the aforementioned factors do largely impact the grouper's recovery, however potentially the most threatening upcoming challenge for the grouper is once again people's ignorance.

There has been a recent push for the re-legalization of goliath grouper fishing, for reasons including documentation of their biology, reducing their "strain" on more lucrative fish populations, and making humans safer — beliefs that are not supported by facts. People are, in many cases, undereducated about goliath groupers, which leads to them forming incorrect opinions. Despite having been overfished to near extinction starting in the 1800's, the species has been placed into a role as a scapegoat. Fishers have blamed groupers for recent setbacks in the fishing industry and goliath groupers have been characterized as nuisances and harmful creatures to both humans and the environment (Koenig et al. 2019). The Goliath grouper is also known culturally as a "bottom-fish" because of its wide variety of prey it feeds on. However, this mischaracterization has been harmful to the species because fisheries use it as justification to continue hunting it. In reality, there are almost no benefits to the fishing of groupers due to their high mercury content, positive impacts on biodiversity, and large body size. Their large body size has, in the past, contributed to both them being overfished and the perceived danger that they may cause. However, they have almost no fear towards humans, making them rather benign, but also makes them ideal targets for spearfishers. Due to their lack of fear, they are often regarded as "gentle-giants" by knowledgeable divers and fish enthusiasts. (US Department of Commerce NOAA 2011). Even so, this pushback still exists and it's been estimated that due to their slow growth rates, hunting a hundred of them annually for four years would have drastic negative consequences on their breeding population.

Species Value

Goliath groupers are a large and important predator in the reef ecosystem, as well as the other ecosystems that they inhabit. There have been noted positive correlations between grouper **biomass** and **biodiversity** exhibited within coral reef ecosystems overall, however, the mechanism and the actual cause of this correlation remain unknown. They feed on a diversity of fishes and invertebrates and also provide a good food source for barracudas and reef sharks (JohnC 2018; Figure

2). Furthermore, as a result of their size and hunting habits, they actively increase the complexity and habitability of their native ecosystems by clearing mud and silt, allowing other species to flourish to a greater extent than before.

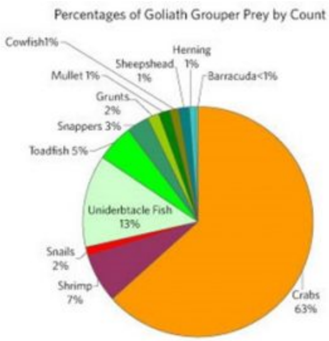

Figure 2. Prey items eaten by goliath grouper. "Pie diagram showing main prey items of goliath grouper diet, adult and juveniles combined" by Koenig and Colemna, NOAA MARFIN Project Final Report, Public Domain

The goliath grouper also represents a potential **biocontrol** for the invasive lionfish. The majority of disrupted and invaded coral reef ecosystems targeted by lionfish are in the Caribbean, an overlapping range with goliath groupers. While natural biocontrols for lionfish are generally poorly studied, they have previously been found in the stomachs of large-bodied groupers, the goliath grouper is the most common representative. These observations were the basis for a revolutionary study in 2011, that investigated two protected areas for groupers. In looking at these two locations, researchers found that there was a statistically significant negative correlation between grouper biomass and lionfish biomass. This correlation indicates that some form of biocontrol was occurring and can continue to occur between these species. The mechanism for this biocontrol is most likely predatory due to lionfish having been found present in groupers' stomachs and the lack of competitive overlap in the two species' resources like food (Mumby et al. 2011).

Similar to the positive correlation between goliath grouper biomass and reef biodiversity, there is also a positive correlation between goliath grouper populations and an increase in the capture of other fish (Koenig et al. 2019). While the complete nature of this relationship is not yet known, it is likely that any negative impacts to goliath grouper populations would also affect this trend and by extension the seafood industry. While there is a lot of pressure from anglers and fishermen to open up goliath grouper fishing at least recreationally, the price of goliath groupers would only be around $34-79 USD, an amount that is almost negligible (Shideler and Pierce 2016). Goliath groupers, unlike these other reef fish, are quite difficult to commercialize due to their large body size and lack of consumable meat products. Based on these factors many knowledgeable fishermen have decided that it is not worth the risk of breaking the fishing moratorium (Gerhardinger et al. 2006).

The vast majority of economic benefits that can be developed from the grouper species do not lie in fishing but rather in the protection of the species. **Ecotourism** presents a great opportunity for economic profit from the goliath grouper, oftentimes in the form of paid diving trips. This boost to the tourist industry can also help to advocate for the grouper's continued conservations, as demand to go to their spawning aggregates has increased since populations returning to the sites have increased, experienced divers, being willing to pay upwards of 200 USD for a single experience (Shideler and Pierce 2016). This data shows that the Goliath grouper has very high economic value with regard to the tourism industry. The money generated from this could be funneled into education and more conservation projects, as an economic incentive to keep the spawning sites as healthy as possible has been created.

Conclusion

In conclusion, the goliath grouper provides many benefits to its biosphere. In order to maintain those benefits, more conservation efforts must be enacted by countries and organizations set on protecting the goliath grouper. Ways this can be done is by educating fisheries on the positive aspects of conserving goliath grouper. This would benefit conservation efforts because many fisheries have called for the calling of goliath groupers in the past several years. Which would drastically harm their numbers and recovery. A policy that needs to be enforced is the ban on net fishing in goliath grouper waters. The benefit of this would be promoting ecotourism that could spread awareness of the species and generate money for continued conservation efforts. If the goliath grouper is caught accidentally the policy is to release it back into the water unharmed and in the location it was caught to ensure its safety (Fisheries NOAA. n.d.). To learn more about the goliath grouper or to donate to conservation efforts go to https://oceana.org/marine-life/ocean-fishes/atlantic-goliath-grouper.

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19. Red Fox: An Invasive Species in Your Own Backyard

Dyllan Cole, Billy Cross, Eric Heiman, and Marissa Lima

Chapter Summary

The red fox (*Vulpes vulpes*) is one of those creatures so common that people rarely give any thought to it. However, the red fox plays an important and unique role in ecosystems across the world. In contrast to the other species in this book, the red fox has a very healthy population size and is actually driving the extinction of other species. Red foxes are highly effective predators and excel in a wide range of ecosystems. To understand extinction, one must look at both sides of the problem, and the red fox is a perfect example of the flip side of extinction.

Red fox. "Foxy Eyes" by normalityrelief, CC BY-SA 2.0

Physical Characteristics

The red fox is a slender **canid**, and is known for its red or yellowish-red coat. The species is also known to have characteristic white fur on its underside, black boots, and a white-tipped tail. Two rare color morphs, cross, and silver, also exist. The cross has yellowish to grayish-brown fur and a black cross on its back. The silver fox is known to have a silver to black body. In general, adult red foxes are known to be between 38.4 and 41.3 in. in length and 9 to 13 lbs. in weight (Huebner 2004). There is also a small degree of sexual dimorphism within the species in which the males are slightly larger than the females, specifically in their cranial shape and size (Hartová-Nentvichová et al. 2010).

Figure 1. Red Fox in wild habitat. Take notice of the yellowish-red fur, white ventral fur, and black boots. "Eastern American Red Fox (*Vulpes vulpes* ssp. *fulvus*) observed in Algonquin Provincial Park, Ontario on January 2017." by Joanne Redwood, CC0 1.0.

Population & Habitat

The exact number of red foxes is unknown because of their broad distribution around the world. Red foxes are extremely abundant, with populations ranging across all of Europe and large portions of Asia. North American populations stretching across most of the eastern contiguous United States and all of Canada and Alaska, as well as populations in Australia and Tasmania (Hoffmann and Sillero-Zubiri 2016). In total, their range covers almost 70 million km2, making them the widest-distributed members of the order carnivora in the world (Hoffmann and Sillero-Zubiri 2016). European populations of red foxes are natural residents of the area (Hoffmann and Sillero-Zubiri 2016), but North American populations are a mix of residents and introduced individuals brought in for fox hunting in the 17th century (Statham et. al. 2012), and Australian and Tasmanian populations are entirely introduced (Hoffmann and Sillero-Zubiri 2016). The few places that this species is not found in are Iceland, the Arctic Islands, parts of Siberia, most of Africa, and Central/South America. This vast population range can be seen in figure 2 below. It is also worth noting that the species has been extirpated in the Republic of Korea due to their population control policies (Canid Specialist Group n.d.). Based on historical data, we can expect the red fox to continue to expand north and east in the future (Allen and Sargeant 1993).

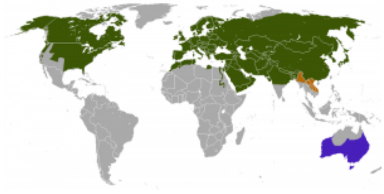

Figure 2. Red fox range, where green = native, purple = introduced, orange = presence uncertain. "Red fox (*Vulpes vulpes*) range map" by Zoologist, CC BY-SA 3.0

For most of the year, the red fox can be found in conifer woods with their ideal habitat changing throughout the year depending on the weather. Altitude also has an effect on where this species lives. Lower altitudes are popular between the warm and cold seasons, and throughout other months, the higher altitudes are preferred (Cagnacci et al. 2010). The red fox prefers to construct its dens out of sand or gravel substrates and sometimes has been known to utilize and enlarge existing woodchuck or badger dens (Vertebrate Collection – The Department of Biology, n.d.).

Food

From a most basic standpoint, like most mammals, the red fox needs shelter, water, and food. In terms of food, the red fox is mostly nocturnal, its most active periods being dawn and dusk. The red fox is flexible in its diet and is known to consume other mammals, birds, fish, reptiles, invertebrates, and plants. In southern Wisconsin for example, its most popular prey are cottontail rabbits (Vertebrate Collection – The Department of Biology, n.d.). Additionally, red foxes have been expanding into the Arctic due to expanded food resources and greater habitability due to climate change. This is of unique concern due to the red fox's competition with the Arctic fox (Elmhagen et al. 2018).

Figure 3. Red fox hunting. "Red fox with nutria, Tivoli-Manzolino oasis, Italy." by Stefano Bettini, CC BY 2.0

Reproduction

The red fox is monogamous for life when it comes to reproducing, and male-female pairs generally form at the start of the winter, in December. Females go into heat shortly after that once per year, in January or February for one through six days. Each litter has between two and ten kits, with a gestation period that averages fifty-three days. After a period of ten months, the kits become sexually mature roughly in time for next winter's mating season; for unknown reasons, the males disperse more than twice as widely as the females once they mature (Huebner 2004).

Age/Sex Ratios

Based on a survey done on red foxes hunted in the Victoria region for Australia, it was found that of the 317 foxes killed, 54% were under the age of 1 year, 71% were under the age of 2, only 4% of animals were over the age of four, and no individuals were beyond 7 years of age. When this data was extrapolated, it compared very similarly to data from Europe (Coman 1988). A similar study in Japan that studied a sample of naturally found fox carcasses located in a museum had some minor differences in their study. In this second study, 6 percent of individuals were 5 years or older and they also found a slight bias to male foxes with a ratio of .587 (Takeuchi and Koganezawa 1994). The slightly older average in fox ages in the Japanese study is likely due to a lack of hunting in the region.

Relation to Human Culture

Red foxes have been adjacent to human society in certain areas for virtually all of modern history; in Europe, for instance, red foxes have occupied their current range for more than 40,000 years with little change or variation (Teacher et al. 2011). This is of particular interest because it is highly unusual for any species to occupy a virtually unchanged range for such a long timespan with little population changes or genetic variation. In Europe, at least, our distant ancestors interacted with the red fox in much the same way that we do today (Teacher et al. 2011).

Since red foxes have a very high population in Europe, some issues have arisen in the culture as a whole. The red fox is known to prey on lambs, which is not favorable for farmers who are trying to breed. Instead of trying to control the population of red foxes, the farmers keep the lambs in the barn for some time after birth to protect them from these potential predators (Baker e .al. 2008). This “solution” is not only creating more work for the farmers but also only temporarily fixing a larger problem with a small and simple solution.

Fox hunting has long been a fixture of western society, which prompted European colonists to introduce foxes into areas they were colonizing purely to create populations that they could hunt (Statham et. al. 2012, Saunders et. al. 2010). In some cases, this has had disastrous effects on the local ecosystem, such as the populations introduced to Australia, an area where local prey animals are not at all adapted to dealing with foxes (Kinnear et. al. 2002).

Invasiveness & Impact on Other Species

As a mesopredator and an extremely widespread invasive species, the red fox has a far-ranging effect on ecosystems, other species, economies, and societies. These effects range from incurred costs from livestock loss on farmers to species extirpation. As a result of these impacts, it is important to understand the red fox and to know how to handle red fox invasions. Additionally, it is important to contextualize this information both historically and sociologically.

Economically, the red fox has been known to incur financial losses on farmers and harm ecosystems that provide valuable services to society. In Australia, a country in which the red fox has become invasive and harmful, the species causes $227.5 million in annual losses due to threatening livestock and general detriments on ecosystems (PestSmart 2011). Furthermore, in Britain's lush lowlands, red foxes frequently prey on livestock and cause economic damages to farmers as well (Baker et al. 2006).

As mentioned previously, red foxes are highly populous predators, which means that they have notable effects on prey animals in the ecosystems they occupy. In environments where they are native, red foxes can integrate well as natural predators without over-predating native prey animals, though they can be a nuisance by eating livestock (Baker et al. 2006), as mentioned previously. However, red foxes' large populations and efficient hunting techniques make them disastrously invasive in areas where they are introduced (Saunders et al. 2010). As discussed earlier in the chapter, red foxes were introduced to Australia in the 1870s for fox hunting; however, the foxes rapidly expanded far outside their initial range and began preying on native species, and have since caused major damage to these species' populations beyond normal expected levels of predation (Saunders et al. 2010).

In more recent years, red fox populations have remained high in mainland Australia, but they have been kept largely under control by competition with dingoes. This phenomenon is known as mesopredator suppression and is an event that takes place when a top predator such as the dingo reduces the activity of a predator such as the red fox through its abundance in overlapping territorial regions (Letnic et al. 2011). They are spread across all parts of the Australian mainland except desert regions (Letnic et al. 2011). In 2010, red foxes were spotted on the island of Tasmania, but a 2015 study, calculated from sighting and hunting data, determined that there were likely no significant populations on the island and they were close to extirpation from Tasmania (Caley et al. 2015).

The arctic fox (*Vulpes logapus*), is yet another species threatened by the expanding territory of the red fox. The Arctic fox is consistently outcompeted by the red fox, which limits its range. On the other hand, the red fox's range in the Arctic is limited only by food availability and climate (Elmhagen et al. 2018). This trend started in the twentieth century and is only speeding up with increasingly rapid climate change (Gallant et al. 2019). According to siting observation data from the Toolik Field Station in Alaska, they have seen an increase in Red Fox sightings over the past fifteen years. Their data can be seen below in figure 4 (Toolik Field Station Environmental Data Center 2021). This concerning trend will be of increasing importance as we continue to battle climate change on planet earth.

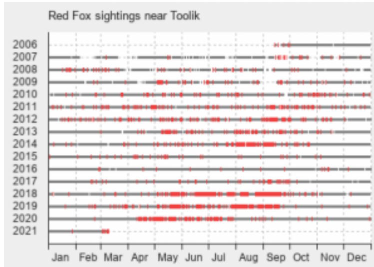

Figure 4. Chart depicting Red fox sightings in the Toolik Area. Red markings depict sightings whereas the grey bars depict observation periods. "Red fox sightings near Toolik" by Toolik Field Station Environmental Data Center, by permission.

Red foxes' harmful effects on prey populations have prompted researchers to recommend management policies that involve reducing the foxes' population in order to allow prey to recover: for example, a team in California modeled fox predation and determined that reducing their population would allow for major recovery of native Californian waterbirds, while researchers working in Tasmania found that the gradual reduction of fox populations on the island led to recovery and expansion by many medium-sized prey animal species (Harding et. al 2002, Kinnear et. al. 2002).

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20. The Keystone of the Tundra: Preemptively Protecting the Arctic Fox

Tristan Andrew, Chase Beausoleil, Alex Davidson, and Ciara Moroney

Abstract

What can we learn from threats facing the arctic fox (*Vulpes lagopus)* to prevent future endangerment of species worldwide? The arctic fox is a **keystone species** who provides various ecosystem services that both maintain the health and prevent the collapse of the tundra. Therefore, preventing its endangerment would simultaneously conserve local environments and other arctic species. After conducting interviews and analyzing many scientific sources, we organized threats facing this species into three categories: food availability, predation, and viable geographic range. This chapter explores the importance of understanding threats to the arctic fox and how it can help other keystone species.

Figure 1. Arctic Fox (Vulpes lapogus). "[Vulpes lagopus](#) in Iceland" by [Jonatan Pie](#), [CC0 1.0](#)

Background

The arctic fox (Figure 1) resides primarily in Canada, Scandinavia, Iceland, and Greenland (Angerbjörn & Tannerfeldt, 2014). It is a small species with a white or blue/gray coat in the winter and a tan or cream coat in the summer. The color change of the fur coat is to help camouflage the fox with its environment, aiding in protection from predators and ease in catching prey. The diet of the arctic fox mainly consists of lemmings and leftover seal carcasses abandoned by polar bears on the arctic sea ice (Angerbjörn et al., 1999).

The arctic fox is being severely impacted by climate change in numerous ways, including decreased food supply and habitat loss. Although the arctic fox is not currently officially classified as endangered, it does not mean the threats it is facing should not be taken seriously (S. Ámundason, personal communication, November 10, 2020). The arctic fox's primary role in the arctic ecosystem is as an **ecosystem engineer**, which means its presence greatly impacts and influences the health of the entire ecosystem. The arctic fox fixes nitrogen in the ground around its den, promoting the growth of arctic shrubbery and other vegetation, which provides a source of food for both the arctic fox and many other species in the tundra (Gharajehdaghipour et al., 2016). The endangerment of the arctic fox would alter the entire ecosystem, with one effect being the reduced vegetation present and subsequently reduced food availability for primary consumers in the **tundra** (Graae et al., 2004). The investigation of the threats the arctic fox is facing could spread awareness of the importance of keystone species in all ecosystems and the long-term impacts of its endangerment across arctic **biomes**. Countries and organizations could be motivated to research threats and design precautionary conservation programs for keystone species that are not on the brink of extinction yet, but whose survival is critical for conserving complex ecosystems.

Our Research Process

In order to conduct research on the arctic fox for this project, we primarily performed an analysis of **scientific literature**. We gathered a large body of various scientific sources that we were able to use to learn about the different facets of the issue at hand. We were then able to synthesize these ideas to layout our research in a manner conducive to our project. At the beginning of our research process, we planned to identify climate change as the primary threat to the species because it catalyzes many of the threats to this species. However, throughout our research we realized this would be an almost insurmountable threat to address, so we turned to categorizing the large threats into three sections: food availability, predation, and viable geographic range. These sections better allowed us to analyze the issues and critically consider solutions that could be proposed.

In addition to scientific sources, we reached out to several experts in our field and were fortunate enough to conduct interviews with two: John Bockstoce (author) and Sæmundur Ámundason (Arctic Fox Centre Manager). These interviews helped us continue our research and investigate new topics that we had not considered before, such as researching the adaptability of the arctic fox species to climate changes in the past and searching for information on how increased human presence in the arctic tundra due to rising global temperatures is threatening the arctic fox.

Viable Geographic Range

Climate change is an overarching threat to not only the arctic fox but all species around the world. Containing the impacts of climate change proves to be a rather challenging task but understanding its complex effects in arctic environments is critical to planning conservation efforts in the future. One major way in which this is affecting the arctic is through habitat loss. While there are many facets to this issue, the primary problem comes from the northward movement of the **boreal forest** (Figure 2). As temperatures continue to increase in the arctic, the boreal forest expands further into the tundra and therefore into arctic fox territory. The warmer climate of the boreal forest is not able to provide a suitable environment in which the arctic fox could survive (Elmhagen et al., 2015). Because of this, the expanding northward movement of the boreal forest reducing the size of the arctic tundra is subsequently decreasing and compressing the **geographic range** of the arctic fox (Chapin, 2007).

Another contributing factor to the habitat loss for the arctic fox is a resident of the boreal forest, the red fox (*Vulpes vulpes)*. The red fox is a species that would not be able to survive in the tundra region normally, but climate change has allowed for the red fox to move into the tundra. As will be expanded upon later, the red fox creates competition with the arctic fox for many resources, food being a primary one. In addition, the red fox also competes with the arctic fox for den space. (Rudzinski et al., 1982). The decrease in den occupancy of the arctic fox is detrimental to the population as the fox has less protection from predators and is discouraged from reproducing (Rodnikova et al., 2011).

A final facet that is decreasing the geographic range of the arctic fox is sea ice depletion. With the constantly increasing global temperatures, arctic sea ice has been melting at a rapid rate that continues to grow. Sea ice is an important aspect of the arctic fox's habitat as it allows the arctic fox uses to traverse the tundra region which allows for higher biodiversity and population spread within the species (Roth, 2003; Geffen et al., 2007). Additionally, the arctic fox uses the sea ice for hunting purposes, gaining access to the animal carcasses left on the sea ice by polar bears and other arctic predators (Greenpeace International, 2019). Without sea ice, the arctic fox's habitat size would be greatly restricted. Overall, the distribution range of the arctic fox is decreasing and will continue to decrease unless actions are taken to combat it.

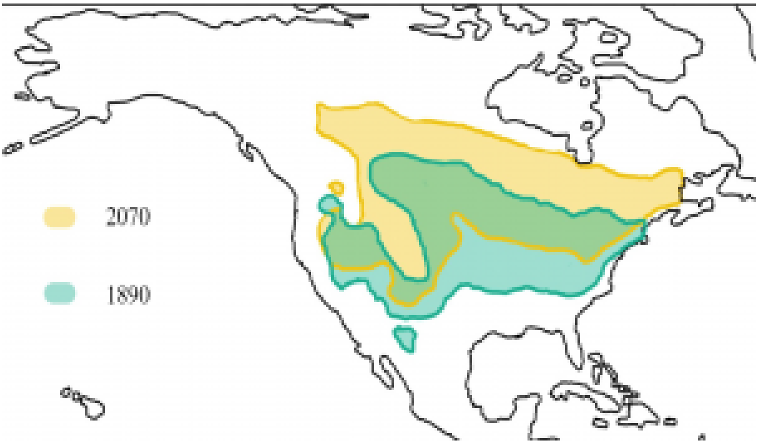

Figure 2. Prairie climate expansion forcing the northward expansion of the boreal forest zone, an uninhabitable climate for the arctic fox, by 2070. Map by chapter authors, based on figures from [Krotz, 2013](#).

Predation

As previously mentioned, the red fox proves to be a large threat to the arctic fox. Although the red fox is in the same species group as the arctic fox, these two animals are vastly different. For the two species to coexist, there must be a harsh environment or low ecosystem productivity to counteract the dominance of the red fox. As a result of the warmer winters and increased food availability, the red fox has been able to expand in numbers and geographic range as the changing environment and expansion of the boreal forest is providing suitable habitat for the red fox (Figure 3) (Post et al., 2009). The reason for recent expansion into the tundra is because the red fox has a higher energy burden than that of the arctic fox (Gallant et al., 2020). This means that the red fox requires more energy to sustain its predatory lifestyle, and when the winters are warmer less of that energy needed for hunting is used for keeping warm. This allows extra energy for the species to work on expanding its geographic reach and reproducing. This expansion of the red has proved to be detrimental to the arctic fox.

One of the main problems is the fact that the red fox is a host for parasites such as sarcoptic mange and fox tapeworm, as well as contagious and lethal diseases like arctic rabies (Norén et al., 2017). The introduction of these parasites to the species brings forward new and unfamiliar diseases, which could potentially be fatal. Furthermore, the two foxes vary in size, with the red fox reaching weights twice as high, while also reaching lengths up to 70% larger than that of the arctic fox (Gallant et al., 2012). Therefore, the red fox proves to be a new predator in the already scarce tundra. This addition of a new predator adds to the strain the arctic fox is experiencing because it is being hunted more frequently and the young foxes have a more difficult time surviving into adulthood. The red fox also brings with it increased competition for food and resources, forcing the arctic fox to retreat to higher altitudes on the mountain tundra where the red fox has more difficulty surviving (Elmhagen et al., 2002). This competition for food is caused by the diet overlap of the two species. Although the two species have a large variation in their diets, their food-niche tends to overlap during most summers, leaning towards lemmings, voles, and similar small species. On top of that, the red fox needs much more food and terrain to sustain itself (Gallant et al., 2012). The arctic fox consumes lemmings more frequently than red foxes do, but with the diet overlap, the decrease in the lemming population poses a threat to the arctic fox's food availability (Elmhagen et al., 2002). Overall, the introduction of the red fox to the tundra is providing new predation and competition for the arctic fox, which could be harmful to the population moving forward.

Figure 3. Expansion of the red fox, a substantial source of predation and competition for the arctic fox, by 2080. Map by chapter authors, based on figures from Simmons, 2008.

Food Availability

Lemmus amurensis, more commonly known as the lemming, is the primary food source for the arctic fox and as a result, **population cycles** of the arctic fox are strongly affected by **microtine** rodent populations (lemmings and voles *(Mus cypriacus*); Roth, 2003). The lemming follows a persistent 4-year population cycle, meaning every four years the lemming population will spike and then decrease again for the next few years (Archibald, 2019). This is believed to result from the interaction of **intrinsic** factors and **extrinsic** factors (Archibald, 2019). Therefore, during these times, harvest records imply that the local arctic fox population also cycles regularly and dramatically (Roth, 2003). During the lows in these cycles, arctic fox reproductive success is low, with them waiting until the peak year in the cycle, where there is a more plentiful food source, to reproduce (Ims et al., 2017). When the lemming population is down, the arctic fox turns to marine resources. While it was found that there is technically an abundance of marine resources available to the arctic fox, there is also steeper competition for the resources, leading the arctic fox to also hunt seal pups (*Pusa hispida*) as a source of food (Roth, 2003). However, this poses a problem because not only are arctic foxes hunting seal pups. Polar bears (*Ursus maritimus*) and the red fox are as well, leading to increased predation of seal pups. The arctic fox does, however, feed on the left-over seal carcasses that polar bears and red foxes leave (Bockstoce, 2018), but a depletion in sea ice is diminishing this access to food.

During a study from 2004-2005 in the arctic ocean, it was found that the amount of **perennial sea ice** in the East Arctic Ocean decreased nearly one half with an abrupt reduction of 0.95*106 km2 (Nghiem et al., 2006). This is very detrimental to the diet and the safety of the arctic fox, as they use this sea ice, especially in the eastern arctic ocean, to travel, find leftover carcasses, and escape predators. The detrimental effects cause changes in the behavior of arctic foxes and occasionally lead to them becoming nomadic in winters when local foods are scarce (Roth, 2003). This means that instead of staying near their dens in the winter they wander around, returning to den sites in the spring for breeding (Roth, 2003). This causes unusual breeding habits, which can decrease the population of the fox.

Breeding in the spring poses a threat to the newborn pups as they can become prey for other scavengers and predators in the arctic. The large litters of pups do not allow for much protection as it is hard for one mother to protect up to 14 pups at once. Therefore, larger birds such as ravens (*Corvus corax*) pose a threat to the pups. This is on rare occasions; however, ravens are opportunistic predators and scavengers (Chevallier et al., 2016), meaning they will feed on anything that is already dead or anything they think they could takedown. Therefore, on some occasions, they attempt to take on small arctic fox pups. However, when they are not doing this, they tend to feed mostly on small rodents and complement their diet with scavenged items, such as carrion left by larger predators (Chevallier et al., 2016). Not only do ravens pose a threat to the reproduction of the arctic fox, but their remarkably similar diet to the arctic fox means there is even less food during the non-peak years of the rodents. This decreases the arctic fox's food availability, which then causes the foxes being affected to become nomadic. As discussed, nomadic foxes pose a further threat to the species because this behavior leaves the foxes and their pups vulnerable to larger predators. When in packs, arctic foxes can take down larger prey and retain greater chances of warding off predators. However, when these foxes refrain from staying in groups due to decreased food and resource availability, they further endanger themselves (Elmhagen, 2014).

Threats Combined

Our research proved that the threats being faced by the arctic fox are vast and seemingly endless. Every minor problem is intertwined with a dozen other problems that form one large web of issues harming the species (Figure 4). A simple decrease in the lemming population or the gradual expansion of the red fox population would individually not be enough to drive the species to endangerment or extinction. However, part of the species' plight is that there is no one threat acting alone. Climate change has initiated the gradual warming of the world's climate, which is slowly allowing the boreal forest to creep into territory previously occupied by the arctic tundra (Chapin et al., 2010). As mentioned, the boreal forest is not a suitable habitat for the arctic fox to survive in. However, it is a particularly good habitat for the red fox to survive in. So, with the growth and expansion of the boreal forest, the red fox is provided with better means to invade previously occupied arctic fox territory (Elmhagen, 2015). Additionally, the lemming is reliant upon a frigid climate to survive, so climate change causing an increase in temperature worldwide is severely harming the ability of the lemming to thrive (Ims et al., 2011). This is one driver of the decrease in lemming populations, but so is the arrival of the red fox, which also preys on lemmings as a source of food. Historically, in years when the lemming population was low, arctic foxes would not reproduce as much as they would in a different year that contained larger lemming populations, and this still holds true (Roth, 2003). So, this decrease in food access is causing the arctic fox to reproduce more slowly while also being hunted by predators at a higher rate, causing intensified stress on their population. All the issues outlined, and more, are compounding one another and working together to create the perfect environment for a substantial decline in the arctic fox population to be observed in the not-so-distant future, which could subsequently prove to be detrimental to the arctic ecosystem.

Despite the inexhaustible amount of information, we discovered describing serious threats to the arctic fox that support the concept of the eventual endangerment and potential extinction of the species, author John Bockstoce, who is one of the experts in the field interviewed by the team, still believes that the arctic fox species is not and will not be susceptible to extinction, or even endangerment. Bockstoce claims that the arctic fox is too adaptable to its surrounding environment to be largely negatively affected by any major changes in temperature or arctic sea ice distribution. Furthermore, the author claims that because arctic foxes are scavengers, the species will consume almost anything, therefore discrediting the threat of reducing food sources as lemming populations and food availability on arctic sea ice decrease (J. Bockstoce, personal communication, November 6, 2020). However, an article by author Fuentes-Hurtado opposes Bockstoce's claim while supporting the findings our team found in our research.

Fuentes-Hurtado's article claims that arctic foxes are more sensitive to changing climate than previously assumed. An "ecological niche modeling approach" was used to study the arctic fox population at the end of the **Pleistocene epoch**, which was a time also known as the "Great Ice Age" due to many periods of glaciations throughout this time (Fuentes-Hurtado et al., 2016). By studying the ancient DNA of this fox species in Europe that dated back to the Pleistocene epoch, this study concluded that the arctic fox species became extinct in Europe directly following this epoch as global climates changed, and temperatures rose. The Pleistocene epoch consisted of vast tundra environments and expansive sea ice. When temperatures rose as the epoch ended, this tundra environment that the fox thrives in decreased in size, threatening the species, and eventually causing its extinction in Europe. Understanding that arctic foxes became extinct in a specific geographic location in the past is especially important because the extinction identifies the possibility of changing global temperatures threatening the arctic fox species to the point of extinction. Luckily in the past, the species was able to survive the end of the Pleistocene epoch due to their large geographic range in which populations of the species remained in favorable conditions and survived (Fuentes-Hurtado et al., 2016). However, if global temperatures today continue to rise and all viable habitats for this species continue to decrease as tundra biomes shrink, the species may yet again be threatened by extinction, although this time more absolute.

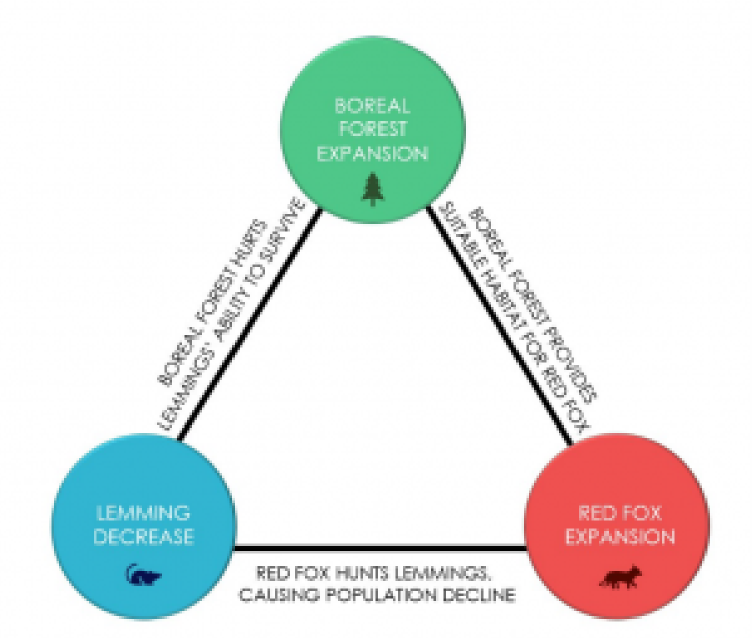

Figure 4. Demonstration of the interconnected nature of the issues the arctic fox is facing. By chapter's authors.

Beyond the Arctic Fox

The safety of keystone species is integral to the health and development of every ecosystem on this planet. They provide a multitude of ecosystem services ranging from contributing to **nutrient cycling**, maintaining a healthy balance in the populations of some species, dispersing seeds of local vegetation, being a food source for other species, and more (Graae et al., 2004). Any threat to a keystone species such as the arctic fox is a threat to the future of the ecosystem itself. However, this plight is not unique to the arctic fox. From sea otters dealing with changes in aquatic conditions to bees facing massive habitat loss, keystone species around the world are beginning to face worsening conditions that can be attributed to climate change, human interference, and more. Right now, many of these problems are in stages that can be remedied with the right education and resources. However, if they are pushed to the back burner until the species is facing permanent extinction, it will likely be too late for any real changes to be made. Through bringing awareness to the current struggle of the arctic fox and continuing to research and monitor the development of their state, perhaps people around the globe will begin to take notice of other species who are facing smaller problems that can be acknowledged now before it is too late.

What Now?

The most efficient way to help the arctic fox would be to fix climate change, as that plays a hand in the formation of all the threats outlined. However, that is relatively impractical and not something that can be fixed immediately. That being said, there are actions that can be taken at various levels to help improve conditions for the fox as much as possible. In the field, one thing that can help the species is controlling the expansion and growth of the red fox population in areas where it interacts with the arctic fox (Larm et al., 2018). Studies conducted have proven that supplementing the red fox's food source with outside food can take pressure off the arctic fox as a source of prey, and even light hunting of the species to decrease numbers can have positive impacts on the arctic fox species (Larm et al., 2018). Similarly, lemming populations can be fostered to help the recovery of their abundance in nature. By making sure that the wildlife the lemmings depend on for food is healthy and abundant, the population can be helped to regrow itself to where it was. The supplementing of the red fox's diet will also help the lemming population because the red fox will not need to eat as many lemmings and that will decrease the competition the red fox is facing for food. These changes in the field are not immediate, but they can produce positive short-term results, that if maintained can continue to support the arctic fox population well into the future.

On a more global scale, educating the public is one of the most important actions that can be taken. This likely will not have a direct or immediate impact on the arctic fox species but can foster long-term change that will be beneficial both for the arctic fox and many other species. Studies have shown that members of the general public who are more educated on issues of endangerment and climate change are substantially more likely to make changes in their day-to-day life that will positively impact wildlife and are also more likely to support larger legislative actions that can help the wildlife around them (S. Ámundason, personal communication, November 10, 2020). Overall, continuing to monitor the arctic fox population will prove to be important, as this can show the effectiveness of strategies being implemented to help with their refinement both for the arctic fox and other keystone species around the world in the future.

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Appendix 1 and 2.

Appendix 1. Number of Bird Fatalities at Lit and Dark Windows and Reduction of Fatalities after Accounting for Variances

Situation	Number of Fatalities		Reduction
	Lit Windows	Dark Windows	
All Lights On	613	0	88%
All Lights Off	0	46	
Mixed Lighting	684	146	83%

Appendix 2. Recorded Number of Fatalities per Year and Corresponding Light Index

Year	Number of Bird Collisions	Light Index
1997	374	10.5
1998	237	9.8
1999	296	9
2000	393	7.9