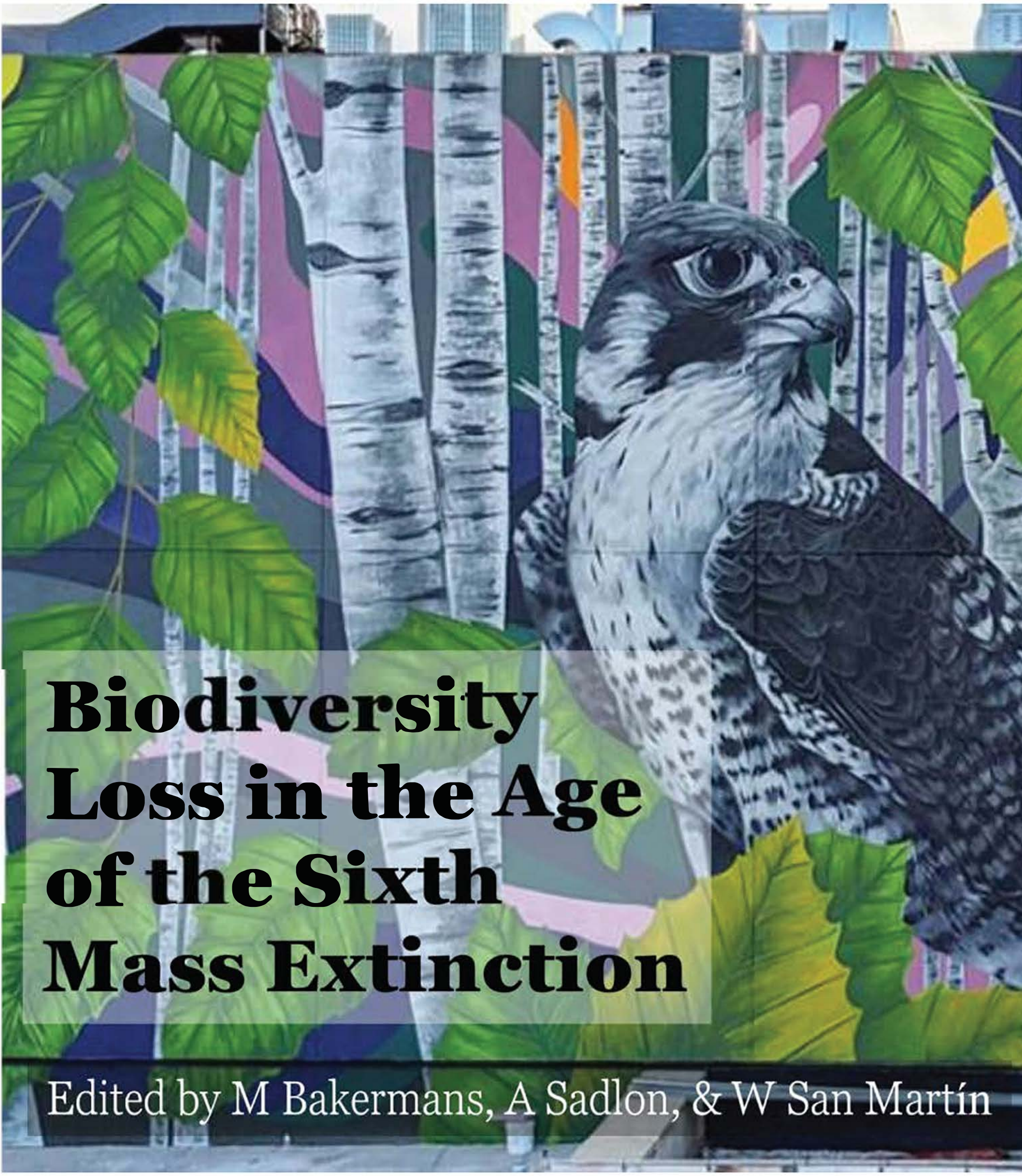

Biodiversity Loss in the Age of the Sixth Mass Extinction

Edited by M Bakermans, A Sadlon, & W San Martín

Cover image: Peregrine falcon mural in Worcester, MA by artist Sophy Tuttle. Photo by Troy Gipps/MassWildlife, with Permission.

Biodiversity Loss in the Age of the Sixth Mass Extinction

Edited by *MARJA BAKERMANS; AMELIA SADLON; AND WILLIAM SAN MARTIN*

WORCESTER, MA, USA

Biodiversity Loss in the Age of the Sixth Mass Extinction was co-authored by undergraduate students at Worcester Polytechnic Institute while exploring issues of extinction and conservation of biodiversity. The book highlights key interests and insights of current students in their quest to create a better world.

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Copyright

Gratitude and Acknowledgments

MARJA BAKERMANS AND WILLIAM SAN MARTIN

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The students who embraced the challenge, conducted research, and wrote the following chapters are the 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.

Meet the Editors

Marja Bakermans, Associate Teaching Professor, Department of Integrative and Global Studies and Biological Sciences, shown here with an eastern whip-poor-will, is a conservation biologist researching drivers of bird population declines. Marja applies a similar hands-on approach with her students in using open pedagogies and co-creating OERs on climate change, extinctions, and biodiversity. For more information about her and colleagues' work on centering diversity, inclusion, and open practices in OERs, please see their report here: https://qubeshub.org/publications/3493/1

Amelia Sadlon is a student of Marja Bakermans and will be graduating in 2023 from Worcester Polytechnic Institute with a B.S. in Biology and Biotechnology and a minor in Environmental and Sustainability Studies. She recently dove into the subjects of wildlife biology and conservation, with a prior focus on medical biology and biotechnology, but hopes to combine these many interests in her future career. (Further details of her academic and professional experiences can be found at https://www.linkedin.com/in/amelia-sadlon-5a24351a4.) Besides enjoying writing in her free time, she also enjoys hiking, baking, reading, and photography.

William San Martín is an Assistant Professor of Global Environmental Science, Technology, and Governance in the Department of Integrative and Global Studies at WPI and a Research Fellow at the Earth System Governance Project, Utrecht University. William is an interdisciplinary scholar of earth-systems sciences and global environmental governance trained in history, international politics & relations, and science & technology studies (STS). His work focuses on international development, science-policy interface, and socio-environmental (in)justices in the Global South. Born and raised in Chile, William has vast experience in policy-oriented research and building collaborations with international organizations and communities. You can follow him on Twitter here https://twitter.com/wssanmartin or learn more about his work here www.linkedin.com/in/wsanmart

Introduction

Biodiversity Loss in the Age of the Sixth Mass Extinction is the second book of a series of open educational resources (OER) created by undergraduate students at Worcester Polytechnic Institute, a private research university in Worcester, Massachusetts (USA). The series is devoted to examining the causes and consequences of global biodiversity loss and species extinction.

Like our first book, *Extinction Stories*, this book combines the final projects conducted by students in the *Great Problem Seminar* (GPS) *Extinctions* course during the Fall of 2021 and the *Biodiversity* course in the Spring of 2022.

WPI's 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 includes Marja Bakermans and William San Martín. Dr. Marja Bakermans is a wildlife field biologist with expertise in conservation biology, migratory bird species, and the impacts of anthropogenic disturbances in North and South America. Dr. William San Martín is a historian and a science & technology studies scholar working at the intersection of earth-systems sciences and governance with expertise in environmental policy, environmental justice, and sustainable development in the Global South.

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 assess and address issues at the intersections of species extinctions, environmental conservation, and sustainable development. Through different perspectives, these chapters examine the role and impacts of human activities, invasive species, and conservation efforts across the globe.

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. *Biodiversity Loss in the Age of the Sixth Mass Extinction* reminds us that our current ecological crises require new ways of thinking about undergraduate research, education, and their place in public debates.

We hope this volume contributes to expanding discussions about how our current socio-environmental challenges are entangled on local and planetary trajectories and that our ability to educate future generations from various disciplines and perspectives will be essential for our shared future on Earth.

PART I

HUMAN DRIVERS

Drivers of species extinctions are complex and compromise multiple spatial and temporal scales. For most of our last century, human actions have become a driving force of ecological change and a leading cause of the extinction of many species. This section explores various human drivers, from the role of microplastics, waste, overfishing, and industrial agriculture to the impacts of palm oil production, climate change-driven wildfires and monocultures on ecosystems and species.

"*Entangled green sea turtle*" *by* *NOAA Marine Debris Program*, *licensed under* *Public Domain*

1. Orangutan Outcasts: How Palm Oil is Destroying the Ecosystem

LILY BEALS; AARON BRADY; LUKAS GANDRAS; NORAH GILES; AND JAI PATEL

Abstract

"Orangutan-bornean" by Julielangford *is licensed under* CC BY 3.0.

The Orangutan Outcast project analyzes Bornean Orangutan (*Pongo pygmaeus*) habitat destruction in Malaysia caused by **deforestation**for **palm oil** plantations. The global demand for palm oil and the local support it provides economies has caused Malaysia's production of palm oil to be at an all-time high. In turn, this causes more natural habitats to be destroyed. This problem is being addressed by conservation efforts and the implementation of sustainable palm oil.

The Problem

The palm oil industry and the demand for products with palm oil are causing Bornean Orangutan habitat destruction in Malaysia, negatively impacting orangutans and their ecosystem. Consumers and local economies are driving the palm oil industry, for which large amounts of forest need to be cleared for agricultural use.

Figure 1. Oil palm plantation. "Oilpalm" by T. R. Shankar Raman is licensed under CC BY-SA 4.0

An example of what the forest is transformed into can be seen in Figure 1. The figure shows a **monoculture** of **oil palm** plants that have replaced the orangutans natural habitat. Deforestation for a monoculture of plants results in **habitat fragmentation** and destruction, which puts Bornean Orangutans in danger. Using research dating from the 1960s to the present, Project Orangutan Outcasts aims to analyze the drivers of the palm oil industry, look at how orangutans are affected, and investigate possible solutions.

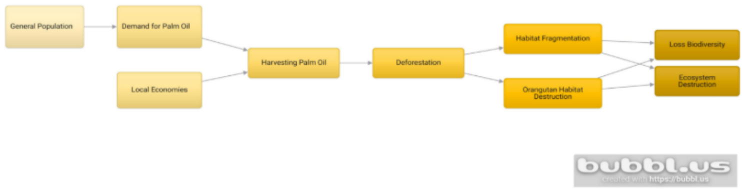

Figure 2. Map assessment of the project. Created by chapter authors.

Based on the findings of our project, we organized it according to the map assessment in Figure 2. Using that assessment, our research questions for this project were: What drives the palm oil industry? What is the connection between local communities and harvesting palm oil? How does deforestation affect orangutan populations and their behavior? How is the decline in orangutan populations being addressed? What is being done to fix deforestation in Malaysia?

Orangutan Background Information

Orangutans are the only great ape found outside of Africa and are uniquely adapted to the tropical forests of Asia. They could originally be found as far north as Vietnam and China but have slowly been shifting southward over the last two million years as a result of natural **climate change** (Galdikas, 2009). There are currently three recognized species of orangutan: Bornean, Sumatran (*Pongo abelii*), and Tapanuli (*Pongo tapanuliens*), all of which are considered critically endangered on the IUCN Red List (Ancrenaz et al., 2016). This project focuses on the Bornean Orangutan, which can be found on Borneo, Asia's largest island. Over the last century, orangutan populations have declined drastically due to forest loss and hunting, among other factors. A 2004 estimate puts the Bornean population at about 105,000 individuals. This number is a massive decline from nearly 300,000 in 1973 and is projected to drop below 50,000 by 2025 (Wich et al., 2012). The habitat destruction of these creatures can be attributed to deforestation for the purpose of palm oil production. Deforestation is driven by economic stability and consumer demand for palm oil, which is often present in industrial foods such as bread, pastries, and cereal, personal care products including soaps, lipsticks, and liquid detergents, and biodiesels (Kusumaningtyas & van Gelder, 2017). If their habitat continues to be destroyed at this rate, the Bornean Orangutan will be put at even further risk of extinction.

Global Palm Oil Industry

The causes of the large demand for palm oil are twofold—the wide use of it by businesses and a lack of knowledge by consumers. Since there are so many different uses of palm oil, a large variety of businesses have it in their products.

Figure 3. All the companies that use palm oil in their products. "[A Few of the Thousand of Products with Palm Oil]" by Margherita Ragg is in the [Public Domain, CC0]

As seen in Figure 3, numerous different companies use palm oil in their products, ranging from Charmin to Taco Bell. Despite these businesses having completely different products, they all reap large profits from their products with palm oil. They are not going to go out of their way to inform the public what the effects of harvesting palm oil are; rather they hide the fact that the product contains palm oil and change its name to one of its other hundred different names. The most common name for palm oil is vegetable oil, however, not all vegetable oil is palm oil (Ragg, 2019). This trick by businesses builds on the general lack of knowledge by consumers. People are not aware of which products contain palm oil and the environmental effects of palm oil. Manufacturers are not clearly labeling products that contain palm oil, which misleads consumers trying to avoid palm oil. In addition, people not aware of the problem will continue to look past it because they do not know what palm oil is and what products contain it. With these complications, consumers lose motivation to buy products with no palm oil and give up looking for opportunities (Sundaraja, 2021). Since there is a severe lack of knowledge on the consumption of palm oil and businesses' wide use of palm oil, the demand from around the world has not lessened. One of the leading countries supplying palm oil for this demand is Malaysia. In fact, Malaysia is the world's second leading producer of palm oil. In 1961 Malaysia produced a total of 0.108 million tonnes of palm oil. This number increased to 19.919 million tonnes in 2017 (Ritchie & Roser, 2021). This proves that the production of palm oil in Malaysia has been increasing drastically for the past 50 years. Not only is palm oil production growing but its growth has been exponential since 1961. The growth of production is due to the increased demand and importance of the industry to local economies.

Local Palm Oil Industry

Local communities play an impactful role in the palm oil economy and orangutan populations. Both palm oil harvesting and consumers' demand for palm oil must decrease for the ecosystem to recuperate and prosper. Through studies that have been conducted around local communities in Malaysia, we have been able to identify the perspectives of these citizens. A considerable sum of individuals are aware of the threats that orangutans face due to **anthropogenic** activities such as palm oil harvesting; however, only a small portion are aware of the decline in orangutan population (Taylor et al., 2016). In areas that are undeveloped, communities depend more on palm oil in order to maintain a stable economy. Without large businesses and corporations, they must rely on hand harvesting products like palm oil, which they can trade for money or other products. In areas such as Malaysia, palm oil accounts for 5-10% of the entire regional economy, and the local industry provides tens of thousands of jobs for citizens in these nations (Taylor et al., 2016). Governments focus heavily on keeping their unemployment rates as low as possible. As a result of this, the Malaysian government has no intention of passing laws to prevent the deforestation of palm oil trees. Overall, consumers' knowledge about palm oil harvesting is increasing; however, more people need to become aware of the effects it has on orangutans. The nations where Bornean Orangutans live are incredibly dependent on palm oil, which creates a sense of turmoil between conservation efforts to stop the harvesting and the people dependent on the local economy. In addition to these countries having limited resources to enhance their economic state, the palm oil industry is driven by consumers around the world.

Deforestation

In the early 1930s, South Asia introduced palm oil farms run by families which are known as smallholders. About 90% of all palm oil exports rely on palm oil smallholders in Malaysia and Indonesia (Pakiam, 2021). The palm oil extraction factories must be in proximity to the smallholders to ensure the quality of the crops containing palm oil is ripe. Since these locations are the main habitat for orangutans, harvesting palm oil decreases the quality and quantity of the land. Orangutans in Borneo have lost up to 90% of their habitat in the last 10 years as a result of deforestation relating to palm oil (Dziama & Batista, 2017). Figure 4 is a map showing deforestation on the island of Borneo.

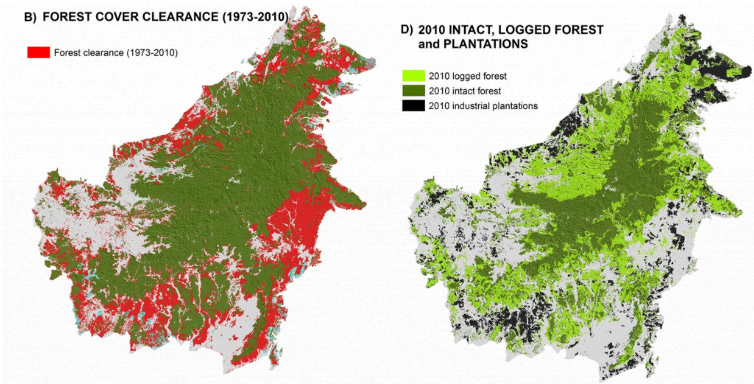

Figure 4. Maps of deforestation. "[Figure 3](#)" by [Gaveau et al. 2014](#) is licensed under [CC BY 4.0](#)

The left image shows forest clearance in Borneo from 1973-2010 with the cleared forest in red, and the right image shows an intact forest in dark green, logged forest in lime green, and industrial plantations in black in 2010. As seen in the maps, much of the land has been lost to deforestation and logging. Human-modified landscapes for the production of palm oil cause deep-rooted problems in the natural forest ecosystem.

Deforestation in Relation to Orangutans

The large amount of deforestation required to produce palm oil and support the local economy has significant consequences for the environment. As deforestation occurs, fragments of forests are broken up into segments. Plants and animals in the region start to decline in number, which affects other species since the forest is one interconnected ecosystem. While orangutans can survive in oil palm agricultural fields, modeling found they have a strong preference for living in their natural forested habitat (Seaman, 2019). Diverse forested lands are replaced by monocultural oil palm trees, destroying the ecosystem through unsustainable practices like **slash and burn** and illegal logging. A study analyzing conservation methods for orangutans found that greater amounts of deforestation result in less orangutan migration and a lower orangutan population (Seaman, 2021). A lower orangutan migration could negatively impact the spread of genetic material between different groups of orangutans. This is extremely problematic for the population because the lower the spread of genetic material, the more similar individuals are to each other. This lowers their chances of survival because diseases are more likely to spread throughout the entire orangutan population. Habitat fragmentation, or the separation of habitat because of deforestation or roads, can severely limit orangutan movement (Sloan, 2018), and, therefore, the flow of genetic material. The loss of orangutan habitats induces **edge effects** between humans and wild Bornean orangutans; this can increase the spread of zoonotic diseases between orangutans and humans. Habitat fragmentation can also seriously impact orangutan populations. A comparison of two aerial surveys, looking for orangutan nests, found that Bornean Orangutan populations declined by about 30% in fragmented regions of Kulamba in Sabah, Malaysia, and about 15% in fragmented regions of Tabin in Sabah, Malaysia over the course of fifteen years. This decline is far greater than in areas with non-fragmented forest (Simon, 2019). As more and more deforestation occurs in Malaysia, valuable stretches of orangutan habitat are lost or fragmented, negatively impacting orangutans and the entire ecosystem.

Methods

In order to create a bridge between identifying our research questions and potentially developing a solution, we developed a method section as follows in order to analyze our steps thus far. Going back and analyzing the research we conducted is crucial to ensure it is reliable and clearly represents the problem we are facing.

While conducting our research we selected relevant sources covering a variety of viewpoints to analyze. We wanted to research this problem from the perspectives of local community members, workers in the palm oil industry, conservationists, and other stakeholders, as this allowed us to fully assess the problem. If only one viewpoint was analyzed, then our research would be biased and one-sided. Our goal while critically analyzing the sources was to connect specific ideas across sources and to develop the thesis. During the research, we found journals, videos, expert and local knowledge, modeling, and survey data. These sources provided us with information on the production of palm oil in relation to the global and local economy, local community knowledge on palm oil and orangutans, palm oil plantation data from 1960-2016, deforestation due to palm oil, and changes in orangutan population and behavior as a result of habitat destruction. With this information, our team kept a narrow focus on the palm oil industry impacting local economies, deforesting surrounding land, and destroying the habitat of orangutans. When writing this paper, we first conducted initial research that helped to define the problem and we were able to narrow down our focus into specific pathways (shown in Figure 3). Once we established these pathways, we developed new research questions by continually reflecting as a team on the research. The collaboration of our team led to the development of our research, ultimately allowing us to form our thesis and analyze our solutions. We intend to inform the general public to raise awareness of this problem.

Solutions

Orangutan Conservation

An important step in solving this complex issue is orangutan conservation. Conservation efforts that are currently taking place include habitat protection, as well as helping orangutans in more specific ways. Efforts have been made to protect forested lands; for example, the Sarawak Government in Malaysia has set aside more than 200,000 hectares (ha) of forest for orangutans to live in (Pandong et. al., 2019). Government protection of forested areas not only reduces illegal logging and hunting but also prevents habitat fragmentation. These factors play a major role in the decline of orangutan populations, so this protection is a very important step in the right direction. Sustainable logging practices and agricultural management can also make a difference; although rarely utilized, these methods allow natural resources to be used without further degrading forest habitats or harming orangutans (Wilson et al., 2014). It has been proven that "orangutan density can recover with forest regeneration and the retention of fruit-bearing trees" (Wich et al., 2008). In other words, orangutans can greatly benefit from mature forests with diverse food and fruit sources. They are also less likely to wander into oil palm plantations or other agricultural fields because their basic needs are met. Mother orangutans tend to enter palm oil plantations with their young in order to find food; adult orangutans are often met by palm oil plantation workers and are beaten and often killed in order to stop stealing crops. Young orangutans who are left motherless are frequently sold into the illegal wildlife trade to be further sold or kept as pets. When these animals are rescued by professionals, they often go to orangutan care facilities (Chua et al., 2018). Adult orangutans are sometimes taken in by these care facilities. Once there, orangutans are rehabilitated with as little human contact as possible to go back to the wild in government-protected areas (Chua et al., 2018).

Sometimes these orangutans enter land that is not protected by the government. In these areas, it is more likely that poachers will hunt the orangutans, as no one is there to stop them from doing so. Some of the responses from local communities have been to form anti-poaching patrols to lessen the number of orangutan deaths. This also provides the local community with occupations because this issue is prevalent near their homes where palm oil plantations and agricultural areas are located. When anti-poaching patrols are combined with authorities such as conservation partners and law enforcement officers, they can arrest and prosecute illegal poachers, thus lessening orangutan mortality (Pandong et. al., 2019). Implementing these anti-poaching patrols can help retain and increase Bornean orangutan populations immensely. Conservation efforts such as orangutan rehabilitation, forest protection, and anti-poaching patrols can help the orangutan population recover.

Sustainable Palm Oil

In addition to conservation efforts in Malaysia, the palm oil industry has been making efforts to help address the problem. The solution the industry has been implementing is sustainable palm oil. The Roundtable on Sustainable Palm Oil (RSPO) is an organization that aims to promote the global and local benefits of using sustainable palm oil, in contrast to regular palm oil. The main difference between the two deals with the techniques used in harvesting palm oil. Unsustainable palm oil is obtained by the vast clearing of land by means of logging (Gaveau, 2014). This destroys the forests, which in turn destroys the natural habitat of the orangutans. In contrast, sustainable palm oil is more eco-friendly as it involves clearing much less land. In addition, obtaining an RSPO certification is a promise to the consumers that the production practices of palm oil are entirely sustainable. In 2021, 3.36 million hectares of palm oil production area were RSPO certified. This land area was responsible for producing approximately 18.7% of the global palm oil (RSPO, 2018). The 3.36 million hectares of sustainable palm oil make up about a sixth of the total agricultural palm oil area in the world. The approximate percentage of contribution to global palm oil production shows that there is not a decline in yield using sustainable practices because the palm oil produced is still proportional to the area used. In simple terms, the production of palm oil is unaffected by harvesters changing to sustainable practices.

Sustainable palm oil production is monitored throughout the production chain. The monitoring of sustainable palm oil is in the preliminary stages as sustainable palm oil is still a new practice. As of today, there are two ways to determine if palm oil is produced sustainably or not. The first method is chromatography (Ramli, 2020). Once the palm oil is separated, the people monitoring the production can find different chemicals in one type of palm oil compared to the other. This allows the producers to ensure that the palm oil was sustainably harvested. The other method involves examining isotopes. This method provides a geographic location where the palm oil was grown. Specific isotopes are found in different areas of Malaysia, so when the manufacturers are examining the palm oil they can see where it was produced (Ramli, 2020). Both methods are expensive and time-consuming for the producers, so there is more research currently being done to produce the best technique to monitor the production of sustainable palm oil.

One of the largest importers of palm oil is the European Union (EU). The parliament declared that the EU would eliminate all imports of palm oil by the year 2020 (Oosterveer, 2015). However, with the widespread use of palm oil, this was not practical. Acknowledging this, they postponed the date, and today all imported palm oil in the EU is sustainable palm oil. They only import trustworthy certified palm oil to guarantee that their goal of palm oil is sustainable (Ramli, 2020). They are global leaders and, along with other non-governmental organizations, are influencing other nations to take similar actions. The EU committing to only import sustainable palm oil will set precedent for other nations. This in turn will influence non-sustainable palm oil harvesters to practice sustainable techniques, because if they do not, they will not be able to export their goods as buyers are only consuming sustainable palm oil. Smallholders and regional efforts to switch to sustainable palm oil are a large step forwards in preventing further land destruction.

Conclusion

Individuals may feel far removed from the problem, as it is occurring far away from many of us. However, it is important for consumers to recognize how the choices they make contribute to making the problem worse or helping to fix the issue. While it can be difficult to find information on palm oil in products since it is labeled in products under many different names, taking the time to research is key to fixing the solution. Finding palm oil alternatives and using sustainable palm oil whenever possible is also very important. To aid consumers in finding alternate products with sustainable palm oil (or no palm oil), apps have been created that will provide the consumer with information about the product. Not many people are aware of this problem and the devastating effects palm oil can have on wildlife, so sharing information is an important way to help fix the problem. In addition to these methods of helping, people can also donate to orangutan conservation centers or participate in many of the "adopt an orangutan" programs if they are interested. The "adopt an orangutan" programs allow an individual to donate money in support of a particular orangutan at a care center, helping the orangutan and allowing the individual to feel more involved in conservation efforts than they would otherwise (Swarna Nantha et al., 2008). The best thing you can do as an individual and a consumer is to be aware of the problem, change your purchasing habits to limit unsustainable palm oil practices, and spread awareness of the issue.

Acknowledgments

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2. Plastic is Forever. Dolphins are Not: Microplastics and Dolphins in Florida

MARISSA BURATI; JULIANA FOX; SONA HANSLIA; AND NICOLAS VALENTINO

Abstract

The research was conducted in order to determine the cause of the ingestion of microplastics by the bottlenose dolphin (*Tursiops truncatus*) in Sarasota and Tampa Bay, Florida. Wastewater released from wastewater treatment facilities was looked at specifically, in addition to the number of particles that remained after treatment to determine that 18.5 million particles are released into Tampa Bay every day. Wastewater regulations were also examined to understand the effect they would have on microplastic release.

"Bottlenose Dolphin" by naturalengland is licensed under CC BY-NC-ND 2.0.

The Problem

The bottlenose dolphin is a flagship species, which means that this species can indicate the well-being of entire marine ecosystems. As a flagship species, monitoring the population's health and behaviors can provide information about health risks that may occur in the future for humans (Battaglia et al., 2020). Microplastics may enter aquatic ecosystems in a variety of ways, and one of the most prominent methods is through the discharge of wastewater into the environment. The bottlenose dolphin could experience the negative effects of these microplastics, which would be devastating for the ecosystem. A 2019 study found that 71% of the sampled dolphins in Sarasota, Florida were found to have at least one phthalate metabolite in their urine, which are toxic chemicals found on microplastics (Hart et al., 2018). These phthalates are known to impair reproductive systems and endocrine systems in mammals (Hart et al., 2018). This report aims to determine why microplastics and the toxic chemicals attached to them are found in dolphins and dolphin urine, with our research focusing on Sarasota Bay and Tampa Bay from the years 2010 to 2019.

Figure 1. *A map of Florida. “Florida Political Map” by Kwh is licensed under* CC BY-SA 2.5

Background

The Bottlenose Dolphin Species

The bottlenose dolphin (Figure 2) is one of the most common cetaceans, with a population distribution that spans globally through oceans and inshore regions (Wells et al., 2019). Bottlenose dolphins are primarily found in warm coastal waters and tend to congregate near shore (FAO Fisheries, n.d.). This contributes to the issue of plastic ingestion because they are often found close to areas with high human populations. Areas with higher human populations have been shown to have higher concentrations of microplastics in their surrounding waters (Gola et al., 2021).

Their complexion ranges from a partial black and white color to light grey with a pink stomach (FAO Fisheries, n.d.). The bottlenose dolphin can also be distinguished by the "dark stripe from eye to flipper, and a faint dorsal cape on the back" (FAO Fisheries, n.d.). As of 2008, the bottlenose dolphin was determined to be on the IUCN Red List of Threatened Species, under the category of least concern (Wells et al., 2019). Today, the bottlenose dolphin remains under the status of least concern on the red list, most likely because of the lack of known total population trends due to the global distribution of the species.

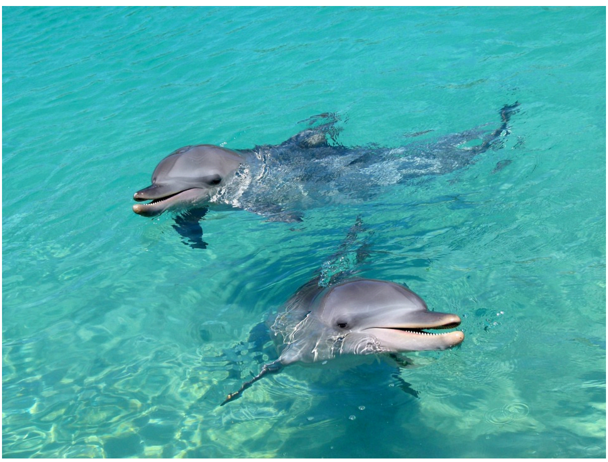

Figure 2. *Two bottlenose dolphins swimming by the shore. "Animal Aquatic Water Playful Marine Dolphin" is licensed under Public Domain, CC0*

The bottlenose dolphin is an important member of the marine ecosystem. Dolphins are apex predators (Hart et al., 2018), with a wide variety of prey including "fish, squid, and crustaceans" (FAO Fisheries, n.d.). A healthy dolphin population keeps the fish, squid, and crustacean populations in check, which allows for a balanced ecosystem. If the population of the bottlenose dolphin is negatively impacted, the ecosystem is disrupted. The prey of this species of dolphin will briefly increase in population due to the decline in dolphins; however, this will lead to a lack of resources to support the prey population. This will result in the prey population declining.

This boom and bust cycle will continue until its population can be kept in check (WWF, n.d.). The fishing industry in Florida is vital to Florida's economy, and the decrease in fish, squid, and crustacean populations could be devastating to the ocean economy in this area (FDACS, n.d.).

Microplastics and Their Effect

"Microplastic" is a term used to describe tiny plastic fragments, from the size range of 0.3 mm to 5 mm. There is an emerging high concentration of microplastics in oceans, which poses a threat to marine ecosystems (Andrady, 2011). Ingestion of microplastics has been documented in many different species, and as the plastics degrade to be even smaller, the risk of ingestion increases (Law & Thompson, 2014). Chemicals and contaminants are transferred to marine environments via microplastics, as seen with the phthalates transferred to the bottlenose dolphin's environment (Deng et al., 2020). Phthalates are chemicals used to increase the flexibility of plastic products. They also act as emulsion agents and are used in cosmetic products. These chemicals have been seen to disrupt hormones, locomotor activity, and metabolism in crustaceans and fish. The impact of phthalates on dolphins is not known, but other chemicals that could be carried by microplastics (ex. polychlorinated biphenyls) have been shown to impact cetaceans negatively (Hart et al., 2018). The presence of phthalates in bottlenose dolphin urine in Florida strongly suggests the ingestion, and, therefore, the existence of microplastic pollution in Tampa Bay and Sarasota Bay waters (Hart et al., 2018). This is further supported by the presence of microplastics in the gastrointestinal tract of stranded bottlenose dolphins in South Carolina, indicating that the bottlenose dolphin has ingested microplastics (Battaglia et al., 2020). By determining the potential causes of microplastics in marine ecosystems, further regulations can be put in place to prevent microplastic pollution.

Even without carrying toxic chemicals, the ingestion of microplastics can be dangerous. High levels of microplastics can clog digestive tracts, which can put individuals at risk of death by starvation (Hernandez-Gonzalez et al., 2018). Microplastics can enter the food web through accidental consumption by prey (Nelms et al., 2019). This contaminated prey is then eaten in large amounts by predators, leading to more and more microplastics being ingested by each trophic level in a process called biomagnification (Florence Sullivan). Therefore, high-level trophic species like the bottlenose dolphin are at risk of ingesting a large number of microplastics. In turtles, the leaching of toxins, specifically phthalates, on microplastics could disrupt their endocrine systems, affecting their hormones (Hart et al., 2018). Although this has not been proven in dolphins, we can speculate that microplastics would have a similar effect on dolphins.

Wastewater and Regulation

Wastewater is defined as any used water. It includes substances such as human waste, food scraps, oils, soaps, and chemicals. In homes, wastewater includes water from sinks, showers, toilets, washing machines, and dishwashers (USGS, n.d.). Microplastics can enter wastewater in a variety of ways, including laundry. When textiles are washed, they can release synthetic fibers composed of plastic, which allows for microplastics to enter wastewater daily (Galvão et al., 2020). Wastewater also includes storm runoff, which is more water that needs to be treated. There are harmful substances that wash off roads, parking lots, and rooftops that can harm our rivers and lakes and the species that live in them (USGS, n.d.). Microplastics could also enter wastewater in this way, as stormwater carries them into wastewater (Liu et al., 2019). Wastewater is treated at facilities in order to remove solids and release the remaining water back into the environment (USGS, n.d.). Currently, if a wastewater facility is authorized to discharge surface water, they are subject to the requirements set in place by the National Pollutant Discharge Elimination System (NPDES). All other wastewater treatments and discharges are regulated by the Environmental Protection Agency (EPA) under the Clean Water Act (U.S. EPA, n.d.). Such regulations are further examined in this paper.

Methodology

By sorting through peer-reviewed publications we were able to gather data on the amount of wastewater being produced by wastewater facilities near Sarasota Bay and Tampa Bay daily. We found the approximate number of microplastic particles in Tampa Bay from a study done in 2019. We then multiplied the measurement, in gallons, of wastewater being released by these facilities by the average number of microfibers remaining in wastewater after being treated. This was in order to calculate the number of microfibers released every day by wastewater facilities. Along with this calculation, we created a timeline of wastewater regulation from 2010 to 2019, to understand the effect regulations imposed had on microplastic levels and what is currently being done to prevent this pollution. Regulations were found in government documents and reports. To gather additional information we spoke to two scientists, Florence Sullivan and Anna Sosa, both of whom provided information on how to conduct our research along with answering our many research questions. Florence Sullivan, a research analyst stationed in Hawaii, was able to explain how, by looking into the anatomy of the dolphin and the effects of biomagnification, we can discover in the long run how the population is affected. Whereas Ana Sosa, a Ph.D. student in the Marine Estuarine Environmental Science program, was able to explain what microplastics are and more specifically how they pose a threat to aquatic life. Based on their expertise in researching marine life and behaviors, in addition to the harmful effects of microplastics, they broadened the scope of our research and portrayed different perspectives of the problem overall.

Results

Figure 3. *A compiled timeline of regulations spanning from 2010 to 2019. Created by chapter authors.*

Our research found that 18.5 million microplastic particles are released every day into Tampa Bay from wastewater treatment facilities alone. As of 2019, there were about 4 billion microplastic particles found in Tampa Bay (McEachern et al., 2019). There are an estimated 24.4 trillion microplastic particles in the upper ocean (Isobe et al., 2019). This shows that microplastic pollution is a global issue, and the number of plastics in Tampa Bay is not abnormally high. We found that, in 2015, the Leah Schad Memorial Ocean Outfall Program was implemented in order to prohibit the construction of new domestic wastewater ocean outfalls and expansion of existing outfalls, which helped limit overall wastewater production in Florida (Florida Statutes, 2021). Additionally, in 2017, revised methods of analyzing wastewater for chemical and biological components were implemented (U.S. EPA., 2021), which allowed for better data to be collected. The timeline created shows that the regulations being imposed do not adequately prevent the release of microplastics into the water, as 18.5 million particles are still released every day.

Conclusion

The findings of our research show the extent of microplastic pollution in Tampa Bay, and how microplastics may enter the water. Wastewater release has been proven to be a large contributor to pollution. Fibers from clothes enter wastewater when washed, and other plastics may end up in wastewater due to runoff. Those microplastics can enter the food chain once released into the water, and work their way up to the highest trophic levels through a process called biomagnification. The ingestion of microplastics could be harmful to the dolphin population and other species due to the toxins that the plastics carry and the possible inability to digest large amounts of microplastics. Past regulations were compiled and analyzed to understand how regulations would combat microplastic release. Although more regulations are being implemented through the years, microplastics are still being released into the water at an alarming rate.

The ecosystem would be disrupted if the bottlenose dolphin populations go down. The prey of these populations could go up which could have negative effects on the environment. The decrease in dolphin populations could suggest that many other marine populations are also experiencing the effects of microplastics. This assumption can be made due to the bottlenose dolphin's role as a flagship species. If marine species are decreasing in population in Tampa Bay, it could negatively impact the fishing industry in Florida, especially small towns that may rely entirely on fishing for their economy. Our research shows that the best way to prevent microplastics from entering the ocean is to reduce the overall use of plastic. If fewer microplastics are in the ocean, marine life can thrive without the threat of ingestion and toxins.

What Now?

Solution I: Microfiber Filter for Washing Machines

Microplastics enter wastewater through laundry since many materials in clothing contain plastic fibers. These fibers were the most common type of plastic found in Tampa Bay; this is likely due to microfibers left in wastewater after it was treated and released (McEachern et al., 2019). A way to prevent microfibers from ending up in wastewater is to install filters for washing machines (Ana Sosa, personal communication, December 10, 2021). A product that already exists is a filter named Lint Luv-r which claims to be efficient at capturing microfibers from laundry. This filter is separate from the washing machine, and the water passes through the filter after a wash. Another product is the Coraball, a ball that collects microplastics when thrown into the laundry. These products have been shown to be effective in collecting microplastics. In order to increase the use of products like these, consumers need to be made aware of the microplastic pollution issue. If enough of the population begins to use products like these, the rate of microplastic release will decrease greatly.

A related solution could be a government mandate that requires filters to be included in washing machines, but this may take a while to be put in place (Ana Sosa, personal communication, December 10, 2021). A consumer-led solution is likely the best for a short-term plan.

Solution II: Federal Ban of Harmful Chemicals Used in Products

Phthalates and polychlorinated biphenyls have both been found to be harmful to mammals and fish, and these toxins are ingested by animals when they ingest microplastics. Polychlorinated biphenyls are classified as highly toxic chemicals that were discontinued but still are present in the environment. Similar government action could prove to be necessary for phthalates. Phthalates are used in many plastic products and are associated with hormone and reproductive issues. This could prove to be harmful to many populations. Humans could also be affected by these chemicals, as they are transported by microplastics in waterways. A ban on phthalates would not prevent the issues that arise from ingesting microplastics, but discontinuing the use of these toxins could decrease negative effects.

Solution III: Reduced Plastic Use Incentives for Companies and Consumers

The most effective method of reducing the number of microplastics being released into Tampa Bay would be reducing the amount of plastic being used in general. A large reduction in plastic consumption would be a major cultural shift, so this reduction would have to be imposed gradually. This could begin by providing companies with incentives to switch from producing plastic-based materials to eco-friendly materials. This could be done by convincing the consumer to prefer eco-friendly options. Companies will cater to the needs of consumers, so if there is a push for green products, companies will have to comply (Ana Sosa, personal communication, December 10, 2021). However, many companies tend to "green-wash" materials, which are labeled as eco-friendly, but they are mass-produced so they ultimately hurt the environment (Florence Sullivan, personal communication, December 3, 2021). This is something to be cautious of when considering this solution.

Future Steps for Researchers

The exact impacts of ingestion of phthalates and microplastics on bottlenose dolphins are unknown. Individual populations of dolphins should be monitored in areas of high microplastic population; this would allow for researchers to determine if there are negative effects, and how extreme these effects are. More research also needs to be done on the sources of microplastics and how likely they are to carry toxins. Not much is known about the number of microplastics released globally.

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3. The Effects of Waste on Organisms Around the World

AINSLEY CLARK; TAYLOR FIORE; GRACE PHILLIPS; AND JAKE MAGLIO

Abstract

Overconsumption and consumerism cause high waste production that directly impacts the health of humans and ecosystems alike. This paper describes mismanaged wastes' negative effects on environments across the globe. If not slowed, the production and accumulation of waste that is currently happening will endanger many species and ecosystems, but this paper offers solutions people like the reader can implement, no matter their current involvement, in handling their waste responsibly.

Introduction

Many people in the U.S. do not think about what happens to their garbage once they throw it away. It simply seems to disappear into the trash can, or perhaps the recycling bin. This luxury of living in a developed nation separates us from the people, species, and environments that all suffer from the consequences of our waste. The reality is that waste, when mismanaged, poses an existential threat to the existence of all life on the planet, and trash is mismanaged far too often. Of the roughly 300 million tonnes of plastic produced every year, over 60 million end up in unsanitary landfills or the open environment (Meijer et al., 2021; UN Environment Programme, n.d.). Such blatant mismanagement allows trash to ravage populations of organisms, both human and nonhuman.

"Waste" is a large and complex problem. The amount of waste the world produces has been on the rise since the 1900s, and it is likely to continue rising unless we change our behaviors and the systems that facilitate them (Stromberg, 2013). There are many types of "waste", including rubble produced by construction and demolition sites, hazardous materials like pesticides, lightbulbs, and batteries, e-waste like broken computers, and **municipal** solid waste (MSW) (US EPA a, 2021; U.S. EPA b, 2021). Our paper focuses on MSW because most people create and interact with it on a daily basis, but it is important to note that the other types of waste all have effects on the environment, as well. Unfortunately, such effects are too far outside of our scope to cover, but MSW on its own has deep, troubling impacts on the world. MSW causes habitat destruction and can pollute the environments surrounding it, which can lead to the death of organisms and impact the reproductive abilities of species (Australian Government, 2019; Cornell Waste Management Institute, 1991; Williams et al., 2019; U.S. EPA, 2002).

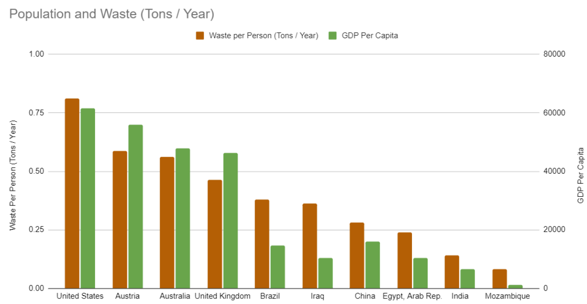

Figure 1. *A graph showing the relationship between a nation's GDP per capita and the waste they produce annually per year (Kaza et al. 2018, License: [CC BY 3.0 IGO](#)).*

Every year 2.01 billion tonnes of municipal solid waste are produced globally, but the burden of trash creation is not distributed evenly across the world (Kaza et al., 2018; What a Waste, n.d.). People in wealthy nations with higher GDP per capita, like the U.S., tend to make more MSW than people in poorer nations, as seen in Figure 1. This is likely because richer people can afford to participate in a buy-more, waste-more lifestyle, hopping on fast fashion or decorating trends, buying the newest smart device even when their older ones still work, or letting some of the food they purchase go to waste (Chancel, 2021; Cooper, 2018; van de Bos Verma et al., 2020). Under a capitalist system, it benefits companies for every person to purchase as much as possible, so they attempt to market things as the hottest trend and make people feel their old things are obsolete, even when they are not. Additionally, as populations grow, there are more people who must use more materials in order to survive, creating more waste (U.S. EPA, 2002). Ultimately, using additional objects creates additional waste, which is a problem, because waste harms organisms around the world, from the smallest plankton to the most powerful human.

In this report, we intend to demonstrate how household waste affects global ecosystems, local ecosystems, and human well-being, and propose solutions that citizens and politicians can initiate in order to remedy these problems. We will demonstrate that trash inside and outside of landfills can negatively affect the environment. Our research goals are to inquire how MSW is mismanaged and determine its impact on the environment and humans. We also aim to offer individual and systemic solutions that can help take steps towards solving this massive global issue of waste.

Methods

The first thing that we did was narrow down the scope of our project into something that we would be able to research. From past projects and general knowledge about the issues of the world, we decided to look into the effects MSW had around the globe. We started by reading building and maintenance regulations for landfills, which led us to read papers and articles about mismanaged landfills, and, subsequently, mismanaged waste. From there, we read studies and other research papers about the negative effects that mismanaged waste has on the environment. We then compiled all our research into a paper and drew conclusions about the effects that waste has on the environment. Finally, we suggest items for personal action and proposed legislative solutions that both aim to help alleviate the worldwide issue that is waste.

How Waste Becomes a Problem

The main underlying problem with waste is its mismanagement. The best case scenario for any piece of MSW is for it to end up in a sanitary landfill. In properly managed landfills, trash is physically contained, **leachate** is collected and treated, and methane, a potent greenhouse gas that is produced as a by-product of waste breakdown, is burned as an energy source. U.S. landfills that follow the proper legal guidelines are built in a layering system to protect against contaminants and properly process the products of decomposing waste. A dense, packed clay, topped with a high-density plastic liner makes up the lowest layer of a modern landfill, which prevents the contamination of groundwater under the landfill by leachate (Cifani, 2018). The second layer consists of a drainage system to collect contaminated liquids from decomposition and rain running through the landfill. The third layer is a system that collects the methane gas produced by landfills so that it can then be used as an energy source.

However, those U.S. regulations only apply to large landfills that receive more than 20 tons of solid waste per day (U.S. EPA, 2021). These large landfills are mandated to implement as much infrastructure as possible to handle waste, such as by collecting methane for fuel (U.S. EPA, 2021). Smaller landfills evade this regulation, but they still must monitor the groundwater around them to ensure no toxins are leaking out. Many countries in the developing world do not have such regulations, however, and likewise do not have government-maintained or even privately-owned landfills. Instead, unregulated dumps arise in cities, roadsides, waterways, and open land as people dispose of the trash they are producing in whatever ways they can (Garbage Challenges, 2021; Williams et al., 2019). In fact, about 93% of waste in low-income countries is disposed of this way, compared to 2% in developed countries (Williams et al., 2019).

While those in poor nations often have no choice but to mismanage their waste, those in wealthy nations sometimes do so even though they have access to proper systems. Where recycling systems are offered, well-meaning but misinformed people may participate in an activity known as “wish cycling,” throwing objects that belong in the trash into the recycling (Dance, 2018). This can strain the facilities that sort recycling and cause the value of the recyclable loads to diminish, decreasing the incentive for anyone to process and actually recycle them (Dance, 2018).

Figure 2. *People left municipal solid waste and abandoned a vehicle in this unregulated dump site in northern Oregon. Bureau of Land Management Oregon and Washington "Dump site and abandoned vehicle North Unit Canal in the Prineville area" by Bureau of Land Management Oregon and Washington is licensed under CC BY 2.0.*

Individuals may also mismanage waste by littering or otherwise illegally dumping their trash. This may result in the creation of impromptu, improperly managed dumps outside of national legislation (U.S. EPA Region 5, 1998). These dumping grounds often occur in abandoned buildings of all kinds and empty or infrequently used lots, alleys, and roadways (U.S. EPA Region 5, 1998). Rural roads and railways have a heightened risk of being a victim of illegal dumping (U.S. EPA Region 5, 1998). People most often dump trash illegally during the hours of the night into the early morning, in warmer months (U.S. EPA Region 5, 1998). This can encourage other people to dump more waste—including hazardous waste—in the same area, causing the unmaintained landfills to become larger (Dump Site, 2006).

From impoverished nations' inability to create waste management systems to landfills outside the law to wish cycling, trash is often improperly disposed of, which can have devastating effects on the surrounding ecosystems.

Environmental Impacts of Household Waste

When waste is mismanaged, it allows heavy metals, microplastics, and other pollutants to leak out into the open environment, causing serious issues for local and global ecosystems. Illegal junkyards, such as those mentioned above, can leach toxins and heavy metals, like cadmium, chromium, lead, copper, and zinc, into nearby soil, water, and plant life (Cornell Waste Management Institute, 1991; Sriuttha et al., 2017). This creates an unhealthy environment for both animals and plant life. It can also cause snails, prawns, fish, and frogs to consume heavy metals, which can then make their way up the food chain in a process called biomagnification (Beiras, 2018). Through biomagnification, toxins become more concentrated in the bodies of organisms at higher trophic levels, because energy is transferred inefficiently from trophic level to trophic level (Drouillard, 2008).

Toxins can become extremely dangerous at higher concentrations. For example, high concentrations of phenols, a toxin released by some waste, can affect the health and fertility of animals and plants exposed to it (Australian Government, 2919.; Cornell Waste Management Institute, 1991). Long-term exposure can cause low growth rates in plants, death, shortened lifespan, reproductive problems, changes in behavior, and lower fertility in animals (Australian Government, 2019). Phenols are very persistent in water, making their presence in leachates more concerning and dangerous for the environment affected (Australian Government, 2019).

Even when the waste makes it into a landfill, it can cause issues similar to those created by waste left in open environments. Uneaten food attracts many species to city landfills. Animals too often eat out of landfills and cause themselves harm by consuming food not meant for them (Seif et al., 2017).

In addition to causing direct harm to species by exposing them to harmful substances, waste, even when properly managed, can also cause change to environments themselves. 1.8 million acres of otherwise undeveloped land have been used for sanitary landfills in the U.S., and scientists estimate up to 300 species are lost for every hectare (about 2.47 acres) cleared (Vasarhelyi, 2021). Waste left in open environments can block drainage canals and gullies, increasing the chance of floods, which can also destroy habitats. This can then displace fish and other aquatic animals, spread water-borne diseases, and even carry the toxins the waste produces into environments further from the original mismanaged waste (Williams et al., 2019; U.S. EPA, 2002). If these floodwaters enter the ocean and carry the toxins there, they can cause additional harm to an environment that is already bearing the brunt of the effects of our trash.

Oceanic ecosystems are seriously harmed by contamination with MSW. The largest and most well-understood threat to marine life comes from oceanic plastic, 90% of which originates from land-based sources like mismanaged landfills (Williams et al., 2019). Once in the ocean, most of the plastic is pushed together by the ocean's **gyre** (Goldstein & Goodwin, 2013). Once there, it attracts barnacles and plankton who will latch onto the plastic waste and feed on it (Goldstein & Goodwin, 2013). Not only does this cause the barnacles and plankton to be feeding almost exclusively on plastic, but it also causes the plastic to break down faster, turning into microplastics – which are very small pieces of plastic (Goldstein & Goodwin, 2013). Microplastics are even more dangerous than macroplastics because microplastics are able to be inhaled through the gills of various sea creatures. Researchers have found that when inhaled, microplastics can stay in the body of those marine animals for several more weeks, as opposed to when they are simply ingested (Goldstein & Goodwin

2013). Microplastics also carry and attract toxins such as heavy metals, which will be inhaled or consumed along with the microplastics (Campanale et al., 2020). Additionally, since microplastics are much less dense than water, they sink to the bottom of the ocean and mix with the sediment, which can cause an increase in the death of coral reefs. However, it is extremely difficult to analyze and measure just how much of an effect these microplastics have on coral reefs without causing more damage to the coral reefs or the surrounding plant life (Tsang et al., 2017).

As dangerous as microplastics are, macroplastics are still a serious threat. Marine life can be harmed via entanglement in large pieces of plastic, which in some cases can lead to death if they are not freed (Campanale et al., 2020). Even if they evade death initially, young birds entangled in plastic have their agility impeded and growth constricted, which leads to a reduced quality of life and a greater chance of death. Marine life and seabirds will also mistakenly feed on small pieces of plastic from the ocean or landfills, thinking they are food (Campanale et al., 2020; Seif et al., 2017). This results in pseudo-satiation, a process wherein a creature dies of starvation with a full stomach as it exclusively feeds on plastic, which it cannot break down (Campanale et al., 2020; Green & Magin, 2019).

Figure 3. *This Laysan albatross died with copious amounts of plastic filling its stomach. "Laysan albatross plastic filled stomach" by Claire Facker,* NOAA *is licensed under* Public Domain.

Despite its devastating effects on the ecosystem, eliminating plastic production altogether would not be wise. Plastics provide cheap medical products, like syringes and IV bags, that can be easily disposed of to avoid cross-contamination between patients (North & Halden, 2013). Also, carbon polymers, molecules similar to plastics, have allowed for the development of synthesized tissues and prosthetics that would not have been possible without them (North & Halden, 2013). It would be unethical to eliminate these discoveries and reduce the quality of life of many people who utilize them. We call for a significant reduction of plastic production, especially of single-use plastics that end up as MSW, like those used as packaging for processed foods—not the elimination of plastics.

Human Impacts of Household Waste

As much as plastics have improved humans' lives, they also do a lot of damage to our health after they are disposed of. Humans across the globe can be harmed by microplastics and nanoplastics. These small particles of plastic often contain or **adsorb** toxic chemicals like flame retardants and heavy metals, which can then harm the human body if people inhale or eat the plastics (Campanale et al., 2020). This consumption is already occurring; Cox et al. found that there are about 0.44 microplastics in every gram of sugar intended for human consumption, 0.11 MPs/g of salt, 94.37 MPs/g of bottled water, and even 9.80 MPs in every m^3 of air (2019). If either eaten or inhaled, the particles can damage **epithelial cells** and **macrophages**, enter the bloodstream, and cause inflammation (Campanale et al., 2020). This can eventually lead to damage to systems throughout the human body, including the immune system, the respiratory system, and the digestive system (Campanale et al., 2020).

Humans around the world are experiencing the influx of microplastics into their daily lives, but those in poor nations are encountering significantly worse health and welfare issues. Approximately two billion people, mostly in developing nations, live in close proximity to trash because they do not have access to waste management, which poses a direct health hazard (CIWM & WasteAid UK, 2018). When one lives and works amongst trash, one has a much higher risk of becoming ill, commonly from cholera and other diseases contracted from human excrement. Discarded bundles of children's stools containing such pathogens can leak into their surroundings (Gower et al., 2020; Williams et al., 2019). The diseases can then be transmitted by flies to food and drink, which happens much more often when trash is adjacent to where people live and eat (Gower et al., 2020; Williams et al., 2019). Plastic containers and rubber tires hold water that mosquitoes—vectors of dengue, Zika, and other deadly viruses—preferentially use to breed. Other household waste in urban environments becomes shelter and food for rats and dogs, which are reservoirs for zoonotic diseases (Krystosik et al., 2020; Pepe et al., 2019). If people resort to burning the trash or if it catches fire spontaneously, which happens regularly in unregulated dumps, the fumes can lead to lung and eye irritation (Cogut, 2016; Gower et al., 2020). Altogether, household waste creates an incredibly unsanitary environment.

In low- and middle-income countries, trash also negatively impacts the livelihoods of farmers and fishers. Farmed cattle and goats may eat plastic when out foraging, causing the animal to experience pain and intestinal problems as well as depression, anorexia, lowered milk yield, and, eventually, death via starvation (Williams et al., 2019; Ramaswamy & Sharma, 2011). The loss of the milk and the animals themselves can have devastating consequences for the farmers, putting them under mental and financial strain (Ramaswamy & Sharma, 2011). Additionally, people who work in ocean-related tourism jobs, like those providing opportunities to engage with beaches or coral reefs, are negatively impacted by the trash in the ocean, as well as up to 820 million people whose livelihoods and food security depend upon marine fishing (Williams et al., 2019).

However, removing the trash dumped in poor communities is not as ethically simple as it seems. The trash creates an important societal niche for outcast and marginalized people, known as waste picking (CIWM & WasteAid UK, 2018). People transport, collect raw materials from, and fashion new resources out of trash, which is difficult, dangerous work that reduces the workers' lifespans, but it is work that they would not have had access to without the trash (CIWM & WasteAid UK, 2018; Williams et al., 2019). When implementing plans to support the environment, it is important to consider how it affects all people and species involved and create plans to support everyone through the transition.

Our waste also affects the global climate. Plastic production and end-of-life burning both create millions of tons of greenhouse gasses per year and organic waste breaks down into methane, a greenhouse gas about 30 times more potent than carbon dioxide, which will exacerbate the climate crisis if not captured (Gower et al., 2020; Micales & Skog, 1997; Williams et al., 2019; Varun et al., 2017). As the crisis continues, floods and fires will increase in frequency and ferocity, and humans around the world, especially those who are without the means to escape them, will suffer (Herring & Lindsey, 2020; United Nations, 2018). Trash harms humans, animals, and the world, and if we take no action to reduce waste production driven by high consumerism and improve our waste management systems, all of the above problems will only continue to worsen.

Potential Solutions and Conclusions

Waste production is proportional to the consumption of products; therefore, overconsumption creates exorbitant amounts of waste. When mismanaged, waste endangers species, imbalances ecosystems, and threatens human health and livelihoods. Even properly managed waste can have a negative impact on the environment surrounding it, and negative effects on the environment always find their way to impact humans negatively as well.

The problem may seem overwhelming, and one might feel paralyzed by fear of the future and unable to contribute. However, not all hope is lost; we can still take action to improve the situation.

One thing that everyone can do is to make a personal action list containing activities that can break down a big problem, like waste production, into smaller manageable things that anyone can do to help. Writing actions one wants to undertake on the list as they become apparent and regularly completing actions from the list will help one overcome indecision and demoralization in the face of such a great problem. We suggest that the reader's personal action list include some of the following items:

First, we suggest one takes note of the trash one accumulates. Paying attention can help one determine where cuts can be made, by buying items with less packaging or purchasing fewer items in general. Next, we encourage one to research and write down one's local rules for recycling. Avoid putting trash in the recycling; if an object is ambiguously recyclable, throw it out (Dance, 2018). Additionally, readers may engage in conversations about waste management and the importance of using what one has instead of buying more – regarding everything from food to clothes to toys to home decor – with friends or family. Furthermore, use more reusable bags and containers; that way one cuts down on the use and production of single-use plastics. The use of compostable one-time-use products, although it still creates waste, causes less harm to the environment than the use of disposable plastic ones, and entirely reusable objects typically create even less waste (Covey-Smith, n.d.). Similarly, before throwing something away, see if it can be repurposed. For example, one could try to repurpose one item from the trash every week or set another goal that is more obtainable for one's lifestyle. An old milk carton could be turned into a bird feeder, or an old shoe into a planter. In the same fashion, investing in a compost bin is a great way to help the environment. There are many indoor or outdoor options available for under $100. If one is unable to have a compost bin, it may be possible to send one's organic waste to an organic recycling facility.

Those are all examples of individual change, which is important and necessary. If everyone takes the mindset that their actions will not make a change, then no one will act and no change will occur. However, realistically, individual change cannot get much done in the face of the overwhelming issues the world is facing. Individuals must simultaneously be involved in calling for systemic change to tackle the root of this problem. For us in developed nations, this can start in ways like lobbying the local government for easier access to recycling bins across the city or seeking out citizen science projects that help trace waste streams or determine waste's effects on ecosystems (Anguiano, 2021; US EPA a, 2021; Green & Magin, 2019.). Additionally, we encourage you to write to your local and national representatives imploring them to work with the governments of less wealthy nations and provide money and technology for them to implement solid waste management systems, increase regulations on landfills of all sizes, and ensure that when MSW from your nation is exported to be processed elsewhere, the correct facilities are in place in its destination and the waste is being processed properly (Green & Magin, 2019).

It is important to remember that the problem of waste production, and even MSW production, is extremely complex and is contributed to by many factors that are outside of our control. For example, there is a proportional relationship between population size and waste production. However, there are decidedly few, and arguably no, ethical actions that can be taken to slow down or halt population growth. On the matter of ethics, those in developing nations where there are no landfills have created a certain societal niche called waste pickers. As mentioned previously, people will go out and pick up the waste that piles up in dumps around their towns for money. To simply remove the waste from these countries would be depriving many people of a job, which they need to support themselves. In order to remove the waste from these places, governments would have to work together to find replacement jobs for all of the waste pickers. Governments are not the only ones who have to make changes. Large companies create a large amount of waste, as they are the ones who design the packaging of their products (Alppm, 2019). Companies making eco-friendly changes in their packaging and production would reduce MSW production. However, this is most likely not going to happen without legislative or societal change that makes using environmentally-unfriendly packaging models unsustainable from a business's perspective, as the cost-effectiveness of plastic packaging currently helps increase companies' profit margins (Alppm, 2019). These factors introduce complicated ethical concerns to our environmental efforts and make it difficult to determine if and how personal and legislative actions improve the situation; however, to simply ignore them would be to allow the issue to continue getting worse.

It is important to remember that in the modern world, some amount of waste will inevitably be produced by human activities. There is no individual solution on how to solve the problem of waste; however, if everyone can make some reduction in the waste they produce, the world will be better off than if we leave things as they are.

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4. Death & Destruction: The Tragedy of the Atlantic Bluefin Tuna

JOHN PATTINSON; CALVIN THOMAS; AND DAVID VAN SICKLE

Abstract

Once a mighty apex predator that roamed the Atlantic Ocean in seemingly inexhaustible numbers, the Atlantic bluefin tuna (*Thunnus thynnus*) was nearly wiped out in a matter of years. The natural history of the bluefin will be further explored along with population size, status, and current conservation projects surrounding the species. Additionally, this chapter will discuss the species' ecological, cultural, and economic role in our society, both past and present. Atlantic bluefin tuna were once the apex predators of the sea, but have fallen into disarray due to overfishing and poor regulation. New 21st century conservation efforts hope to bring this once prosperous fish back into its former glory.

Figure 1. The Atlantic Bluefin Tuna just below the ocean's surface. Relative figure of the fish can be observed. "Regulations announced today will help Atlantic bluefin tuna (above) in the Gulf of Mexico and off Cape Hatteras." by NOAA is in the Public Domain.

Biology of the Atlantic Bluefin Tuna

Atlantic bluefin tuna have existed for thousands of years supplying countless Atlantic and Mediterranean coasts with food and resources. The Atlantic bluefin tuna is a large fish reaching lengths of 15 feet and weighing up to 2,000 pounds; the Atlantic bluefin is the largest of all tuna (Fromentin and Powers 2005). Both males and females carry the signature blue and yellow dorsal and pectoral fins that the species is named for (Figure 1). The species has limited **sexual dimorphism** and are difficult to discern at first glance (Johnson 2006). The tunas use countershading to help them blend in with the ambient colors of the ocean below and the surface above (NOAA 2019). The Atlantic bluefin tuna also has a **lunate tail** and strong musculoskeletal system that allows power thrusts to be transmitted through the slow twitch muscles of the fish (Gleiss et al. 2019). This warm-blooded fish has a high aerobic capacity, allowing it to thrive in cold waters and travel far distances even at top speeds of 44 miles per hour (Gleiss et al. 2019). The Atlantic bluefin tuna outperforms most other fish when swimming. Their torpedo-shaped bodies streamline their figure and aids in their hunting of prey (NOAA 2019). This is an adaptation that the fish developed to become faster in water.

Diet and Habits of the Atlantic Bluefin Tuna

The Atlantic bluefin tuna is a widespread species ranging across the Atlantic Ocean, as well as the Mediterranean Sea. The species does not typically venture south of the Mexican Gulf latitudes. The fish prefers to remain relatively close to the coast (Galuardi et al. 2010), except during migratory periods. When in coastal regions, the bluefin tends to remain within a few hundred meters of the surface of the ocean but will occasionally dive up to a few thousand meters (Fromentin and Powers 2005).

The Atlantic bluefin tuna is carnivorous, with an adult diet made up of mostly **chordates**, such as the Atlantic menhaden (*Brevoortia tyrannus*) and gulf kingfish (*Menticirrhus littoralis*) (Butler et al. 2014). Juvenile tuna consume small fish, squid, and crustaceans (NOAA 2019). The species utilize their aggressive behavior to hunt their prey by outswimming those around them. Tuna hunt around the **epipelagic** zone, 200 meters and higher (Golet et al. 2015). The major predators for matured bluefin tuna are orcas (*Orcinus orca*) and pilot whales (*Globicephala*). Juveniles must be wary of bluefish (*Pomatomus saltatrix*) and common seabirds (NOAA 2019).

The rate at which Atlantic bluefin tuna grows is slower than other species of tuna. The species has a long lifespan, which can last up to 20 years, and in some cases longer (NOAA 2019). Most Atlantic bluefin tuna will not spawn until they are eight years old. The female members of the species can produce up to 10 million eggs per year. The eggs are fertilized throughout the **water column** and take approximately two days to hatch. The spawning period of this species lasts from April to August (NOAA 2019). The primary areas where spawning occurs surround the Gulf of Mexico or the Mediterranean Sea, for western and eastern bluefin tuna respectively (Fig 2). The species' migratory period is heavily correlated with the spawning habits of the Atlantic bluefin tuna. Most of the spawning grounds for the species are found where the fish finish their migratory period in temperate waters surrounding land masses.

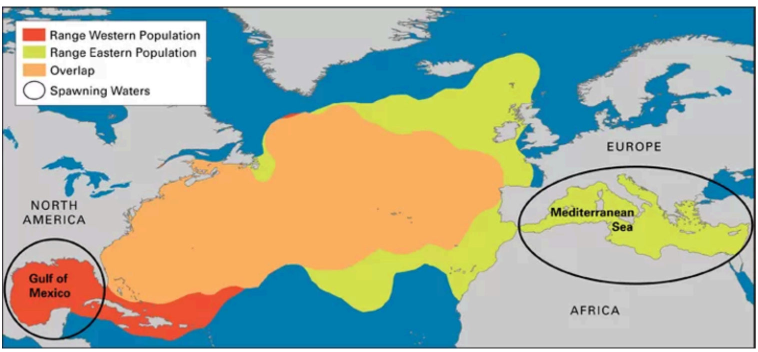

Figure 2. Range of Atlantic Bluefin Tuna. "[Atlantic Bluefin Tuna Distribution Map]" from [Smithsonian Ocean], [Terms of Use].

The Importance of Atlantic Bluefin Tuna Ecology

The Atlantic bluefin tuna remains an important species in the Atlantic and Mediterranean ecosystems and plays a large role in the ecological trends observed there. An important factor of the bluefin's presence is its feeding tendencies, specifically the types of creatures they consume. Atlantic bluefins feed on a variety of species throughout the day. For example, bluefin tuna feed on larger prey during the day, and smaller **diel migrating species** at night (Battaglia et al. 2013). This phenomenon means that the bluefins frequently feed on **mesopelagic** and **bathypelagic** species which are higher in lipid content (Battaglia et al. 2013). This allows access to greater energy for the tunas and thus a continued habit. Scientists conclude that the Atlantic bluefin tuna has a unique foraging rhythm (Battaglia et al. 2013). This rhythm means a foreign species is a predator in a region that it does not live in; the ecological impacts of this mean the bluefin is a regulating or balancing factor for the ecosystems of the mesopelagic and bathypelagic zones of the ocean (Battaglia et al. 2013). The Atlantic bluefin tuna also has an impact on species residing in the Gulf of Mexico. The larvae of the tuna are laid here, where they feed on various plankton and microbial species (Stukel et al. 2021). Here the larvae act as a predator that regulates the food web and subsequent ecosystem (Stukel et al. 2021). This results in impacts on the chemical makeup of the surrounding waters, specifically nitrogen concentrations. Much of the plankton and microbial species rely heavily on nitrogen and utilize it to grow and replicate. It is observed that the larvae of the bluefins are laid where more nitrogen is found and where these smaller species congregate (Stukel et al. 2021).

Overfishing of Atlantic Bluefin Tuna Populations

The Atlantic bluefin tuna population has both suffered and thrived as a result of human interactions. The population dynamics of the Atlantic bluefin tuna involve population trends, endangerment status, enacted policies that impact the bluefin tuna population, and other conservation efforts. Population estimates for Atlantic bluefin tuna in 1970 came in at approximately 1.2 million tunas; 30 years later this number dwindled to just under 600,000 (Collette et al. 2021). The Atlantic bluefin tuna has declined by at least 60%

in the past ten years in the eastern Atlantic stock, and by at least 82% since 1970 in the western Atlantic stock. These trends can be traced to overfishing in the Atlantic, and the effects of this have been detrimental to the species. In the population, age **truncation** has occurred as fishermen select older and larger specimens when harvesting (Secor et al. 2014), as shown in Figure 3. This trend has had an odd effect on the species' population by forcing the age of reproduction of the fish to occur at a younger age (Secor et al. 2014). Inevitably, the resilience of the species has also suffered from this change, so the entire population suffers as a result. This means that the time period for adult spawning is shortened. Beyond this, the **storage effect** was reduced in the region and, in return, other species that share the same ecosystem are being affected (Secor et al. 2014). This explains any sort of changes in the coexistence of different species in the same ecosystem. The decline in population number is directly correlated to the amount of fishing that occurs in the Atlantic and Mediterranean. Fishermen can be paid more than ten thousand dollars for a bluefin tuna right off the dock (PEW 2017). The market for Atlantic bluefin tuna is massive, thought to be the most valuable fish in the Atlantic or the Mediterranean Sea. This high demand for the species results in overfishing; numerous policies were established to limit predatory fishing practices against Atlantic bluefin tuna.

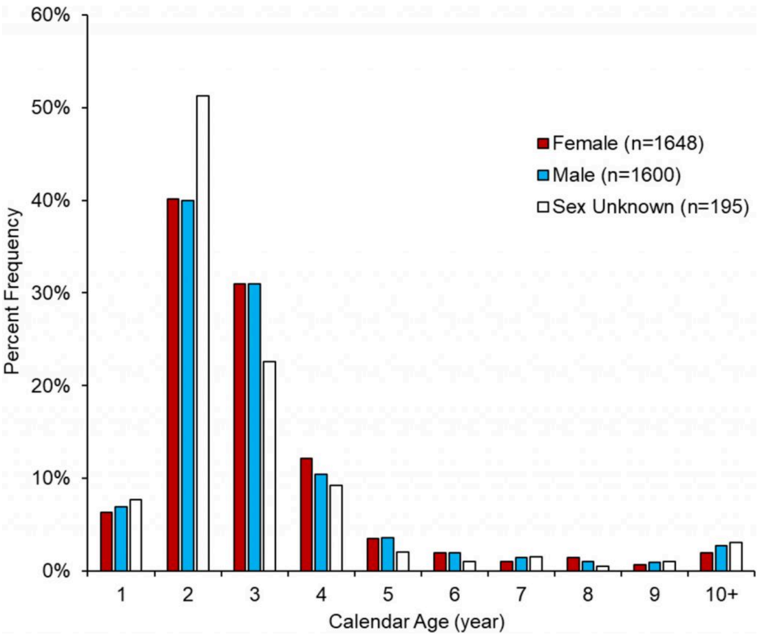

Figure 3. Graph detailing age estimates for tuna. Although this figure depicts data for Yellowfin tuna, the trend is similar for Bluefin tuna. "[Figure 3]" in [Pacicco et al. 2021] is licensed under [CC BY 4.0].

Conservation Movements to Protect Atlantic Bluefin Tuna

Due to aggressive overfishing, conservation movements and organizations have arisen to reverse these trends by enacting conservative policies. Due to overwhelming numbers proving population decline in Atlantic bluefin tuna from overfishing, the United States, Japan, and South Africa formed the International Commission for the Conservation of Atlantic Tunas (ICCAT) in 1966 (Safina and Klinger 2008). Since then, ICCAT has grown to over 50 members today and will continue to grow over time. ICCAT works to protect and manage Atlantic bluefin tuna populations through scientific research and government body lobbying. In the 1990s, the commission voted at an annual meeting in Madrid to reduce the catch quota by 50% in the western Atlantic (Safina 1993). This decision had a lot of backlashes, however, and exporters of the tuna lobbied the government to revoke this decision. The proposal was changed to a phase in which the structure would take several years to eventually reach a 50% reduction. Later on, though, the U.S. realized that the quota reduction put in by this organization cannot be greater than that of their own quota reduction (Safina 1993).

The National Oceanic and Atmospheric Administration (NOAA) is in charge of managing the fisheries in the United States and imposes numerous regulations on the bluefin tuna fishing industry. One such regulation is known as TAC, or Total Allowable Catch (Safina and Klinger 2008), which limits the total tonnage of fish allowed per annum. Commercial and recreational fishermen must possess a permit to harvest bluefin tuna, and are provided strict quotas for the amount of bluefin tuna they are able to harvest (NOAA 2020). In addition, there is a minimum size limit which the fishermen must abide by, and there is certain gear that fishermen are prohibited to use to catch bluefin tuna. As shown in Figure 4, conservation efforts were able to slow, and then level out adult Atlantic bluefin tuna decline between the years 1981 and 2010; before that, overfishing led to a sharp drop in tuna populations from 1970 to 1981. While the bluefin tuna has seen vast population changes over time, their status has fortunately been moved from endangered to least concern in 2020 (Collette et al. 2021), primarily as a result of imposed conservation and regulatory policies.

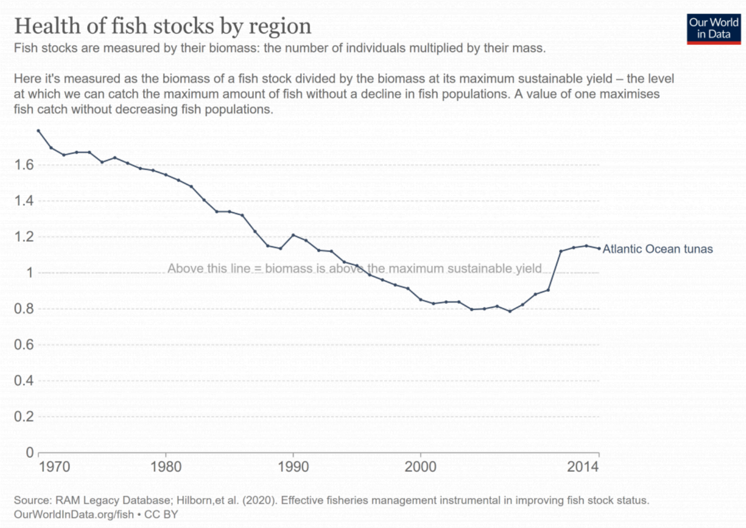

Figure 4. Graph displays the biomass decline of Bluefin Tuna from 1970 to 2010, followed by stabilization due to conservation efforts. "Health of fish stocks by region" by Our World in Data is licensed under CC BY 4.0.

Atlantic Bluefin Tuna and the Global Market

Many nations exist that prioritize the consumption of bluefin tuna, as it serves as a status symbol within these communities. One such community is Japan, which consumes nearly 80% of the world's bluefin tuna supplies (Fukui 2014). Before the 1970s, bluefin tuna was not as valued as it is today. Due to the high-fat content, bluefin tuna spoiled much more easily than other types of fish, and was less preferred for sushi in Japan, being referred to as neko matagi, or "fish that even a cat would disdain". Following the westernization of Japan after WWII, a cultural shift towards fattier red meats occurred, and tuna became more widely accepted in the Japanese diet. With the improvement of flash freezing technologies in the 1960s, it was much easier to preserve bluefin tuna, and international transportation became much easier. Simultaneously, the United

States began to accept Japanese cuisine more, leading to the heightened popularity of sushi in the western hemisphere (House 2018). Global demand for the fish skyrocketed, and the species became viewed as luxurious trophy fish. In turn, the heightened cultural significance surrounding both sushi globally and the high quality of the fish meat resulted in harsh consequences for the species population as a result of high demand (Fukui 2014).

Atlantic bluefin tuna on average weigh more than triple their next closest competitor, bigeye tuna (*Thunnus obesus*). However, this weight advantage that the Atlantic bluefin holds over all of the other major tuna species does not translate to market value. A study by the Pew Research Center found that the end value of Atlantic bluefin tuna was $1.1 billion, with a market share of 2.68% (McKinney et al. 2020). Skipjack (*Katsuwonus pelamis*) and yellowfin (*Thunnus albacares*) had similar end values of $16.1 billion and $15.8 billion respectively. The combined market share of just those species was 78.18% (McKinney et al. 2020). Why is the value of Atlantic bluefin tuna so much lower than its counterparts? The truth is they aren't less valuable, Atlantic bluefin tuna are just caught far less. Given their increased size, fishers have to work much harder to land an Atlantic bluefin. Additionally, conservation efforts are more stringent on the smaller population of Atlantic bluefin tuna than the larger populations of skipjack and yellowfin. In terms of total landings per year by species, skipjack, which had the highest end value, made up about 57.83% of all catches; this amounts to about 2.9 million fish. Atlantic bluefins had just under 30,000 catches, 0.57% (McKinney et al. 2020). The valuation of Atlantic bluefins comes not just from the increased struggle to land them, but also from their major uses. Atlantic bluefins are heavily sought after by high-end sashimi and sushi restaurants across the world, increasing their price.

Conclusion

The Atlantic bluefin tuna was once a species that densely inhabited nearly all parts of the Atlantic Ocean. By the 1970s, however, the species experienced immense overexploitation that resulted in population declines of nearly 55% (PEW 2017). The overfishing of this species can be directly linked to its increased market demand as a result of the increased popularity of bluefin tuna in sushi, mainly in Japan and later in the international markets. This sharp decrease in the species' population resulted in reactionary conservation measures taken by numerous nations bordering the Atlantic and Pacific Oceans. Although it has not recovered to its former population sizes, the efforts of various nations and their subsequent policies have renewed hope for population growth. No longer an endangered species but still subject to overexploitation, conservation measures are still needed if this fish is to thrive like it once did decades ago. For serious population growth to occur, both cultural and economic change must occur for the bluefin to spend more time in the ocean than on the plate.

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5. Effect of Late Blight on Monocultures

STEPHANIE DEAN; ELIZABETH HOWIE; MARY LOMBARDI; AND MICHELLE MILLER

Abstract

Potato blight, or late blight (*Phytophthora infestans*), is a plant **pathogen** that causes potato crops to become unusable and unable to be consumed. Potato blight is highly adaptable and spreads quickly with detrimental effects on farms and ecosystems. The scope of the research covers the analysis of the severity and frequency of blight over the last century. An impact rating was given to each decade to form a graph that demonstrated an oscillating curve. Solutions to reduce blight include allowing fields to **fallow** in the winter, cross-breeding potatoes with immunity genes, and creating stricter federal laws.

“*Phytophthora infestans potato Parel*” *by Rasbak, licensed under* CC BY-SA 3.0.

Background

Blight is a plant-borne fungal disease that negatively impacts plants, often making their harvest unusable for human consumption (Lu et al., 2018). This has been a widespread issue throughout the world, but the first main outbreak in the United States occurred in the early 1840s, as immigrants from Ireland fled the **Great Potato Famine**, bringing contaminated goods with them (Barakat et al., 2012). Blight has become a common disease that farmers in the United States must face (Lu et al., 2018; Barakat et al., 2012; Fry et al., 2012).

The most destructive and common strain is late blight, with a recent outbreak in 2009 in the New England area as infected potato transplants were shipped in large quantities throughout the Northeast (Fry et al., 2012). It was only after these transplants were introduced into larger farms, big box stores, garden centers, and personal gardens, that the early signs of blight were discovered. In many cases, entire sections of farms were destroyed in a late attempt to contain the spread, resulting in massive financial losses in the region (Fry et al., 2012; Olanya et al., 2006). A different outbreak in the 1980s to 1990s in rural New York resulted in farmers discarding entire trucks filled with infected and rotted crops in ditches on the side of roadways. This led to local flora becoming infected, but to a lesser extent than seen in the **monoculture** farms. Many farmers reported losing 80 to 100 percent of their total crop yield that year (Fry & Goodwin, 1997). In severe cases like this, blight causes damage to the local environment in addition to causing financial stress to farmers and consumers.

Blight affects crop viability — and in a world dependent on trade, the possibility of introducing new strains poses an extreme threat (Olanya et al., 2006). Plants can develop resistance to common blights in their local region, but trade encourages new outbreaks to continually negatively impact farmers (Barakat et al., 2012). Above this, the increase in monoculture farming and a lack of **biodiversity** allow blight to infect entire farms, as there is no natural defense against pathogens. Instead, farmers must rely on **fungicides** that target specific strains to combat possible outbreaks, but blight is constantly adapting to these countermeasures. Some possible long-term solutions include using crossbred potatoes, letting all plant matter on farms die over winter, and increasing federal regulations around the transportation of produce (Pacilly et al., 2019; Hwang et al., 2014).

Broader Applications

Blight has social, economic, cultural, and ecological impacts at regional sizes that range from the entire world to very localized areas. Socially, blight can — and has — caused massive famines that affect local, regional, and sometimes global communities, which is in part due to the migrations of people affected by blight (Anderson et al., 2004).

The economic downturn caused by a decrease in agricultural products can also affect societies. The economic downturn in one region or locality may have a butterfly effect, affecting trade in a myriad of different ways and causing shortages or surpluses of many other products. This expanding cascade of effects will only grow as **globalism** continues to spread (Anderson et al., 2004). Politics ties into economic and supply chain issues as well, as countries bargain for resources to fulfill their citizens' demands. In times of discontent, political factions often become more split. Different cultures also have different methods of managing an epidemic of blight and attempting to minimize its spread.

The ecological effects of a blight can spread far beyond the affected species as well. Blight can cause many problems for local fauna that rely on a source of nutrition that has been infected (Fisher et al., 2012). Blight's social, political, cultural, and ecological consequences greatly affect the world around, on a local, regional, transregional, and global scale.

Research Questions

Although blight affects a variety of plants, there are still many questions that scientists need to answer (Jeger et al., 2018). The primary question was how the frequency and severity of potato blight have changed over time in the United States (Figure 1). The research was focused on places with a lack of biodiversity, such as large monoculture farms ranging from the 1920s to the present day. Another question was how the lack of biodiversity on farms increases the likelihood of blight and other diseases while decreasing an area's natural ability to handle these threats.

Figure 1. "PEI Potato Farm II" *by* John Beales *is licensed under* CC BY-SA 2.0

Time and Region of Research

It was also important to focus on a specific location and time period to get specific data so the research was not as broad. Potato blight began in Ireland slightly before infecting the United States in the 1840s (Lu et al., 2018). Due to the immigration of people from Ireland, this disease was brought over to the United States and spread from there (Lu et al., 2018). It was decided to primarily concentrate on the last century — from the 1920s to the present day — for collecting data on blight. Furthermore, globalism became more prevalent in the 1920s because of the end of World War I, particularly in the United States. This led to more trade and thus more spread of goods and the pathogens those goods may carry (Martin et al., 2013). For a more focused approach, data was primarily collected from the Northeast of the United States where potato farms are common. By focusing on a specific location, time period, and set of research questions, specific data can be used to help ecosystems in certain locations in the United States.

Methods

To determine how the frequency and the virulency of blight in potatoes in the United States have developed over time, literary sources and references from the university library databases were analyzed. Additionally, an interview with an expert on the topic of plant pathogens was conducted for further information. Important data was collected, particularly information involving described financial losses, percentages of crops ruined due to blight, cost of managing blight symptoms, and reported instances of blight. The number of growing seasons a blight lasts and the landmass affected by a specific instance of blight were also considered. All references were then compared based on the time period that the literature discussed. The frequency and severity of blight during each decade were ranked on a scale of one to ten where one was the least detrimental and ten was the most detrimental in reference to viable crop loss.

From this comparison, a chronological timeline of blight was created to analyze the changes in frequency and severity of blight over time. Once the comparisons were made, the severity of potato blight was ranked based on the characteristics of each decade, including length, severity, and local impacts. A line graph was created with the time period as the independent variable and the rank (1-10) as the dependent variable. A trendline was added to the graph to determine any trend in the frequency and severity of blight, which clearly noted if the severity and frequency of blight were increasing or decreasing overall. The prediction was that blight frequency and severity have increased over time due to the loss of genetic diversity in potatoes and the highly adaptable qualities of potato blight (Garelik, 2002). However, it was also expected that there would be many oscillations in the frequency and severity of potato blight due to developments aimed at combating this pathogen.

Results

The impact rating that represented the severity and frequency of blight (Figure 2(was determined through the analysis of important events related to blight for each decade. Each decade had blight severity ranging from little to no effect to very severe effects. All events discussed here from each decade are shown in the timeline (Figure 3), and the rankings for each decade are derived from the graph (Figure 2).

Blight was first present in the United States due to the Great Potato Famine in Ireland. This strain was extremely aggressive, causing it to have a significant effect on potatoes in the United States. The majority of potatoes in Ireland were unusable due to blight, causing many citizens to migrate to the United States (Yoshida et al., 2013; Martin et al., 2013). The 1840s, while not included in either of the figures, were considered a 10 due to the severity of blight in Europe and in the United States. In the 1920s, blight caused over 10% crop loss in New York and Pennsylvania, with 5-10% loss in the majority of the northeast United States (Cox & Large, 1960). The resultant crop loss due to late blight was substantial and therefore the decade of the 1920s was considered to be an 8 on the impact rating scale. Furthermore, there was a moderate to severe loss of crops in Florida due to blight in the 1930s (Cox & Large, 1960). The impact rating for the 1930s was a 7 due to the variation of loss that was significant yet not at an extreme. In the 1940s, there was once again a moderate to severe loss of crops and the intensity of blight oscillated throughout the decade ranging from severe to slight (Cox & Large, 1960). Therefore, late blight was not consistently severe, and an impact rating of 5 was assigned. During the 1950s, there was a discovery of late blight-resistant genes in potatoes. With this new discovery, the loss of crops from blight was moderate, with overall fewer cases (Cox & Large, 1960; Stefańczyk et al., 2020). Therefore, the 1950s were ranked a 4. In the 1960s and the 1970s, fungicides were widely used to combat blight, greatly reducing its impact (Fry & Goodwin, 1997). Due to the use of fungicides, which decreased the severity of blight on crops, both the 1960s and 1970s were ranked 1.

New strains of fungicide-resistant blight emerged in the 1980s, which significantly increased blight occurrence in this decade (Fry & Goodwin, 1997). Therefore, the 1980s were ranked a 7. In the 1990s there was an 80% crop loss in New York due to blight, which was considered an extreme loss (Fry & Goodwin, 1997). Due to the severity of the loss of crops in the 1990s, an impact rating of 9 was assigned. During the decade of the 2000s, there was a rise in the strength and frequency of late blight in the northeast because of the movement of infected crops. This instance of blight primarily affected small farmers and home gardens (Fry et al., 2015). Though there was still an intense effect on crops, it was not as serious as in other decades. Therefore, the impact rating assigned was a 5. There was a new outbreak across the northeast of the United States in the 2010s (Fry et al., 2015; Haverkort et. al, 2009). Since this new outbreak was not as severe as others, the ranking assigned to this decade was a 3.

Discussion

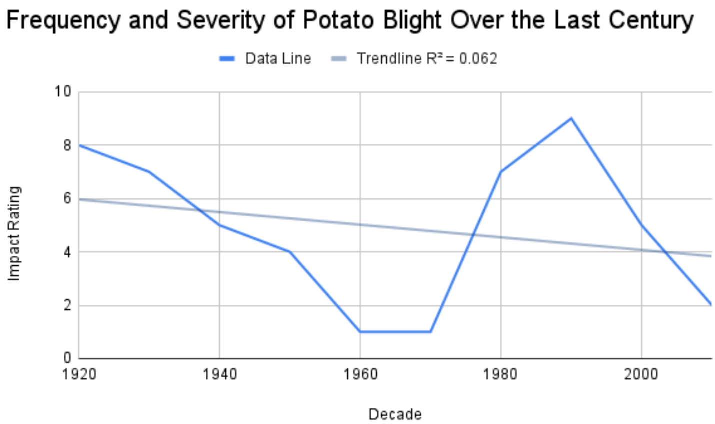

Figure 2. Frequency and severity of potato blight over the last century. Created by the chapter authors.

From the results of the collected data, a graph was created to demonstrate the severity and frequency of potato blight over the last century (Figure 1). The trendline based on the data showed that the severity and frequency of blight over the last century were decreasing. However, the data line has an oscillating curve based on the ranking for each decade. While this was not entirely expected, the trend is understandable. Potato blight is highly adaptable and has evolved into many different strains that continue to affect potatoes (Garelik, 2002; Haynes et al., 1998). Developments in blight control and technological advancements in agriculture over time cause the severity and frequency of blight to decrease. Blight adapts and evolves to overcome these advancements in disease control, which causes another spike in the severity and frequency of blight. An example of this is the development of different fungicides in the 1960s and the 1970s, which caused a lower impact during those two decades. However, potato blight then evolved to overcome the fungicides and had a much greater impact during the next decade (Fry & Goodwin, 1997).

The time period over which this data was collected is relatively short in comparison to the potential amount of data outside that time range. This means that there could be a better understanding of the data if the scope of research was expanded beyond a century. However, it can be inferred that this oscillation of high and low severity and frequency of blight will continue to occur as more advancements are made while blight continues to adapt. Ideally, as there are more concrete solutions implemented, the amplitude of the wave oscillations will decrease continually until there is no blight. Realistically, it will be incredibly difficult to develop a consistent solution to prevent potato blight and therefore it is likely that the oscillation of high- and low-impact of blight will continue for a long, if not indefinite, time.

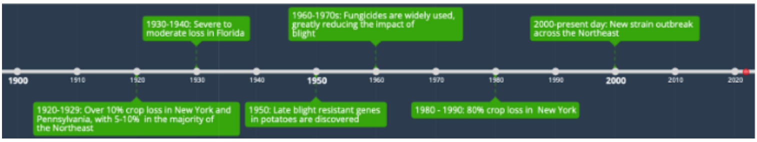

Figure 3. Timeline of key events in potato blight. Created by the chapter authors.

The timeline (Figure 3) depicts the important events of blight or lack of blight that were used to determine the impact ratings for the graph. The timeline and the graph depict the same collected data in different ways —the graph shows the data numerically and the timeline shows the data visually. This way the data can be viewed from different perspectives that offer different insights into how potato blight has developed and changed over the last century.

There were many difficulties and drawbacks throughout the process of collecting data about the severity and frequency of potato blight. Due to the variety of sources used to understand how potato blight developed in each decade, there was no definite baseline of what was considered severe, moderate, or slight. Different sources discussed different years having severe, moderate, or slight blight but did not confirm what those terms meant. This made it difficult to compare the information to determine the impact ratings for the decades. Furthermore, the impact ratings were discussed as a group to limit bias, though bias is certainly still present.

Conclusion

There are many possible solutions to reduce the severity and spread of blight. These include, but are not limited to, letting all plant matter die out over the winter, cross-breeding cultivated potatoes with their wild counterparts, and increasing federal legislation around transporting produce.

Blight can only survive in live biomatter, which naturally dies off over the winter (Vega et al., 2019). However, many farmers grow winter wheat, meaning they plant wheat over the winter to reduce erosion of topsoil. This crop of wheat provides a place for blight to survive and increases the chance of infecting the next year's crop. Instead, a suggestion is to install erosion barriers to protect topsoil and let fields fallow over winter to eradicate any habitat for blight to survive (De Castro & Bolker, 2005). The topsoil can then be redistributed over the farm for the new planting season, effectively stopping the cycle of infection (Robinson et al., 2017).

A wild **diploid** species, *Solanum bulbocastanum*, has evolved with the current prevalent strain of blight, becoming immune in the process. At this moment, there is no easy way to cross cultivated potatoes with their wild counterpart, but partial cross breeds, known as "backcrossed progenies" have been developed that slow disease development, offering more time for farmers to catch and address an outbreak (Song et al., 2003; Brown-Donovan et al., 2021). Production quality and quantity can be affected in favor of increased immunity with crossbreeds. Targeting immunity alone is not a viable option for blight control and fungicides may still be used but to a lesser extent (Becca Hall, personal communication, November 18, 2021).

Lastly, an increase in federal laws regarding the transportation of produce could decrease outbreaks. Farmers are not required to test produce for asymptomatic diseases unless there is a current outbreak in the area. Farmers may volunteer to have samples tested, a service offered by most agricultural universities for about forty dollars, but this service is rarely used and, depending on location, may not be readily available (Becca Hall, personal communication, November 18, 2021). This has led to many outbreaks as infected produce was unknowingly transported around the United States. Often these outbreaks are new strains, resistant to the current fungicides, and can demolish an entire farm's yield (Fry & Goodwin, 1997). Required preemptive testing could decrease the frequency and severity of these outbreaks.

Late blight causes multifaceted issues, and there is no one clear solution to stopping its spread. However, with the solutions described, it is likely that the effect of blight can be greatly reduced and eventually eliminated. These solutions can then be applied more broadly, both to other plant pathogens that affect crops and even to wild flora. The extension to other crop pathogens is quite simple and will likely have a very similar efficacy rate to that of late blight. In wild flora, providing genetic material from a wider region may create greater resistance to some diseases.

The other two solutions—providing conditions in which the disease cannot survive and increasing legal requirements to prevent the spread—can also be extended more broadly. Conditions in which blight cannot survive are the same conditions in which many other plant pathogens cannot survive. Therefore, leaving fields to fallow over winter—or for longer instances in particularly severe cases of soil-surviving pathogens—will eliminate those pathogens from recurring during the next planting period (Hwang et al., 2014). Legal measures are particularly useful in establishing a type of quarantine that will prevent large outbreaks of disease. Outbreaks can be prevented by requiring broader testing for more diseases before crops and animal products are distributed nationally and internationally. This broader testing protocol can prevent the spread of various diseases from the local level of diseased garden plants to international pandemics.

As these solutions are extended outward from the specific issue of potato blight, they could have a significant impact on the preservation of biodiversity. By increasing a species' overall resistance to one or more diseases, more individuals will be able to survive and pass on their genetic material. This will increase the diversity of all future generations, and allow other traits to survive that may have been eliminated by natural selection based on disease resistance. This can help a species survive other issues that currently plague the natural world, including climate change, habitat loss, and invasive species.

Potato blight is a massive issue in and of itself, as it affects economies, food security, and even other species. The oscillation present in the graph in Figure 2 shows the downsides of the current management solutions; blight evolves to overcome them because they do not successfully eradicate a significant enough portion of blight pathogen. The solutions presented in this chapter offer a chance to drastically diminish the effects of potato blight on the world and may offer an opportunity to further reduce disease in many other areas.

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6. Beeline to Extinction: How Bees Benefit Humans and America's Economy

CJ ANDRES; JESSE BEERS; TANNER THATCHER; ETHAN WILSON; AND CALEB PROUTY

Abstract

This chapter will cover the devastating consequences of Colony Collapse Disorder (**CCD**) in European honey bees (*Apis mellifera*). European honey bees are the largest pollinator in the Americas and add 15 billion dollars to the value of American agriculture each year. Unfortunately, beehives are dying off by roughly 30% each year from a myriad of problems that all fall under the category of CCD. Without its most valuable pollinator, the American food supply would collapse. This chapter will discuss the causes of the problem, its consequences, and what can be done to stop it.

Figure 1. Andres, C. (2021) "Bee Aware." Created by chapter authors.

Physical Traits

The European honey bee is one of the most recognizable insects in the world, with a body split into three main sections: the head, the thorax, and the abdomen. Within the hives, there are also three main sizes or classes of bees (Britannica, 2020). The queen is the largest and is the only breeding female (Britannica, 2020). The second largest are the male drones whose main purpose is to mate with the queen, and they only live for three to six months (Britannica, 2020). Lastly, the smallest class is the male worker bees, who are responsible for keeping the hive alive. Their responsibilities include maintenance, construction, and proliferation of the hive. All classes of bees have 6 legs with sharp claws at the end used for grabbing onto flowers. The three classes also have stingers that are used to fend off threats, but the queen's stinger has a reduced barb so it will not come out and kill her when she stings (Britannica, 2020). The antenna at the top of the head of bees is covered in scent sensors used to locate flowers for pollinating. The eyes of the male bees are much larger than the eyes of the females. Both have a long **proboscis** located at the top of the head, which is a long tube used for sucking nectar into their systems so they can bring it back to the hive (Britannica, 2020).

Figure 2. The Queen. "Apis mellifera, European Honey Bee" by David Illig is licensed under CC BY-SA 4.0

History

As in its name, the European honey bee is not native to the United States (U.S.). They were brought to the U.S. as early as 1621 from Europe (Kellar, 2011). Just like humans, disease, weather, and other harsh conditions limited honey bees to the east coast for another 230 years (Kellar, 2011). These bees were especially important for the early development of U.S. agriculture because they pollinated the European crops that settlers brought over when they first arrived. Through this process, the bees also changed the environment, making it more accessible and habitable for livestock that we depended on (Kellar, 2011). By the end of the 17th century, bees had followed humans and spread north to cover all of New England, and through the 18th century, the interest in the benefits of beekeeping continued to expand (Kellar, 2011). Five American beekeeping books were published containing documentation of the uses and benefits of bees (Kellar, 2011). By this time, bees were starting to be kept as farm animals for more personal use, such as the harvest of honey and the pollination of crops. Many documents have been kept on the history of the European honey bees and their journey through the U.S., but this is the brunt of the research. Even though exact figures on colony populations or profits were not recorded, research shows through various personal documents that bees were an integral part of early U.S. agricultural development.

Framing of the Problem

Honey bees, like many other species in today's world, are becoming extinct. Specifically, European honey bees, are the main species used for nearly all bee pollination in the U.S. As the world and U.S. population have grown, so has our food supply, and with it, the demand for pollination. An increase in population has brought attention to the severity of the many causes of Colony Collapse Disorder, which is killing off beehives to the extent that bees are being overexploited in the U.S. Some solutions are available but having a deeper understanding of the value of European honey bees and what Colony Collapse Disorder does to them is vital when assessing where to focus effort and funding.

Background

As stated earlier, the most common type of honey bee found in

North America is the European honey bee, which was first transported to North America in the 1600s (Lubeck, 2019). They were brought over along with many of the native European plants that they now help pollinate. These bees are responsible for pollinating over 90 U.S produced crops (FDA, 2018), and are an essential part of the U.S food supply. Making up colonies ranging from 20,000 to 80,000 individuals (Canada Agriculture and Food Museum, 2021) and collecting nearly 40 pounds of honey per year (Lubeck 2019), the U.S bee population is a substantial force in our ecosystem.

The term Colony Collapse Disorder (CCD) first became common in 2006 (NPIC, 2015), and is a term that describes when most of the worker bees in a colony die or disappear, leaving the queen stranded (NPIC, 2015). CCD is the most dangerous in winter when an average of 15% of managed colonies are lost each year (Amadeo, 2021). CCD has been increasing from an average of 30% of colonies a year, to closer to 35% (Amadeo, 2021); the U.S. has lost almost 50% of its beehives since 1950 (Lubeck, 2019).

Colony Collapse Disorder is caused by 61 different sources (NPIC, 2015), with no one cause being the primary perpetrator. Across the board, overuse of **insecticides** has weakened the U.S. bee population making it more vulnerable to **vectors** causing CCD. One group found that some bees had even become addicted to **neonicotinoids**, a nicotine-based pesticide, causing CCD (Kessler et al., 2015). Another high-profile cause of CCD is the invasive **Varroa Mite** (USDA, 2013), which is a parasite that feeds off the bee's body and can easily spread viruses to them (LeConte et al., 2010). These mites are only able to reproduce in a honey bee colony and are extremely difficult to remove from a colony (LeConte et al., 2010).

Besides the necessity of European honey bees to pollinate our crops, their economic value is also substantial. According to the FDA, these bees bring in close to 399 million dollars a year (FDA, 2018) in the honey and bees wax they produce. However, this direct source of income is spare change compared to the value they add to the crops they pollinate. Bee colonies across the U.S. increase the value of U.S crops by 15 billion dollars a year (Lubeck, 2019), which is up to 20 times the value they bring in from honey or wax. Another benefit that is harder to directly measure is the psychological and emotional benefit humans get from bees in the environment (Matias et al., 2017). For example, a living environment with lots of flowers and other wildlife is much better mentally and health-wise for humans than one without.

The effects of CCD on both the U.S and the global economy are deep and widespread. Demand for honey bees has increased dramatically for fruit, nuts, and vegetable growers, whose crops make up close to one-third of the average global diet (Amadeo, 2021). Pollination fees in California have increased from 51.99 dollars in 2003 to between 180 to 200 dollars per hive in 2016 (Amadeo, 2021). The bee industry has spent roughly 2 billion dollars over the past six years in replacements for 10 million hives (Amadeo, 2021). For an industry that only makes approximately 500 million dollars each year, this cost is unsustainable. The result of these losses is an increase in price across the board for almonds, beef, and dairy products, among others.

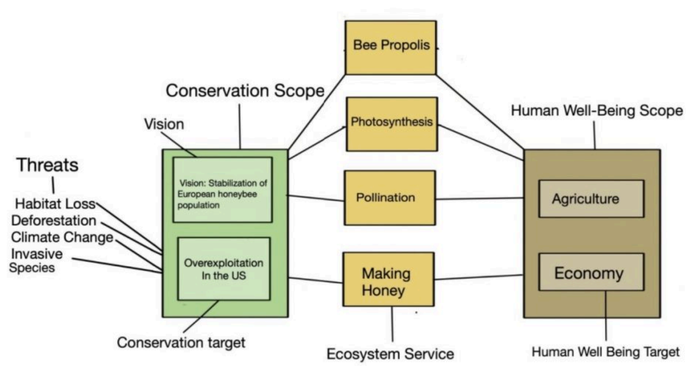

Figure 3. Situation model of potential paths our research may take. Created by chapter authors.

Methodology

Our research mainly consisted of reading and documenting scientific articles from various sources. Some of the sources we used were the USGS, FDA, Encyclopedia Brittanica, and the National Pesticide Information Center, among others. Each source was investigated to ensure we were not recording false information, and we corroborated sources as often as possible. While these articles made up most of our research, another key component was interviews we conducted with experts in the field. These interviews gave us unique perspectives on the situation we were analyzing as well as providing details that would not have been found elsewhere. Altogether, these various sources gave us the tools to create a comprehensive picture of the problem we are facing. Autodesk Sketchbook was also used to create our situation model, pictured above.

Results and Findings

Through our research, our group was naturally led to focus on economic impacts, where the group learned how large of impact bees have on the economy. Our research then looked at why the economic support from bees was in decline. Colony Collapse Disorder was the answer to all these issues and the capstone problem as to why bees are still not thriving.

A crucial part of the research process involved interviewing real beekeepers to look at their perspectives and knowledge compared to the information that we had gathered ourselves. When comparing our research with what we learned from our interviews, we saw no discrepancies in our research, further proving the validity of the research.

Conclusions of the group's research go beyond CCD and economic importance thanks to the questions the team asked during our interviews such as: how have you found that bees can thrive within an urban setting? The necessary solution to this issue is to make sure there is a space for bees to thrive in close proximity. An urban beekeeper, Kevin Dutt, explained how his bees fly straight up and then out to find plants. To my surprise, not only does the obvious implementation of concrete hurt the areas that bees can pollinate, but the planting of grass does as well (K. Dutt, personal communication, November 21, 2021). Bees needing 40 pounds of honey for the winter is crucial knowledge for beekeepers to know, and something that only experience would allow people to learn (K. Dutt, personal communication, November 21, 2021). His opinions allowed for a better understanding of, and connection to, the efforts of companies who provide products for anyone to have bees. It is a very concrete solution to preserving populations of bees in about any area: the hive takes up such a small space and is not in the way of anything in even the small yard that they have in Boston. Adding to the growing list of dangers to bees, such as pesticides, mites, and fertilizers, that the group had looked at before the interviews, mosquitoes were added to the list.

Another beekeeper, Jim Fitzsimmons, gave a thorough explanation of the process for harvesting honey, as well as details about the life cycle of bees. Jim gave a specific distance for how far bees can travel, explaining that they can fly from three to six miles away from their hives to pollinate (J. Fitzsimmons, personal communication, November 22, 2021). He explained how honey is only ready to harvest when it has been "capped" by beeswax and the beeswax is saved for candles (J. Fitzsimmons, personal communication, November 22, 2021). Locally, honey sells for around $12 per pound (J. Fitzsimmons, personal communication, November 22, 2021). Finally, he spoke about how there is a lack of flowers for bees to pollinate (J. Fitzsimmons, personal communication, November 22, 2021). Fitzsimmons owns a farm of bees, known as an **apiary**, which gave a different perspective compared to the single hive that Kevin spoke to the group about.

Conclusions and Broader Impacts

Throughout the process, the group found that there are a plethora of issues revolving around bees and their ability to thrive. Examining these issues helped team members to understand bees, not as nuisances, but as complex organisms that provide for their ecosystems. This is one solution: making people aware of these issues and where to focus our priorities on. Priorities can be established based on preventing the dangers to bees and allowing local citizens to gain access to beekeeping with proper preparation and knowledge.

The agricultural industry needs bees. However, the group found that our research has immense potential as it can help turn the tide on the extinction of bees. We can bring awareness to this problem that seems to be flying under the radar due to the public having little knowledge of the problem. This research can bring the extinction of bees to light and help bring support to the cause. An example of these remedies can be finding ways to harvest honey or bee propolis that would not intrude on the bee's economy or kill off some of the bees living in the hive. With a new and less intrusive way to harvest or create honey, we can increase the production of honey from beehives in the next few years. This situation is also prevalent in Europe as they are having a similar problem and the approach can help their situation. Others can learn from our project by realizing taking certain products directly from the source is not always the best approach if it harms what makes this product. This is because bees would not be going extinct if humans were not intervening to get honey and other products. Others can also learn that bees are not simple pests that fly around, but instead, we can view them as benefactors to the economy with their honey and other products. Changing this viewpoint can also help to increase awareness because people would rather save something if they knew the benefit.

Most concerned people with this topic can make changes more passionately than other people in the world. The initial problem framed in our problem statement is that the significant impact that bees have on our ecosystem and economy is diminishing as bees decrease in population. The first recommendation would be to make conscious efforts to bring beehives into our lives by, for instance, volunteering at an apiary. An apiary is a farm for bees and this option allows people who cannot commit enough time to care for and take care of bees in their own time. Also, an apiary is a place where people can learn how to interact so that the bees benefit the most. The second-best action to take for bees involves promoting proper bee care in terms of not taking too much from them. This builds off learning how to care for bees yourself, but if you cannot get out onto the field and act, words can change how people behave as well. Neonicotinoids and varroa mites are two examples of factors hurting bees that humans can be more aware of in order to prevent as much impact on the bees. In agricultural aspects, only select people can prevent the nicotine that bees intake from neonicotinoids, but those who care most about bees can stop varroa mites from infiltrating colonies. Planting bee-friendly plants is another action that about anyone can take and the majority of people who do this are not even aware that they are assisting bees. Finally, steps researchers can take to deepen our research and further investigate this issue include finding ways that bees can make a comeback in terms of having the same influence on agriculture and biodiversity as they used to only a few decades ago.


NPS
I DIDN'T KNOW THAT!
Planting for Pollinators
We need pollinators.
Pollinators are responsible for 1 out of 3 bites of food we take each day.
Pollinators need our help.
Worldwide pollinator populations are declining due to habitat loss and pesticides.
Native plants support pollinators.
Pollinators and native plants have evolved together and they need each other to survive.
You can help pollinators!
1
Plant a Native Pollinator Garden
2
Reduce or eliminate your use of pesticides.
3
Buy local and buy organic.
idkt!
go.nps.gov/idkt

Figure 4. Tips for protecting pollinators, like bees. "Planting for Pollinators" by the US Dept. of Interior, National Park Service licensed under Public Domain, CC0.

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7. Wildfires and Specialists: A Deadly Connection

SEAN MAGUIRE; ALYSON CRAWFORD; LINDSAY MASAMERY; MICKEY MIKITARIAN; AND JACK PSZENICZNY

Abstract

"koala" by Mathias Appel is marked with CC0 1.0.

Wildfires burn through regions across the globe each season, which impacts biodiversity levels in these areas. Example areas particularly affected by wildfires are California, United States, and South Wales, Australia. Specialist species are organisms that are adapted to one specific environment. Therefore, specialist species are at substantial risk from wildfires because they cannot adapt to other environments. Koalas (*Phascolarctos cinereus*) in South Wales and pygmy rabbits (*Brachylagus idahoensis*) in California are specialist species with populations that have been declining as a result of an increase in wildfires. The research was intended to spread awareness and produce practical solutions to promote population growth among these species. Educational programs, advertisements, and controlled burns are ways to help alleviate the damage to these vulnerable populations.

Framing the Problem

Wildfires are natural processes that have been ongoing for millions of years. However, humans have been linked to the escalating unnatural causes of wildfires (Figure 1). Therefore, as human activity continues to increase, the severity of these fires will also increase. This leads to harsher and more frequent wildfires that impact the regions they burn through. Within these regions, there are species that are uniquely adapted to their environments. These specialist species are often threatened with extinction because they cannot adapt to drastically changing environments. Consequently, wildfires burn these species' homes and leave them vulnerable to predators and other threats. Wildfires have caused declines in ecosystem diversity and species diversity. As wildfires have ripped through large areas, animal species and vegetation species have lost substantial populations, pushing many species towards endangerment, extirpation, or extinction. Because wildfires cannot be stopped altogether, awareness is a necessary tool to help educate and prevent severe wildfires. The project mainly focused on how human-related activities created and aided the spread and intensity of wildfires and how these wildfires affected specialist species like the koalas and pygmy rabbits.

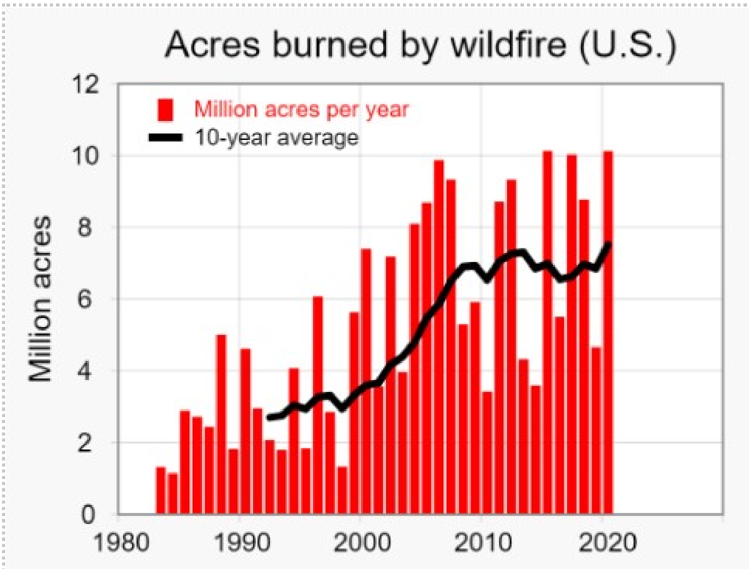

Figure 1. *"Wildfire acres burned in the United States" by Our World In Data is licensed under CC BY 4.0*

Specialist Species

Specialist species are organisms that require specific conditions to live and thrive. Distinct attributes are clear in isolated places such as the Galapagos Islands where the varied species have evolved specifically to survive the conditions in their environment. These species are around the world surviving in various specific environments, not always on small islands. A couple of examples of specialists are the koala in Australia (South Wales) and the pygmy rabbit from the United States (California) shown in Figure 2. Relying solely on other species (Eucalyptus Trees and Sagebrush, respectfully) for food, these two species are more vulnerable to natural disasters such as wildfires. This vulnerability comes from the fact that these animals do not have the flexibility to move around between environments, limiting how far they can flee from wildfires. Without the ability to adapt quickly to new habitats, koalas and pygmy rabbits are perfect examples of how specialist species are affected more heavily by wildfires. Generalist species (such as Kangaroos in Australia) can evade natural disasters more easily and adapt to living in a different environment either temporarily or permanently. Since specialists are more easily affected by natural disasters, they are better examples of the increasing impact that wildfires have on biodiversity.

Figure 2. *"Juvenile Pygmy Rabbit" by Jim Witham is in the Public Domain*

Human Activity

The growing threat of wildfires has been linked to human activity. In fact, human activity is known as one main cause of the increase in wildfires. However, this poses the question: how exactly has human activity aided in the spread and severity of wildfires? Humans are known causes of the increase in global warming and climate change through pollution, which creates a positive feedback loop as the increase in atmospheric temperatures causes an increase in size, magnitude, and frequency of wildfires. A concerning 96% of wildfires that threaten human homes and businesses are caused by human activity (Deweerdt, 2021). While this is not in the wild, a lot of these can spread to nearby vegetation and begin massive wildfires. Most of the wildfires in California are caused by human activities (NOAA SciJinks, 2019). These human activities that can cause these wildfires range from arson, cigarettes, accidents, campfires, fallen power lines, blown transformers, or housefires. While humans do play a large role in the increase of wildfires, natural disasters like lightning or earthquakes are also a main source of the ignition of wildfires. However, human activity is a massive source of wildfires, which is why there needs to be more widespread knowledge on how humans can reduce their impact on this increase in wildfires.

Methodology

The information collected comes from scientific reports on human activities that cause wildfires and the changing populations of species in Australia and California. Worcester Polytechnic Institute's (WPI) online database and internet searches were utilized to gather this research. Additionally, media sources and expert interviews from scientists within the field of study helped expand knowledge on the effects of wildfires on specialist species. The expert, Cole Doolittle, provided insight into the relationships between species, wildfires, and how specialists are at greater risk when fires burn through their habitats. The discussion with Doolittle helped narrow down the research and what needed to be done to further the project. As the project progressed, the exact topic of research narrowed further. Data on biodiversity levels, in general, are difficult to quantify. Therefore, the project focused on pygmy rabbits in

California and koalas in Australia to better present the problem and potential solutions. These species were selected because they are specialist species and have been impacted by wildfires more severely in recent years. Therefore, creating solutions that spread awareness and support the recovery of these species is essential to preserving biodiversity across the region.

Results and Findings

The lack of mobility and adaptability of specialist species proves especially costly to them during and after a wildfire. Large species such as deer or elk are typically able to escape an area that is burning due to their mobility. In the case of koalas, pygmy rabbits, and other specialist species, they struggle to escape in the middle of the fire. Typically, during a wildfire, pygmy rabbits will seek shelter in their burrows. However, during the large-scale fires of recent years, the heat penetrated the ground and killed the rabbits in their burrows (Koch, 2021). As a result, researchers have estimated that after a fire has passed through pygmy rabbit habitat the population can decrease by up to 50% in the worst cases (Roos & Green, 2021). After the fire passes through an area and destroyed the habitat, pygmy rabbits and koalas cannot change their diet from sagebrush or eucalyptus, leaving them without food or shelter. In the case of the pygmy rabbit and their habitat, as sagebrush is burned, it is replaced by an invasive species called cheatgrass which is not suitable to support pygmy rabbits (Woods et al., 2013). During research, information that could be utilized was limited based on the country of origin and the specific language it was written in. The problem of wildfires is not limited to specifically the western United States and South Wales, Australia. Across the globe, in places such as Siberia and Greece, wildfires are on the rise. Increasing levels of wildfires cause a decrease in biodiversity not only in the U.S. and Australia but all around the world.

***Figure 3.** A prescribed burn.: "[Pompeys Pillar National Monument Prescribed Fire"] by Colby K. Neal, Bureau of Land Management is in the [Public Domain]*

Fire Management Practices

There are many forms of fire management that have developed over the past million years. For example, indigenous people all around the world (this includes both the United States and Australia) throughout thousands of years have utilized prescribed burns (Figure 3). In this process, a small fire is set in a controlled area to get rid of debris and dead vegetation, which reduces the threat of wildfires in that given area. These prescribed burns range from about a few hectares to thousands of hectares in size (about 20 square miles), and they are set in cycles of three to four years. However, in areas that are more at risk of wildfires and produce a lot of debris or dead vegetation, the prescribed burns can be set yearly. Normally, when this practice is not used, the dead vegetation and debris fuel the wildfires making them stronger and larger, so prescribed burns get rid of this fuel. However, it is understandable how it might seem that this is counteractive to promoting biodiversity and preventing wildfires as it could potentially kill the living species within the area, and it is setting fire to prevent fire. However, prescribed burns are slow-moving and typically allow enough time for the species in the area to move to fire refugia. Fire refugia are areas in which there is no fire and where many species go to seek refuge when a fire hits their homes. Indigenous peoples used this practice for thousands of years, but when western Europeans took over indigenous areas, these practices were ignored as they were viewed in this interactive way. Since then, there has been a return to fire management practice, but not on as great of a scale as it should be.

Problem Solutions

Some solutions that were found for the wildfire epidemic include prescribed burns, wildfire advertisements, fire watches, and camera traps. As stated before, prescribed burns are a great solution in which there is a controlled burn in a small area. This allows a decrease in the amount of fuel that a potential wildfire could use to supply its fire. These burns are also much slower than actual wildfires, so it allows time for species to become aware of the danger and escape. Fire safety and precautions advertisements can help spread awareness to humans that show the actual effects of wildfires on specific species. In the U.S.A., Smokey the Bear is utilized to educate Americans on the dangers and risks of wildfires and what they can do to prevent them. Although Sam the koala is not utilized in the same sense as Smokey the Bear, Sam the koala was one bright moment during the horrific fires in Australia. This brought the reality of what happens to species in these fires and raises awareness constantly for Australians. One way to limit human interaction with areas that are susceptible to burning is to prevent development in areas that are high risk for wildfires. This can be factored into an education program that highlights the dangers that people pose to a high-risk area. The majority of wildfires are related to human activity whether it is a result of a careless act or completely unintentional. The best way to stop human-related wildfires is to stop people from encroaching on rural areas where a fire can be sparked easily by human action. A fire watch is a group of volunteers to are assigned to a certain area that is at a high risk of wildfires. These volunteers are expected to watch these areas avidly and report any dangers or risks of wildfires proactively. Camera traps are cameras set up in various locations of an area at high-risk wildfires. This allows footage of species in this area to be recorded. Camera traps are not as much of a solution and are rather a way to analyze the species populations in certain areas. This can alert scientists and ecologists about which species are rarely impacted by these wildfires and which species have a diminishing population due to these fires. Therefore, environmentalists can work with, and try to assist specific species. With all these precautions and steps taken to raise awareness, wildfires by human activity can and will decrease.

Conclusion

Wildfires have posed an immensely dangerous threat to specialist species and ecosystem biodiversity. This directly impacts the west coast of the United States in California and the southeast coast of Australia. The species focused on were the pygmy rabbit from California and the koala from New South Wales. The pygmy rabbit has recently entered the International Union for the Conservation of Nature (IUCN) red list in 2016. This is due to the loss of their habitat and food source of sagebrush, a highly flammable brush. The koala entered the red list in 2014 and is currently listed as vulnerable. This is because of the bush fires that spread to large areas causing a huge loss of species (Rachlow, 2016). Although wildfires are considered a natural disaster, humans have furthered the severity and number of wildfires in these areas. Awareness needs to be raised and humans need to take action. Some solutions that have been found include prescribed burns, fire watch, increased fire safety and precautions, and camera traps. With these precautions, wildfires can and will decrease significantly.

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PART II

INVASIVE SPECIES

Invasive species are often blamed in public debates for the deterioration or destruction of complex ecosystems. However, it is often forgotten that invasive species are frequently a product of unintentional and intentional human actions and that questions about "invasiveness" require close attention to issues of scales and the governance of people's activities. This section includes chapters examining the impacts of species introduced as pest management and ornamental and agricultural plants and due to the long-term effects of human mobility and trade from the 1800s to the present.

"Pulling invasive species" by U.S. Fish and Wildlife Service, licensed under the Public Domain

8. Toad-al Chaos : The Cannibal Toad Invasion of Australia

NATHAN BARGMAN; MADELINE PERRY; RONIT BANERJEE; AND SAMUEL NG

Abstract

"Adult cane toad" by brian.gratwicke is licensed under CC BY 2.0.

The cane toad (*Rhinella marina*, formerly known as *Bufo marinus*), an Australian menace originally introduced to the continent to deal with a crop-eating bug, has eaten anything and everything in its relentless expansion throughout the northeast. Due to their extremely high population numbers, cane toads are forced to cannibalism for food and driven further and further from their initial induction point. Scientists continue to try and find ways to slow cane toad growth and limit their population. Further research and understanding of these toads can lead to a permanent solution.

Natural History

The cane toad (Figure 1) is a species native to northern South America, Central America, and southern Texas. Cane toads are considered **environmental generalists**. They are robust and can survive in a multitude of habitats, but tend to prefer open grassland (Tyler and Doughty 2009). Female cane toads use wetlands and breeding ponds in the summer to lay clutches of over 30,000 eggs, and male toads can typically be found in these areas looking for mates (Gonzales-Bernal et al. 2015). As tadpoles, cane toads grow up to 30 mm in length, with their tails being the majority of their body length (Government NT 2018). Their skin is shiny, with an ovalish body shape that comes to a point at the snout. Juveniles are under 4 cm and keep their smooth skin from their tadpole stage, but now gain the typical toad physiology (Government NT 2018). At 18-24 months, they are considered adults and are much larger than juveniles, as they typically range from 9 cm to 15 cm, but can even grow up to 24 cm (Government NT 2018). In terms of the physiology of the cane toad, they are **sexually dimorphic** through their skin color, texture, and the length of their forelegs (Kelehear and Shine 2020). Males tend to be larger, with longer limbs, bigger head widths, and rougher skin.

Figure 1. *Cane Toad by Joydeb halder via Wikicommons under CC BY-NC-SA 4.0*

Cane toads are **opportunistic feeders** that have a large range of diets. Common prey for them are beetles, ants, millipedes, toads, and crickets, but within the stomachs of these toads, researchers have found 284 identifiable prey (Figure 2) (Reed et al. 2007). Cane toads have even been observed to eat one another, as well. The cannibalistic nature of the species has altered its **evolution**, as individuals who grow rapidly survive to maturation over their smaller peers that get eaten. This trait is specific to cane toads in Australia, which were introduced and had no natural predators (Gamillo 2021). This **intraspecific competition** has helped the cane toad spread across Australia (Figure 3). For instance, they have experienced **morphological** changes to aid in their invasion (Hudson et. al. 2016). The cane toads that can spread further from members of their own species experience less competition and continue to reproduce. This form of **natural selection** promotes traits that increase their dispersion rates.

Common Name	Frequency
Beetle	147
Ant	111
Millipede	94
Grasshopper	88
Earwig	67
Spider	59
Pillbug	54
Vegetation	47
Unidentified	42
Snail	33
Grub	31
Centipede	30
Roach	25
Worm	19
True Bug	15
Fly	15
Vertebrate	11
Caterpillar	9
Wasp	5

Figure 2. *This table was created from data in "Diet composition of the invasive cane toad (Chaunus marinus) on Rota, Northern Mariana Islands." (Reed et al. 2007)*

In a failed attempt to suppress the cane beetle (*Dermolepida albohirtum*), a devastating insect pest of sugarcane crops, the cane toad was purposefully introduced into Australia's tropical north-east in 1935 as a form of **biological control** (Shanmuganathan et. al. 2010). The toads immediately adapted to their new surroundings and became an **invasive species**. They now live in the majority of Australia's tropics and subtropics, as well as western Australia. According to models, global warming will allow toads to expand their range southward. Cane toads are toxic during all stages of life—egg, tadpole, and adult—creating serious environmental consequences. The toads contain bufadienolides, which are alkaloid compounds harmful to vertebrates and induce mortality in predators that consume them (Shanmuganathan et. al. 2010).

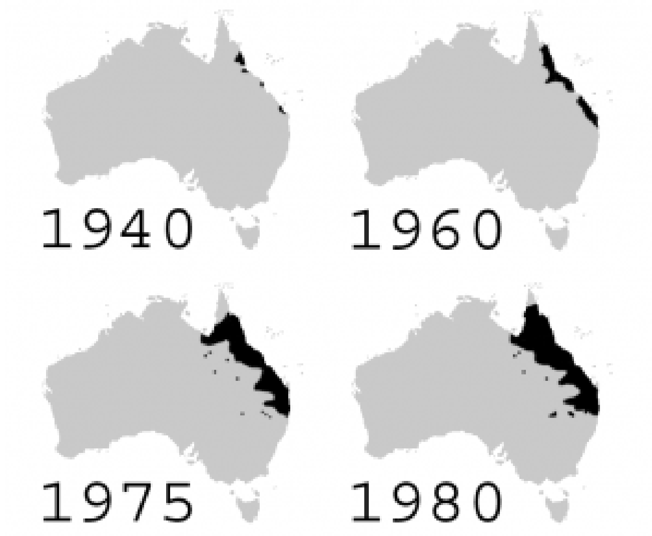

Figure 3. *The spread of cane toads in Australia since 1940. "Cane toad distribution map" by B kimmel is licensed under CC BY-SA 3.0.*

Population and Control

Cane toads were first introduced to Australia in 1935 and since have spread westward across the continent at an average rate of 40-60 km per year (Cane…c2021). As shown in Figure 3, it did not take long after their introduction for the species to spread across the continent. According to the World Wildlife Fund, Australia was home to over 200 million cane toads in 2019, which grew from an original population of 102 individuals. Their movement is assisted by human transportation of timber, construction material, and potted plants from the species' native habitats and places where they have colonized (Cane…c2021). Toads will latch on to the plants and then be brought to other parts of Australia. Spikes in populations can be attributed to such human activity (Greenlees et al. 2018). Additionally, research has concluded that the cane toad's extremely cannibalistic nature causes them to prefer unoccupied breeding pools to those already occupied with spawn. This not only has caused them to spread faster, but also prompted some issues within conservation efforts involving chemically induced cues, and may also lead to a different approach to species management (McCann et al. 2020). Controlling the cane toad population is of great importance, as their toxins kill many of Australia's native predators (Cane…c2021).

Various methods have been tested to control the growing population of cane toads in Australia, such as biological control and physical barriers. The usage of native species as predator control for the cane toad population is one that is often considered; because of the cane toad's lack of predators in Australia, management plans have considered species endemic to Australia as a possible form of predator control. A family of snakes that inhabits Australia, known as **colubrids**, had some success against the cane toad's toxins in smaller doses. Specifically, the keelback snake (*Xenochrophis piscator*) and slaty-gray snake (*Stegonotus cucullatus*) have been seen in the wild eating juvenile cane toads without any major effects on the snake's health (Phillips et al. 2003). However, it has been recorded that fully grown cane toads are capable of producing enough toxins that can be lethal to these colubrids, thus leaving these snakes only successful against juvenile cane toads (Phillips et al. 2003). Because of this, the usage of these colubrids to manage cane toad populations is not always effective.

Another native species that targets the earlier life stages of the cane toads is the meat ant. This ant species feeds on cane toads in their early metamorph stages, when individuals are small and do not yet have enough toxins to kill the feeding ants. In a 2010 study, meat ants attacked about 84% of cane toads present in a controlled environment within two minutes (Ward-Fear et al. 2010). However, this solution presents the same problem as colubrid snakes in that the ants can only control cane toads during a single life stage. Another more simple method of control is physically blocking breeding pools with fences or flora, as well as mass culling of populations through manual extermination. Taren Point in Sydney, Australia, for example, saw success in eliminating its cane toad population through these methods (Greenlees et al. 2018). Finally, the Australian government encourages individuals to educate themselves on what a cane toad looks like so that they may remove individuals from their property humanely. They also recommend that landowners check their ponds and streams for cane toad eggs and dispose of them before they hatch. The Australian government continues to fund research on controlling the cane toad population but has not made a definite choice between the methods described previously.

Ecological Impact

The toxins of the cane toad do not only impact animal species. Humans also have suffered impacts from the cane toad's **bufotenine** as far back as the 1950s. Researchers discovered that bufotenine is very similar in composition to serotonin, prompting research into how the toxin affects humans. Subjects reported hallucinatory effects similar to LSD, but also nausea and chest pain. In 1989, the topic of cane toad toxin as a drug began to circulate again when two American teenagers were hospitalized after licking cane toads to achieve a high, and one Australian died after ingesting cane toad eggs for similar purposes. The toad was quickly at the center of drug-war media headlines (Horgan 1990).

In terms of Australian predators, large predators are most at risk due to their size and ability to eat cane toads whole. For example, the saltwater and freshwater crocodiles of Australia have had their population experience a large dip since the cane toads were introduced. Depending on the location, rivers and other bodies of water have seen populations of crocodiles decrease between 15 to 80 percent (Letnic et al. 2008). This is primarily due to crocodiles having a long development period (12 years), which affects their

breeding population. Smaller aquatic predators tend to go after cane toad eggs and tadpoles rather than their adult counterparts. The eggs contain a gelatinous coating that masks their toxins, meaning predators are less likely to spit them out as they may with tadpoles or adults. Fortunately, the short breeding season and quick **metamorphosis** period of the cane toad means that the risk to aquatic predators in Australia is low (Greenlees and Shine 2011).

Not all groups of species are impacted in the same way, however. According to research conducted by scientists at the University of Sydney, many species of larger predatory birds in Australia tend to survive interactions with cane toads (Figure 4). The underlying issue is that it's difficult to identify all of the species of birds potentially being impacted in the first place. However, the researchers were still able to gather data on specific groups of birds (larger ones that are more visible to humans in particular), and interestingly enough, 16 species ate toads with no ill effects, four died after consuming toads, and three species had no sufficient data (Beckmann and Shine 2009). The authors ultimately found that out of 42 cases with interactions between predatory birds and cane toads, 34 of them survived the encounter, which translates to 81% of the predatory birds surviving.

Figure 4. *[“Kookaburra with Cane Toad”] by Andrew Mercer is licensed under [CC BY-NC-SA 4.0]*

The cane toad’s ecological impacts go beyond just being toxic; they are typically cannibalistic and eat pretty much everything. Since their population numbers are so high, they rarely can find sustainable food sources and end up eating each other. However, researchers have found that some ecosystems, like **apiaries** and livestock farms, can sustain large populations of toads. Instead of their typical cannibalistic and spreading-out behaviors, toads congregate around bee boxes night after night (Silvester et al. 2018). Although this behavior is detrimental to the health of these bee farms, because the cane toads don’t migrate away, the strain on nearby ecosystems is lessened.

Conclusion

To summarize, the cane toad population is a native South American toad that continues to impact a multitude of species and ecosystems throughout Australia. Even though they were originally introduced to deal with insect pests in sugarcane crops, the invasion of these toads has gone much farther than their intended purpose. The case of the cane toads is an ongoing issue of an invasive species that got out of hand due to its ability to adapt, voracious appetite for anything, and ability to produce toxins. The methods of controlling cane toads are still being researched, with some species of native snakes, ants, and birds having some success in controlling the cane toads. Manual extermination is currently an effective practice to reduce these populations, but researchers are continuing to look into a solution that could help mitigate the growing population of cane toads without harming the Australian ecosystems any further. With global warming, the cane toads are expected to move southward and continue damaging even more Australian ecosystems.

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9. The Invaders of North America

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Abstract

This chapter will discuss the issues of invasive species in North America, specifically pertaining to wetland, freshwater, and woodland ecosystems. The invasive species in these areas—purple loosestrife (*Lythrum Salicaria*), goldfish (*Carassius auratus*), and gypsy moth (*Lymantria dispar*; Figure 1)—cause biodiversity loss, habitat loss, and economic damage in the areas in which they reside. Globally, invasive species have cost 1.288 trillion dollars over the last 50 years. This chapter will explore various species-specific solutions to the invasive species problem, as well as more generalized solutions including improved education and expanded research techniques.

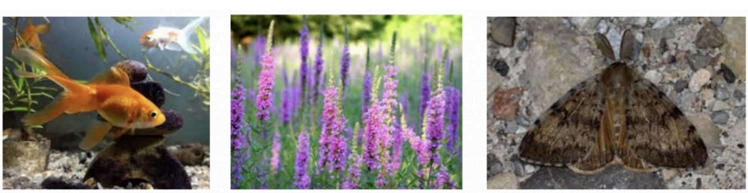

Figure 1.

The Problem

Invasive species cause environmental harm to an area upon their introduction because they are non-native to the environments that they affect, adapting and reproducing in their new habitats quickly. Often, new areas do not contain any natural predators for non-native organisms, and, with plenty of resources, it is easy for new organisms to have a substantial negative impact. The introduction of invasive species can cause detrimental issues such as drastically altering landscapes, like changing forests to meadows or wetlands to prairies (Sodhi et al., 2010). These landscape changes induce other effects including a decrease in biodiversity, habitat loss, and resource depletion, as well as human-centered issues such as economic and industrial problems (National Geographic Society, 2012).

Humans often bring invasive species into new habitats, either purposefully or accidentally (National Geographic Society, 2012). Methods for purposefully introducing invasive species can include using organisms for pest control and the pet industry (National Geographic Society, 2012). Accidental introductions include the contamination of transported items including vehicles, construction tools, and shoes (National Geographic Society, 2012). Regardless of how invasive species integrate into new habitats, disastrous effects are bound to follow for the ecosystems they infiltrate (National Geographic Society, 2012).

The effects of invasive species are largely felt by local species, who face problems like habitat loss, decreases in biodiversity, and depletion of resources. These problems are heightened when the local, native species are forced to compete with non-native, invasive species. Habitat loss not only impacts individual organisms but also the health of the global ecosystem (National Geographic Society, 2012). All animals within an ecosystem are affected by habitat loss; however, its effect is generally more serious for larger animals because they need a greater area in which to have a healthy breeding population (Evans et al., 2011). The increase and expansion of invasive species pose a strong threat to native species as they struggle to cope with highly changing environments. In order to reduce diversity loss, it is important for conservation efforts to focus on reducing the number of invasive species within an ecosystem (Evans et al., 2011).

Invasive species take both an ecological and economic toll on the human population. The economic and social impacts of invasive species include effects on property values, agricultural productivity, public utility operations, native fisheries, tourism, and outdoor recreation, as well as costs associated with invasive species control efforts (U.S. Department of Agriculture, 2020). Globally, it is estimated that the economic cost of invasive species has been 1.288 trillion dollars over the past 50 years (Zenni et al., 2021). These expenditures are used to reduce the losses caused by invasive species. Quantifiable economic impacts attributed to biodiversity loss and the environment tend to be indirect, making them more challenging to collect and estimate. While prevention might not necessarily be cheaper than control and impact-reduction efforts, in many cases it can help diminish the costly environmental, agricultural, and health impacts observed through the introduction and impact of invasive species. The best way to reduce damage costs would be to increase spending on prevention (Zenni et al., 2021).

In order to begin research into the effects of invasive species, the following questions were posed: what is the cascade effect of invasive species, how do different habitats respond to invasive species, and are there benefits gained from invasive species? To analyze the threat of invasive species, three were selected: the purple loosestrife in wetlands, the goldfish in freshwater bodies, and the gypsy moth in woodlands.

Primary sources of reference for scholarly research articles were SCOPUS and Gale OneFile. Newspapers were used to establish a historical record of the three invasive species and their habitats. Academic papers and studies were used to gain more information on the effects of the three species and the degradation of the habitats. Information from government sources like the U.S. Fish and Wildlife Service, the U. S. Department of Agriculture, and the U.S. Department of the Interior were used to compile information on the prevalence of invasive species in the United States. Additionally, quantitative data was compiled, such as statistics on the increasing populations of invasive species and statistics on the decreasing populations of affected species. Included qualitative data focused on descriptions of the changes in each of the three habitats as well as information on the specific issues the affected species face. A series of expert interviews were also conducted, with specialists Sara Campbell and Leigh Greenwood. All data were analyzed by comparing information between the three types of habitats. Similar themes and statistical trends were found through this comparison.

The expected outcomes of this research include a demonstration of habitat changes and decreased biodiversity. When viewing the habitats before and after the introduction of the invasive species, it would be expected to see a decrease in the biodiversity of organisms that are native to these areas due to unregulated competition. The invasive species have no natural predators and are free to reproduce, so they are unable to be naturally controlled and dominate the native species. The habitats that the invasive species overtake would be expected to change as well. Investigating the success and failure of specific plants and animals would contribute to a conclusion on the environmental effects of invasive species. The wetland, freshwater, and woodland areas themselves would also be affected by the invasive species, posing implications for the survivability of native species of these areas that are adapted to the conditions of these ecosystems.

Background

Wetlands are particularly important ecosystems that serve many purposes despite their small size. They are shallow-water ecosystems, with the most agreed-upon depth for shallow-water being six meters (Rejmánek & Simberloff, 2011). They are periodically or permanently flooded with water, inhabited by various species that have evolved to survive in floods (Rejmánek & Simberloff, 2011). There are distinct types of wetlands but the majority fall under three categories: swamps, marshes, and shallow open waters. Wetlands support a variety of animals and plants including herons, egrets, storks, white-tailed deer, alligators, ducks, geese, grass-like plants, and frogs (Mitsch et al., 2015).

Ecologically, wetlands provide numerous systems that encourage biodiversity in plants and animals and allow numerous species to flourish in nature. They provide breeding grounds to migratory birds, food to various mammals, and homes to reptiles and amphibians. Wetlands also store carbon, filter water, and provide other economic services (Rejmánek & Simberloff, 2011). Despite covering less than nine percent of the Earth's surface, they are key to the survival of numerous species and the success of local economies (Rejmánek & Simberloff, 2011). Wetlands can decrease the chances of floods in neighboring areas since they are able to contain large volumes of water (Mitsch et al., 2015). They can filter out pollutants and chemicals from water and can provide more drinking water in drier seasons (Mitsch et al., 2015). Many waterfowl that breed in wetlands are hunted and sold, providing an income to families (Mitsch et al., 2015).

While wetlands can provide many services to both people and animals, they are at great risk of being affected by invasive species. Wetlands depend on well-balanced ecosystems and proper nutrients and chemicals in the water, both of which can be disrupted by invasive species. Invasive species can alter every facet of the habitat, from the vegetation to the water (Rejmánek & Simberloff, 2011). Woody invasive species, like the purple loosestrife, deplete the groundwater leading to wetlands being much drier and prone to fires (Rejmánek & Simberloff, 2011). Some invaders alter the nutrients in the soil, preventing other plants from receiving what they need to continue to grow, and encouraging invasive plants to thrive (Rejmánek & Simberloff, 2011). Floating invasive plants stop light from reaching further into the water, preventing underwater plants from photosynthesizing and providing oxygen, leading to the suffocation of fish (Rejmánek & Simberloff, 2011). The increase in surface plants also makes moving across the water much more difficult for surface dwellers and people in boats (Rejmánek & Simberloff, 2011).

The purple loosestrife was introduced to North America in the 1800s in three different ways, the first of which was accidental (Invasive Species Centre, 2020). Seeds of the purple loosestrife plant had been found in the soil used as **ballast** on ships (Invasive Species Centre, 2020). As ships entered the area, ballast mixed with local water sources, causing the exposure of purple loosestrife to North American water sources, such as wetlands. In addition to ballast, purple loosestrife was brought to North America as a beekeeping plant (Invasive Species Centre, 2020). While the purple loosestrife served as a beneficial contributor to the beekeeping industry, its presence quickly spread to other areas (Invasive Species Centre, 2020). The purple loosestrife was also brought over as an ornamental plant that was found in many North American gardens (Invasive Species Centre, 2020). These three introductions led the purple loosestrife to take over ecosystems, especially wetlands where conditions proved ideal for the purple loosestrife to thrive (Invasive Species Centre, 2020).

The purple loosestrife can thrive due to their "strong, persistent taproot" that "becomes woody with age and stores nutrients which provide the plant with reserves of energy for spring or stressful periods" (Invasive Species Centre, 2020). This strong foundation equips the plant for harsh North American winters, allowing it to compete with native plant species. In addition to its competitive nature, during a growing season, the purple loosestrife can generate 2.7 million seeds (Invasive Species Centre, 2020). These characteristics of reproduction allow the plant to spread rapidly while maximizing its range. The purple loosestrife also has thin stalkless leaves which vary in size according to light availability. Finally, at the tip of the plant lies a spiked cluster of purple and pink colored flowers, which bloom from June to September and are pollinated by bumblebees and honeybees (Invasive Species Centre, 2020).

Although the purple loosestrife captivates people with its natural beauty, the destruction they cause is anything but. The reproduction period of the purple loosestrife is enhanced by weather conditions in North America such as rain, floods, and winds, making it easier for purple loosestrife seeds to spread to viable ecosystems. The purple loosestrife can be found in every U.S. state except for Florida, Alaska, and Hawaii. Figure 2 shows a population density map for reported cases of purple loosestrife in North America, with darker shades of green representing denser areas. In addition, this map only displays reported areas of purple loosestrife presence; however, there is a possibility of many more affected areas.

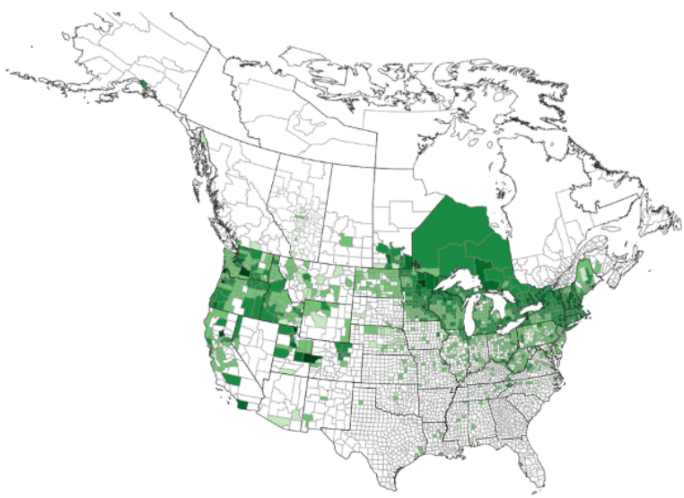

Figure 2. Purple loosestrife range. Available online from EDDMapS, 2021.

Its ability to compete and survive during cold winters with a rapid reproduction period causes the plant to outcompete native species for resources and space. In some locations, “purple loosestrife strands have replaced 50% of the native species” (Invasive Species Centre, 2020). The replacement of native plants with a singular species causes a major decrease in plant biodiversity for the entire ecosystem. In a study conducted in 2011, biodiversity in habitats dominated by purple loosestrife was compared to that of a native plant species called the broad-leaved cattail (*Typha latifolia*) in controlled **mesocosms**. It was concluded that species diversity in the cattail spaces was far greater than that of loosestrife locations. While a certain beetle species thrived in cattail environments, their richness was suppressed in the loosestrife mesocosms (Hovick et al., 2011). In addition, purple loosestrife leaves decomposed at a higher rate than native plant species, causing nutrients to be flushed from wetlands during an earlier part of the year. This change in the timing of chemicals present in wetlands has “slowed frog tadpole development, decreasing their winter survival rate” (Invasive Species Centre, 2020). In addition to frog populations, the thickly wooded roots of the purple loosestrife reduce nesting site availability for birds and fish, causing habitat loss.

Another affected habitat is freshwater bodies. Freshwater bodies such as lakes, ponds, rivers, and streams house a vast and diverse range of species. The sustainability of this biodiversity is being threatened, largely by human activity. Simultaneously, humans benefit from resources such as the drinking water and commercial fisheries provided by freshwater ecosystems. Despite a plethora of environmental directives, regulations, and actions taken at regional and global levels, **anthropogenic** risks have not yet been tackled satisfactorily (Langhans et al., 2019). Of these anthropogenic risks, boating poses many negative implications for the future of freshwater bodies. When boats move between water bodies without taking proper precautions, they can introduce unwanted invasive “hitchhikers” into new environments. Primary sources of exotic species introduction to U.S. waters include ballast water and organisms in trade (Oh et al., 2018). Boating activity is an important contributor to the secondary spread of aquatic invasive species once they become established in U.S. waters (Oh et al., 2018). Freshwater body connectivity and globalization contribute to this issue, and there is a strong correlation between high connectivity and increased aquatic invasive species infestation status (Kao et al., 2021).

Invasive species in aquatic environments pose a huge risk to freshwater habitats. In an interview with Sara Campbell, a specialist on freshwater fish, conservation, invasive species, and biodiversity, (personal communication, November 17, 2021) she informed that invasive species are the second leading case for freshwater fish imperilment. Specifically, in the Great Lakes Region, 20-30 species have been lost due to invasive species and their effect on native ecosystems (S. Campbell, personal communication, November 17, 2021). These effects include drastically changing the habitat and disrupting the food webs.

Goldfish have been an exceedingly popular pet in North America since the 1800s. The fish's popularity grew quickly, and it spread throughout North America. The U.S. Department of Fisheries was the first to receive an official import of goldfish, and they used them as a publicity stunt to increase the popularity of the department (Gulliver, 2012). They sent a goldfish in a glass bowl to anyone in the D.C. area who wrote a letter to them (Gulliver, 2012). This easy method of obtaining the fish enabled many households to have one. The department eventually ceased distributing the fish; however, the damage had been done in the area (Gulliver, 2012). The ease of breeding the fish combined with their flashy orange coloring made them a popular prize at carnivals in the 1900s, making them common in houses with young children (Gulliver, 2012).

Since they are often kept as pets, it is possible that owners lose interest in their fish and release them into a local body of water. Figure 3 shows all reported instances of goldfish found in freshwater bodies, making it clear how often the fish are released by bored pet owners. Once goldfish have survived being a pet, they are considered very fit and have a high chance of surviving in the wild (S. Campbell, personal communication, November 17, 2021). In addition, the lack of natural predators of the fish allows them to thrive in freshwater bodies and easily breed. They can eat as much as they want, consuming nearly all the food in the area (Gulliver, 2012). This leaves little food for the local species, preventing them from eating and surviving (Gulliver, 2012). Goldfish also like to dig, leading to the sediments being disturbed (S. Campbell, personal communication, November 17, 2021). The disturbance of sediments prevents local fish from seeing due to the increased cloudiness in the water (S. Campbell, personal communication, November 17, 2021), and encourages algae blooms by introducing more nutrients into the water (Yin, 2016). The fish often carry diseases and parasites from the aquarium trade (S. Campbell, personal communication, November 17, 2021), leading to local populations being infected by the diseases and dying due to a lack of resistance (Yin, 2016).

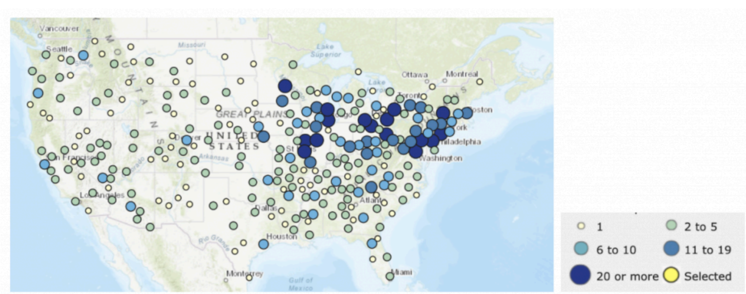

Figure 3. "[Nonindigenous Aquatic Species- Carasius auratus]" by [United States Geological Survey] is in the [Public Domain, CC0]

In North America, goldfish do not have as severe an effect as other aquatic invasive species (S. Campbell, personal communication, November 17, 2021), but the potential for them to be a bigger problem is still there. Goldfish have a higher tolerance than local species, meaning that if there are changes in water pH or the chemicals in a water body, goldfish are much more likely to survive than local species (S. Campbell, personal communication, November 17, 2021). In Australia, goldfish have grown up to 16 inches long, making the water cloudy while breeding rapidly. Scientists fear this trend could repeat itself in North America (Yin, 2016). Goldfish are also able to breed with other local carp species, damaging their biodiversity (S. Campbell, personal communication, November 17, 2021) and making it much easier for the goldfish to blend in with other local species. In Australia, goldfish have started to move in schools and show behavior of being a migratory species (Yin, 2016). Their movement allows them to damage greater areas of the riverbed and increase their spread as they move into various channels and new bodies of water (Yin, 2016). Goldfish are still in an early stage of invasion in North America; however, they could become an even larger problem without any preventative efforts.

Woodlands are another habitat affected by invasive species. Found throughout North America, they are largely dominated by trees but have an open **canopy**, allowing full sunlight to enter the woodland (National Geographic Society, 2011). Woodlands are home to a variety of mammals, such as deer, bear, moose, rabbits, squirrels, as well as birds and insects. Woodlands are also important for increasing urban biodiversity. They are often transition zones between different ecosystems, such as grasslands, true forests, deserts, and urbanized areas (National Geographic Society, 2011). Woodlands provide trees for lumber and fuel, carbon dioxide scrubbing and carbon sequestering, and produce oxygen (Mousam Way Land Trust, 2018). The woodland ecosystem helps reduce the rate of climate change and its effects, stabilize soil, filter water, and provide an escape for people to enjoy time outdoors (Mousam Way Land Trust, 2018). A higher level of diversity promotes a higher activity level of these actions. However, with invasive species moving in and hindering this progress, like the gypsy moth, it becomes harder for woodlands to fulfill their full potential.

The gypsy moth was accidentally released in Massachusetts in

1869 from Eurasia (Johnson et al., 2006), and since then it has spread to the entirety of New England. This small insect has pairs of dots lining its back and body that are covered in dark hair. The males have light brown wings, while the females can have white to cream-colored wings. These moths may look unassuming and extremely common; however, they are responsible for devastating effects on woodland ecosystems. They cause large-scale defoliation due to their rapid leaf consumption, as shown in Figure 4, and are able to defoliate from 700-50,000 km² annually (Johnson et al., 2006). This defoliation causes tree mortality, which affects the species that use them for their habitat. These species are mostly fellow insects, and this habitat loss can lead to endangerment and extinction (Johnson et al., 2006).

Figure 4. "[Extensive gypsy moth defoliation in Southern New England characterized using Landsat satellite observations]" by [Pasquarella et al. 2018] is licensed under Public Domain.

The gypsy moth's competitive nature towards native insect species is an additional catalyst for extinction, as they dominate the woodland areas. In an interview with Leigh Greenwood, an ecologist and entomologist that specializes in environmental conservation, she explained that the gypsy moth has few natural predators (personal communication, November 22, 2021). These predators include the baculovirus, which stops larvae from growing, and birds and squirrels that feed on them (personal communication, November 22, 2021). The presence of these predators does not significantly deter their domination due to their rapid and unpredictable reproduction methods. Gypsy moths reproduce through a process called "ballooning," when the larvae create silk threads that are caught in the wind or attach themselves to animals and people, making their spread extremely hard to contain (U.S. Department of the Interior, 2019).

Results

While the effects of purple loosestrife are largely negative, there are some organisms that benefit from the introduction of this invasive species. The purple loosestrife's flowers are typically pollinated by insects, consisting primarily of bumblebees and honeybees, which promotes cross-pollination between floral morphs (Invasive Species Centre, 2020). Purple loosestrife is still used in flower gardens today and occasionally sold in nurseries, generally for beekeeping and pollination purposes (Invasive Species Centre, 2020). There are also individual bird species, like the Virginia rail (*Rallus limicola*), who are positively influenced by the introduction of purple loosestrife if open areas, like water pools, are present (Tavernia & Reed, 2012).

Although purple loosestrife supports bumblebee and honeybee populations, this invasive plant is responsible for the loss and depletion of native plants like cattails (*Typha*) by out-competing for space, light, and pollinators. Cattails provide homes to muskrats (*Ondatra zibethicus*) and a variety of nesting birds, such as marsh wrens (*Cistothorus palustris*) (The Nature Conservancy, 2019). Purple loosestrife drains the ecosystem of these necessary shelter and food resources for the species. The dense loosestrife roots also clog water channels in marshes. These are places where fish would come to spawn, ducks would feed, nutrients would flow, and insects could hide and feed along the edges. These places and the species that reside there are no longer able to thrive once purple loosestrife is introduced into the ecosystem.

To prevent the spread of purple loosestrife, scientists have experimented with different methods. If a community notices the purple loosestrife early on, it is possible to physically remove each individual organism in order to prevent their spread. In Brook Marsh, Canada, for example, volunteers “canoed between islands in the marsh, pulling up plants as they went. They used trowels to make sure they removed all of the roots” (Ducks Unlimited Canada, 2018). In this instance, the wetland ecosystem was spared from a purple loosestrife invasion, but it took immense physical labor along with the willingness of the community to help.

Another method scientists have experimented with is biocontrol, specifically, the use of insects to control the spread of purple loosestrife. Since 1994 in Wisconsin, scientists have been using four beetle species originally from Europe that kill only purple loosestrife plants (Wisconsin DNR, 2021). Although it is a lengthy process, biocontrol “is likely the best long-term control for loosestrife” (Wisconsin DNR, 2021).

The last popular method for controlling the spread of the purple loosestrife is the use of aquatic herbicides, specifically glyphosate. In Minnesota, residents can obtain permits to spray their infested land with glyphosate and must follow specific regulations for this process. The Department of Natural Resources for Minnesota notes that “glyphosate is nonselective, meaning it will kill all types of plants,” so selective use of the herbicide is necessary (Minnesota DNR, 2021). If done properly, the death of the loosestrife plants will create “holes in the vegetation” that will be filled by native plants (Minnesota DNR, 2021). Although herbicide use is more effective in killing purple loosestrife, the risk of causing biodiversity loss and population declines for native species is far greater than biocontrol and physical removal.

As for goldfish, species benefitted by their spread and behavior of the goldfish are algae, specifically **cyanobacteria** that live in freshwater habitats (McGowan, 2016). These algae can thrive off nutrients released into the water by the goldfish’s feeding and digging habits, having an overwhelmingly negative effect on the areas in which they appear (Gulliver, 2012). Up to 50% of the cyanobacteria species are toxic and lead to sickness in humans and animals (McGowan, 2016). These toxins are known to cause severe sickness, cancer, and even death in those who ingest them from water sources (McGowan, 2016). The toxins can work up the food chain and kill the birds that consume infected fish, leading to losses in the populations of many species (McGowan, 2016).

Found frequently in the Great Lakes, goldfish have begun to establish a population there and disturb the native species (Yin, 2016). One fish affected by aquatic invasive species in the Great Lakes is the shortjaw cisco (*Coregonus*) (Hoff & Todd, 2004). This refers to three different species that were originally found in Lake Michigan, Lake Huron, and Lake Superior. In the 1920s, the shortjaw cisco made up more than 90% of deep-water catches in the Great Lakes (Hoff & Todd, 2004). By the 1970s, the shortjaw cisco made up at most 31% of deep-water catches; however, there were years where that number was 0% (Hoff & Todd, 2004).

Several different methods have been experimented with to prevent the spread of goldfish. In 2019, Carver County, Minnesota used physical removal when the Water Management Organization discovered large schools of goldfish in Big Woods Lake during routine monitoring. To begin, staff used **seine nets** to capture and tag 500 individuals. These individuals were released back into the water so that the team could track them to the most densely populated areas of the lake, and this is where they would focus their efforts. After the data was collected, the team used box nets, seine nets, and dip nets to capture over 100,000 goldfish over the span of one year. The team is currently still working on removing more goldfish from the lake and has removed 11,300 goldfish during spring 2021 (Carver County, 2021).

In addition to physical removal, scientists in Minnesota have experimented with long-term management methods including fish barriers and aerators to increase the oxygen levels in bodies of water (Carver County, 2021). Research has led to new methods of aquatic invasive species control (S. Campbell, personal communication, November 17, 2021). Carbon dioxide bubbles and strobe lights in the water can act as a nonphysical barrier to deter fish movement into new areas (S. Campbell, personal communication, November 17, 2021). In places where trade takes place, it is especially important to monitor and control the movement of invasive fish species so that they are unable to invade new areas. In addition to scientific methods, there are laws in place requiring ships to release ballast water prior to entering port so that nonnative larvae or juvenile fish are not introduced into a local freshwater ecosystem.

Since gypsy moths are responsible for large-scale defoliation, they most directly affect various tree species, specifically oak (*Quercus*). Populations of gypsy moths defoliate trees, but the species of trees typically don't go extinct (L. Greenwood, personal communication, November 22, 2021). Trees in stressed environments may be more susceptible to death due to the defoliation caused by gypsy moths (L. Greenwood, personal communication, November 22, 2021). Gypsy moths also indirectly affect other species within the woodlands, like the New England cottontail (*Sylvilagus transitionalis*). A critical threat to the New England cottontail is the loss of habitat, places where the rabbits can find food, raise their young, and escape predators. Thousands of acres of cottontail habitat have become defoliated by the gypsy moth, preventing the rabbits from expanding and flourishing (Wildlife Management Institute, 2018).

Some measures that are being implemented to stop the gypsy moth spread include various sprays that are applied to the woodland habitats that they infest. The spraying of pesticides is a popular method that aims to kill live gypsy moths. Pheromone flakes have been developed as well, and when they are sprayed, they disrupt the mating process of the gypsy moth, aiming to stop their growth by hindering their reproduction (Jaeger, 2003). These existing methods have not been enough to significantly impact the gypsy moth population, as outbreaks have become more and more common. Additionally, both methods can have dangerous effects on the balance of the environment, as pesticides and pheromones disrupt the entire woodland ecosystem.

Recommendations

To decrease the spread of invasive species in North America, education and research are both necessary to improve current conditions. Education, especially on a local level, would help spread awareness and caution regarding invasive species in local ecosystems. This could be implemented through school programs and local community efforts, so residents are united in their understanding. These efforts would be key in communities that have a direct stake in the affected ecosystems like boaters, pet owners, and flood-prone areas. Without education, there is no baseline for knowledge or strategy on how to approach the problem. To provide adequate education on the issue of invasive species, more research must be done regarding the problem. This research should be done on both large and small scales to provide the public with a cohesive and extensive plan. Research should also be focused on prevention methods and early signs, rather than solely on management. These recommendations will prove successful when better awareness and care towards invasive species is shown and invasive species no longer have as severe of an impact.

Conclusion

Purple loosestrife, goldfish, and gypsy moths were all brought to North America during the 1800s due to a freshly globalized trade enterprise. Since then, all three species have been spreading throughout North America causing a loss in natural habitat and biodiversity. In addition to these ecological effects, invasive species have taken a great toll economically. Purple loosestrife degrades farmlands and clogs irrigation canals (Invasive Species Centre, 2020). The commercial fishing industry is affected by goldfish that decimate the populations of locally consumed fish. Through government expenditures and timber losses, the financial toll of the gypsy moth is an estimated 3.2 billion dollars per year (Leroy et al., 2021). Invasive species have cost a total of 1.288 trillion dollars globally over the last half-century.

Early intervention will decrease expenses, and ecosystems can be better preserved. Greater education will lead to the average person being more aware of their surroundings and making efforts to hinder the spread of invasive species. Better targeted research into identifying invasive species in the early stages can lead to improved legislation surrounding them and a more cohesive course of action to eradicate invasive species.

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10. Mass Attack: A Look at the Invasive Purple Loosestrife in Massachusetts

CAMILLE PRATS; ELIZA DUTSON; MARGARET KRAWITZ; AND HANNAH PELOQUIN

Abstract

This research project focuses on the regulation of the **purple loosestrife** (*Lythrum salicaria*), an invasive plant species common in Massachusetts. The research conducted in this project aimed at finding the reasoning behind the lack of legislation to control **invasive species** in Massachusetts, as well as analyzing how the purple loosestrife can be contained in the state. The overall goal of this research project was to analyze the methods that have been used in other regions of the United States to control the purple loosestrife as well as create a revised and updated solution to minimize the spread of this invasive species successfully and efficiently.

"Purple loosestrife beetle collection" by Oregon Department of Agriculture is licensed under CC BY-NC-ND 2.0

Problem Description

Invasive species are a major driving force behind the current **mass extinction event** being experienced by Earth, and while there are already regulatory methods in place, more action is needed to solve the problem and limit the rate of extinction. This project specifically focuses on invasive species in Massachusetts **wetlands**, specifically the purple loosestrife. This species exemplifies common characteristics of invasive species such as habitat invasion, the spread of disease, and the limitation of biodiversity in the invaded environment. In particular, the purple loosestrife has been known to influence the population size and habitats of certain bird species in Massachusetts such as the red-winged blackbird (Tavernia & Reed, 2012). Some contributions to the spread of this invasive species are increased human use of land, as well as the ornamental plant trade, and the animal (both agricultural and domestic) trade (Malecki et al., 1993). As a result of the uncontrollable spread of this invasive species, ecosystems are being destroyed and human access to resources is declining sharply. The goal of this project is to analyze the previously utilized methods for regulating invasive species in order to create a revised and updated solution for how to manage the spread of this species more efficiently in Massachusetts. Below, Figure 1 depicts the situation model of the project:

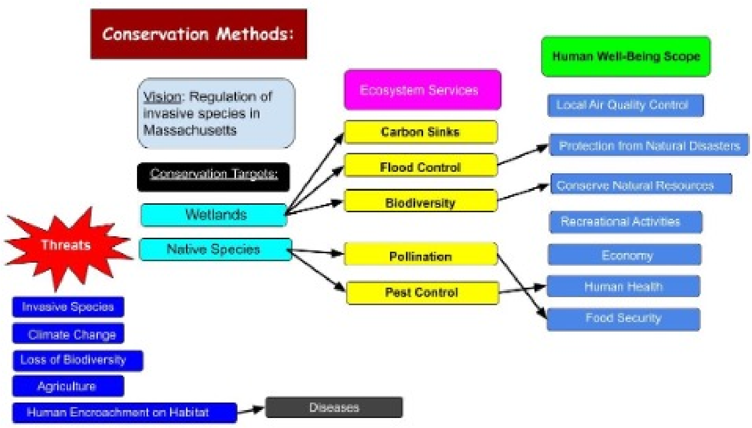


Figure 1. *The situation model for the control of the purple loosestrife. Created by chapter authors.*

Guided Research Questions

Some examples of guided research topics found within this project are the loss and damage that has occurred because of this invasive species, and whether the complete removal of this invasive species would be more harmful or beneficial to the overall health of the ecosystem. Furthermore, conclusions were drawn about what regulations can be created to help prohibit the spread of the purple loosestrife in the future. Using evidence-based data from government sources, the research consisted of analyzing the population changes of invasive species and how this depends upon the regulation methods in place at the time. Methods that were previously utilized to limit the spread of the purple loosestrife in Massachusetts included herbicides and the introduction of **biological control** agents such as insects (Blossey et al., 2001). Additionally, the research considered the cultural causes and effects of invasive species in Massachusetts and how this contributes to potential problems with the current regulatory laws.

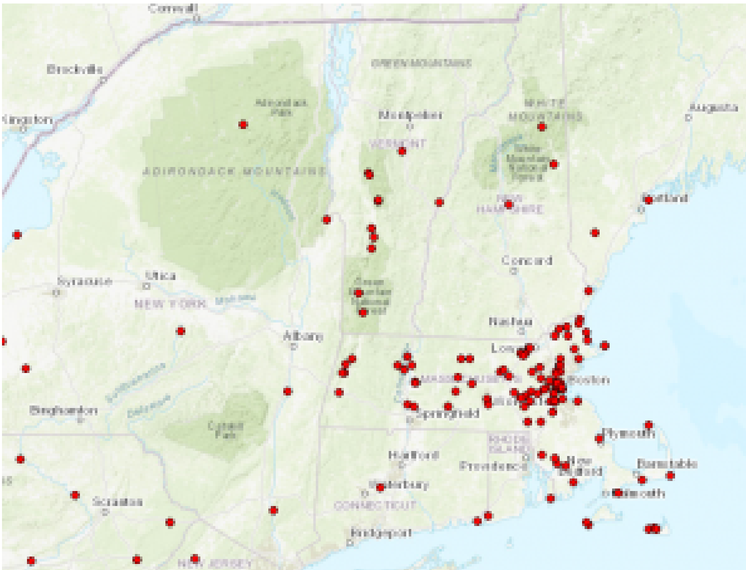
Social, Political, Economic, and Ecological Scope

Environmental regulation has historically been difficult to navigate, especially in the control of invasive species and their effects on native ecology. The balance between scientific theory and the real world is difficult to strike; invasive species could be controlled in an ideal situation by simply shutting down travel in and out of their area of introduction and deploying herbicides or biological controls in the form of a predatory beetle (Arroll et al., 1994). However, both choices have many real-world consequences far beyond the damaging invasive species in question. The other ideal would be to stop the species from invading in the first place, which, in a world that is rapidly globalizing, would be nearly impossible. It is difficult to check every shipment coming in and out of a region, but it is possible to put greater trade and travel restrictions in place, although they can be economically disastrous for the region and businesses they affect.

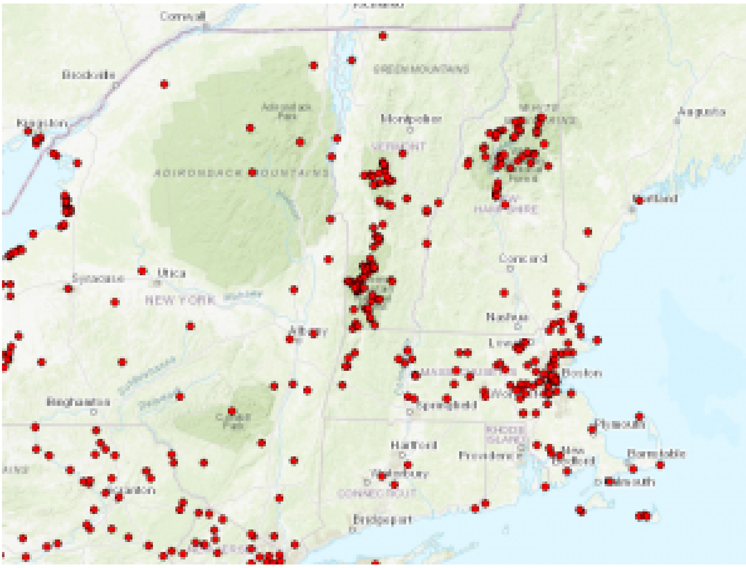
The purple loosestrife is one species that was able to invade North America in the mid-nineteenth century by coming over from Europe in seed shipments, both ornamental and agricultural, which then began to spread out of control (Lavoie, 2009). During the period it invaded there were few checks on **agrarian** import products into the US, especially as cheap British grain began to usurp Anglo-American grain in the American market, which allowed the purple loosestrife to tag along in these shipments (O'Rourke, 1997). It also was an extremely popular ornamental plant; however, its seed spread was such that it immediately grew out of control wherever it was introduced (Liu et al., 2005). When the purple loosestrife is introduced to a new wetland region it creates a desert where it is the only plant living in the region (Liu et al., 2005). The purple loosestrife has had centuries of growth to become entrenched in the ecosystems it destroys, so the question must now also be: would the removal of it negatively affect its host ecosystem more than its continued presence does? Based on the research that has already been done, in this case, the removal of the purple loosestrife can only bring good changes in the affected ecosystem when executed properly with careful methodology. With all the different people who have a stake in this issue, it is difficult to come to a consensus as to how it should be handled, everyone wants something different, and a compromise must be reached before implementation; however, there are some emergency situations where the normal checks and balances are bypassed.

Time and Spatial Scales

The research questions the group has decided to work on were answered through in-depth research, focusing on the effects of invasive species of purple loosestrife in Massachusetts. There is a major focus on searching for credible and reliable sources through university libraries and national park documents, as well as expert interviews. With these, Mass Attack strives to find case studies or articles about the purple loosestrife's effect as an invasive species. More research into the potential methods to prevent these species from spreading and background information on the species' biological and physical impacts like pest control, the effects on human health, and conservation of natural resources, is much needed.



Figures 2 (above) and 3 (below). Population density graph of purple loosestrife in 2000 (top) and 2021 (bottom). "*Non-indigenous Aquatic Species – Lythrum salicaria.*" *by the United States Geographical Survey is licensed under CC* BY-NC-ND 2.0



Because the purple loosestrife has been around for hundreds of years, there is information regarding their invasions and habits dating back to 1814 on the eastern seaboard of the northern U.S. (Montague, 2008). This longevity of information is beneficial for understanding the plant's introduction to the states, how it spreads, and the effects it has on the ecosystems it invades. After conducting extensive research into its progression, our group has chosen to focus on the more recent articles and publications to give us the best understanding of the information needed to answer the questions we are posing. We focused our information on the past 10-15 years because of the spike in loosestrife numbers during that time. When looking into the cause of the spike, it was found that there were more droughts than normal that took place during this time. Because the loosestrife is more tolerant to drought conditions, they were better able to survive and outcompete any native plants that were made vulnerable (Morelli, 2020). Throughout the beginning of our research, there was a big issue with not being able to find any information regarding the population of the loosestrife over time. Fortunately, though, a source involving an interactive map pertaining to the growth and spread of the loosestrife over the years 2000-2021 supplied a perfect figure to help readers understand how fast the growth was over a brief time (Figures 2 and 3). The more recent publications are also vital because they show an increase in threats the loosestrife poses upon these environments. With all the human land-use change that has been occurring to the environment, the frequency of invasive species inhabiting and taking over new territories has increased exponentially. With humans now having disrupted about 75% of land in the world, it has made ecosystems vulnerable and exposed to encroachment from invading species (Public Broadcasting Service, 2021).

Methodology

For this research project, reliable sources utilized consisted of academic journals, government resources, and previously conducted experiments about potential solutions to limit the spread of purple loosestrife. Specifically, the government resources that were focused on were previous regulations created to limit the spread of invasive species in other states around the continent. For example, one government source focused on a trial of using herbicides on the purple loosestrife from the years 1990-1999. The experiments also provided necessary data about potential solutions for limiting the spread of purple loosestrife. For instance, one such source consisted of graphs that illustrated the population density of purple loosestrife based upon the usage of herbicides and other biological control agents.

The data collected consisted of the changes in population size of purple loosestrife over the years 1980-2000 in Massachusetts or New England (Connecticut, Rhode Island, Maine, and Vermont) depending on which regulatory methods have been put in place. This data was split into sections based on the time in which it was collected, and what regulations were in place at the time.

The research plan consisted of analyzing what regulatory methods were used and during what time periods. To do this, evaluation reports of the different methods were examined, to determine which methods were successful and which were not. Consequently, the population size of invasive species was collected during the time to analyze how effective each regulation was in preventing the spread of invasive species. This data was used to create a plan of how to better prohibit invasive species from spreading.

Finally, the project group interviewed two experts in the field of invasive species who have studied purple loosestrife and conducted experiments using this species. These two experts gave the team more insight into some specific methods that could be used to limit the spread of purple loosestrife.

Results and Findings

The first interview conducted by the project group was with Dr. Jessica Rogers, a professor at SUNY Potsdam, who created artificial wetlands to **cultivate** beetles to use as biological control agents against the purple loosestrife (J. Rogers, personal communication, December 1, 2021). This potential solution was found to be simple and inexpensive, so it would be possible for the project group to replicate. The only supplies necessary consisted of a kiddie pool, dirt, a shovel, and 7-9 purple loosestrife plants (J. Rogers, personal communication, December 1, 2021). Since this method is not very costly, it would be an ideal solution for a project of this scale.

In the second interview, the group spoke with Vivian Kimball, a consultant, who also conducted a project focused on the purple loosestrife when she was a graduate student studying conservation biology in 2011. She provided the group with similar information as the first interview since she also utilized beetles as biological control agents (V. Kimball, personal communication, December 2, 2021). In addition, Ms. Kimball discussed the worries and concerns people may have with introducing another non-native species into the ecosystem (V. Kimball, personal communication, December 2, 2021). However, she explained that, based on the evidence she found in her experiment, the beetles tend not to migrate and instead stay in a contained area (V. Kimball, personal communication, December 2, 2021).

Conclusion

Overall, it was determined that the most advantageous and realistic solution to limiting the spread of purple loosestrife would be the introduction of biological control agents. This solution certainly has its own challenges and will require careful public information campaigns as well as transparency about the project itself. Biocontrol is not a new idea; however, it is an obscure one that can be very intimidating to the average person. For this reason, it is suggested to build a campaign that educates the public on this issue (V. Kimball, personal communication, December 2, 2021). It is also not the only viable solution; it's just the most effective, both in economic terms and environmental terms.

Regarding chemical control, it is not the most effective method against this species of plant. There is a grand variety of pesticides that the purple loosestrife does not get affected by, hence it is recommended to use RodeoTM or RoundupTM (Balogh, 1986). Unfortunately, RodeoTM has been discontinued due to how it negatively affects the environment. In the case of RoundupTM, it has been banned in about 20 countries because of its connection to cancer and non-Hodgkin lymphoma (Pintas & Mulllins Law Firm, 2021). Introducing the use of pesticides on these plants would be difficult due to its tedious process. Finding the exact moment at which it would be best to utilize this procedure against the purple loosestrife takes time that would eventually become a great disadvantage (Henderson, 1987). Because time is a major factor involving the spread of more invasive species, the chemical control method is not the most reliable. Besides this, the use of these pesticides can negatively affect water quality in wetland ecosystems.

This issue can be brought up to high school students, creating their own artificial wetlands and testing out the biological control method on purple loosestrife of their own. With this economically effective experiment, young scholars can learn the use of biocontrol as well as how severe the issue of invasive species is.

Acknowledgments

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11. The Giant African Snail: Escargot Away

GAVIN BURKHARDT; FELDMAN; DYLAN HUNT; AND REBECCA YOUNG

Abstract

This report examines the life, history, habits, and impact of the giant African land snail, *Achatina fulica*, as it travels across the globe. It is intended to inform and educate the public in studies and eradication of the snail. The snail originated in Nigeria and has spread to six continents, wreaking havoc on indigenous species and agriculture. Its unique adaptations allow it to survive in extreme climates and multiply rapidly. Countries have attempted to control it with physical, chemical, and biological tactics to varying degrees of success and costs in the millions of dollars. This invasion must be minimized before its threat to numerous industries and species becomes irreversibly realized.

Figure 1. The giant African land snail, achatina fulica. "Giant African Land Snail" by John Tann is licensed under CC BY 2.0

Introduction

It seems astounding that such a slow-moving creature could travel the entire world in less than 100 years, devastating natural ecosystems along the way. The giant African land snail is a globally spread and recognized species of **mollusk**. On average, they are 20 cm long, with a gray-tan body, and a cone-shaped shell, covered in brown and cream-colored swirls, as pictured in Figure 1 (Stokes 2006). It behaves similarly to other snails, preferring moist, dark **habitats** and resting places, and primarily becoming active at night (except for particularly humid evenings, when it may emerge earlier) (Capinera 2011). During dry spells (which are a common occurrence in its native eastern Africa), the snail aestivates, thereby decreasing its food and water intake. It does this either in the dirt, burrowing under and, as a result, increasing soil health, or on tree trunks, protecting itself from ground-based predators (Mead 1961, Stokes 2006). The snail's short-term **aestivation** is mixed with longer-term **hibernation**, which it deploys in longer periods of drought or nutrient deficiency. This **hibernation** behavior allows the snail to survive in damp patches of leaf litter without food for up to five months (Lange 1950). When active, the snail is a **scavenger**, with a diet consisting primarily of fallen leaves, excreta, decomposing fruits, and occasionally crushed members of its species (Lange 1950).

The giant African land snail was discovered before the start of the 18th century, though the exact date is unknown. This discovery was made near the border of present-day Somalia and Kenya. It has since been determined that the snail's natural **range** lies further south, in a moist coastal region shared between Kenya and Tanzania (Stokes 2006). In its natural **habitat**, the giant African land snail occupies places of damp ground where it can maintain its skin moisture.

Not-So-Sluggish Spread

The exact population of the giant African land snail is currently not well documented. It is considered a destructive pest across the majority of its **range**, so the focus of local peoples who come into contact with this snail is often to destroy them, not count them. Instead, the predicted population of the giant snail is more often quantified by its introduced **range**. Figure 2 shows a map of every country where the presence of the giant snail has been officially recognized, though the snail is thought to have already colonized almost every tropical and subtropical region in the world. Within these regions, it has been found that local snail populations are often larger and have greater **biomass** in rural regions than in urban regions. This is to be expected, as rural regions offer significantly more food and desirable **habitat**. However, the fact that a rural pest has been able to successfully establish itself in urban and suburban gardens means that it has likely already invaded other environments it would not be expected (Cano-Perez et al. 2021). Similar to its population, the magnitude of the snail's impacts is also not very well documented. Apart from some monetary estimations from the state of Florida (which stem from an invasion that occurred over half a century ago), estimations of the snail's population numbers and actual empirical impact are sparse, and when they do exist, they are often vague (O'Loughlin and Green 2017).

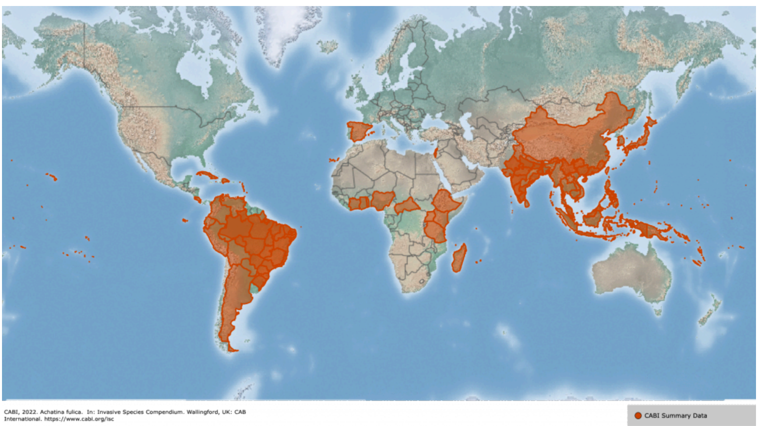

Figure 2. Map of the giant African snail's extent. Achatina fulica (giant African land snail) by CABI, with Permission.

The earliest known spread of the giant African land snail was observed in Madagascar in the year 1800. Its spread over the last two hundred years is documented in Figure 3, including dates. Its **range** did not extend from Africa until human intervention. The snail's first major expansion was by Imperial Japan from 1935 to 1945 (Lange 1950). Originally, the **mollusks** were used as feed for poultry, resulting in the introduction of the snail to most of Asia, as Japanese territories extended that far during that time. After this, the snails made their way to western world countries as pets, most notably Brazil and the U.S. (Wolfenbarger 1971). Some of these pet snails have been released into the wild by their owners, and have since established **invasive** populations in these regions. As shown in Figure 4, the further spread has slowed as the snail has moved farther away from Africa.

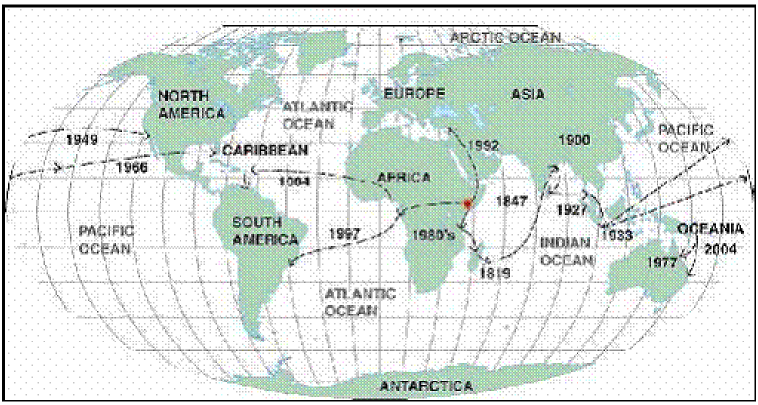

Figure 3. Map of the spread of the giant African snail from its origin. [“Dissemination of achatinid snails from Africa since 1804](#)” by [Heather Stokes](#), no copyright infringement is intended.

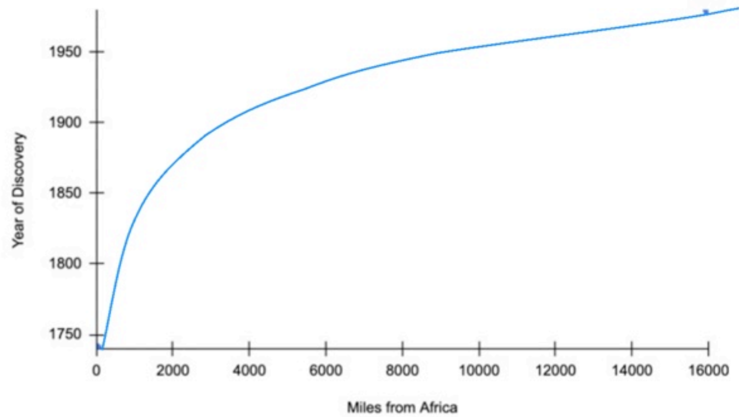

Figure 4. An approximated graph of the giant African snail's dispersion relative to Africa, based on data from Wolfenbarger 1971.

Factors Affecting Expansion

Many factors contributed to the spread of the giant African land snail, including their reproductive capacities, lifespan, and habits. A single snail can lay up to 500 eggs at a time (Lange 1950, Mead 1961). Usually, about 90% of these eggs survive, allowing a single snail to rapidly increase local population size during its five-year life span (Roda et al. 2016). In optimal conditions, clusters of eggs can be laid as often as every two weeks. The usual rate, however, tends to be two to six a year. Additionally, giant African land snails are **hermaphrodites** (Mead 1961). This trait improves the chance of reproduction by allowing a snail to mate with any other member of its species. Other elements that can cause a snail population to increase are an abundance of calcium carbonate in the environment and human disturbance.

Another influence on the spread is the unique physiology of snails, causing many snails, including the giant African land snail, to be immune to the negative effects of many infections and parasites. Their main defense comes from their thick shells and mucus membranes. When infected, their bodies react by producing **antimicrobial** proteins to counter any foreign body (Lima et al. 2020). Despite the natural immunity of snails, many parasites find a way to hitch a ride. One such disease carried by the snail is the rat lungworm, a parasitic **nematode** that causes meningitis in humans, leading to swelling of the brain and spinal cord; this is fatal if left untreated. The snail can also carry *Aeromonas hydrophila* bacteria which mostly affects children or those with weakened immune systems, causing gastroenteritis, tissue infections, and infected diarrhea (Meyer et al. 2008). These parasites can enter the human body via unprotected contact or through food cross-contamination. Despite the potential dangers of these parasites, there have been no recorded instances of infected giant African land snails in the U.S. (Giant… 2019).

Regardless of the possibility of carrying diseases, many still consume and use the snail in religious rituals, holding some cultural significance. In Cameroon, approximately 76% of people consume *A. fulica* meat for its high protein content, aid in blood cell formation, or flavor (Christian et al. 2019). Additionally, about 16% of households in Cameroon are underfed, and since snail meat is cheaper than most other forms of protein, it is a clear choice (Christian et al. 2019). It is also encouraged by numerous studies due to its mineral and **amino acid** content relative to its low fat and carbohydrate composition (Christian et al. 2019). In the Yoruba and Santeria religions (both of which originated in Nigeria), the giant African land snail is used for religious rituals, contributing to the spread of the snail. This has also been seen in Cuba, Florida, and Brazil in the form of offerings to deities (Vázquez et al. 2016). In Brazil, this takes the form of offerings to the deity Oxalá, in which the snail is used as a substitute for another African snail, *Archachatina marginata* (Vázquez et al. 2016).

Impact of Spread

Like any species that are introduced to a new **habitat**, these snails will change their new ecosystems, affecting a broad **range** of elements. The economic impacts of the giant African land snail have largely been felt by agricultural communities (Giant… 2019). The snail has been documented eating at least 500 species of plant, many of which are important crops in the tropical regions to which they are **endemic**. Of these tropical crops, breadfruit, cassava, cocoa, papaya, peanut, rubber, and most species of legumes and **cucurbits** have been found to be their favorite (Tsatsia 2019). Many of these listed plants are cash crops, which can be integral sources of income in farming communities. It is of note that, though the snail is known to consume 500 different plant species, this statistic does not account for how much of each species it consumes – it only speaks to the fact that they have been recorded eating them when offered (O'Loughlin and Green 2017). The snail is also known to prey on some animals, including veronicellid snails, the native populations of which are an essential part of the ecosystem (Meyer et al. 2008).

Control and Prevention

With the spread of the snail quickly spiraling out of control, various methods have been developed to combat them. The main control method of the giant African land snail population for the past century has been the use of chemical baits, containing two different chemicals: metaldehyde and calcium arsenate (Shripat 2011, Achatina…2022). Metaldehyde attacks the snails' **mucous glands**, stimulating them to produce excessive slime and die of dehydration, while calcium arsenate is simply a dehydrating agent. Both chemicals are either absorbed through the **foot** of the snail or ingested. Biological control has been attempted before, as seen in the introduction of the rosy wolf snail, *Euglandina rosea*, in Hawaii (Achatina…2022). These snails are natural predators of the giant African land snail; unfortunately, their introduction has had devastating effects on **endemic** species. In the future, prevention tactics will be vital to avoid further spread, including regulations of international species trade, shipping of agricultural products, and movement of military equipment.

Florida: Invasion and Re-Invasion

The 2010 rediscovery of the giant African land snail in Florida ended decades of its successful elimination. The first invasion occurred in the 1960s, costing an estimated 5.4 million USD (adjusted from 1969 currency to account for inflation) to **extirpate** (Roda et al. 2016). Estimates show that if the snail had been left alone, it would have resulted in annual damages of approximately 84 million USD (Roda et al. 2016). After eleven years of eradication campaigns, the Florida Department of Agriculture and Consumer Services (FDACS) Division of Plant Industry ruled that the **invasive** species was no longer a threat in Florida on October 8th, 2021. To achieve success, K-9 detector dogs were used, as they proved to be effective in searching for snails in dense foliage (FDACS 2021). Meanwhile, the local population played a critical role in informing officials of possible areas of infestation. Florida issued multiple formats of media to educate every citizen. These PSAs discussed the dangers of the **invasive** snail and how to differentiate them from local species which led to the public reporting 97% of core population locations (FDACS 2021). The snail population has not returned due to continual community monitoring.

Conclusion

The giant African land snail has had adverse consequences across the world. Their vast populations make measuring their impact nearly impossible, but the figures that we do have do not look good. Their unique physiology and adaptations have given them the advantages they need to survive across a **range** of climates, contributing to their spread. Fortunately, many mechanical, chemical, and biological methods of control have been developed to control and prevent the future expansion of this dangerous creature. This is a critical time period for these snails to be stalled before they cause more damage to the countries they have invaded.

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12. Wanted: Spotted Lanternfly

ERIC AIMONE; ANDREW BRUSH; THOMAS COX; MATTHEW FORD; AND JUSTIN ROBERTS

Abstract

The focus of the research project was to investigate the environmental impact of the spotted lanternfly (*Lycorma delicatula*) on the U.S. Research was conducted on current solutions, how they are being utilized, and other currently researched solutions. The conclusion of the research was that individual solutions cannot solve the issue completely, but all of them in conjunction may. Most solutions rely on public awareness of the issue, therefore more substantial campaigns must be implemented. Pesticides are largely ineffective and not viable. Instead, there is the potential of bringing over parasitic wasps from the lanternfly's natural habitat, though further research must be conducted.

Figure 1. "A side-top view of an adult spotted lanternfly" by Walthery is licensed under CC BY-SA 4.0.

The Problem

The **spotted lanternfly** (Figure 1) is an **invasive species** known to cause damage to around 70 different plant species. There has been a drastic increase in its affected **habitats** in the last two decades caused by the species traveling between **continental landmasses**, including the Americas. The spotted lanternfly first arrived in the United States in Pennsylvania in 2014. Since then, it has spread to many states, including New Jersey, New York, Massachusetts, northern Virginia, Delaware, and even Indiana (as seen in Figure 3). The lanternfly has spread across a vast area incredibly quickly, leaving a path of destruction to crops, wildlife, and even buildings in its wake (Leach & Leach, 2020). While there currently have not been any sightings in the city of Worcester of the spotted lanternfly, they have been spotted in Fitchburg. Current expansion rates suggest that Worcester Polytechnic Institute (WPI) will experience its first sightings soon, opening the possibility of local investigations being staged in the near future.

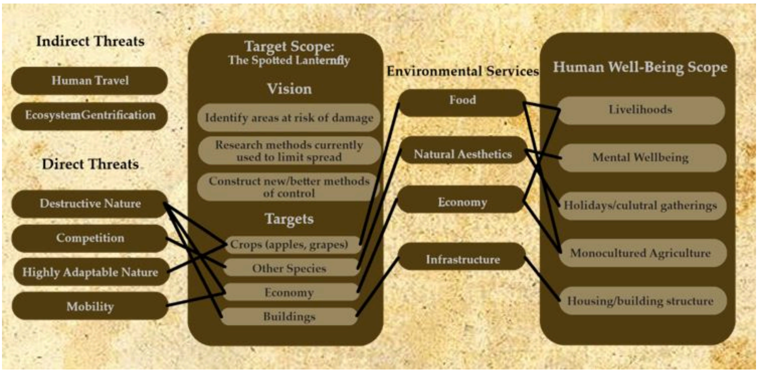

Figure 2. Situation Model that describes issues and factors surrounding the species as well as how they affect the environment and humans. Created by chapter authors.

One of the main concerns about the increasing numbers of spotted lanternfly in the U.S. are its effects on several **commercial crops**, including fruits such as grapes, apples, cherries, apricots, and peaches, as well as several different types of trees used for lumber, such as oak and maple. The lanternfly causes some damage by eating into a plant and then secretes a sugary byproduct called **honeydew** that attracts more insects and fungi to destroy the rest of the plant (Wakie et al., 2020; Urban, 2020). Farmers are currently trying to use **pesticides** to kill off as many of the lanternflies as they can, but it is proving to be ineffective. Very few pesticides have any significant effect on the population, and the few that do work are only around half as effective as pesticides normally are. **Thiamethoxam** and **bifenthrin** are the only two chemicals that reached the 50% mark (Leach et al., 2019). Researchers have yet to see an **evolved resistance** from the spotted lanternfly to these pesticides, and this could potentially be due to how recently this became a prominent issue. The low mortality rate of pesticides does little to mitigate the damage to crops in the northeast. This means that a larger number of pesticides are being used that are destroying the environment, sparking the need for a more holistic method of stopping the spread of the spotted lanternfly. The rapid spreading, as well as the destructive nature of this species, could very easily cause other species to go **extinct**, leading to a cascading effect that could cause many more to succumb to extinction (Leach et al., 2019).

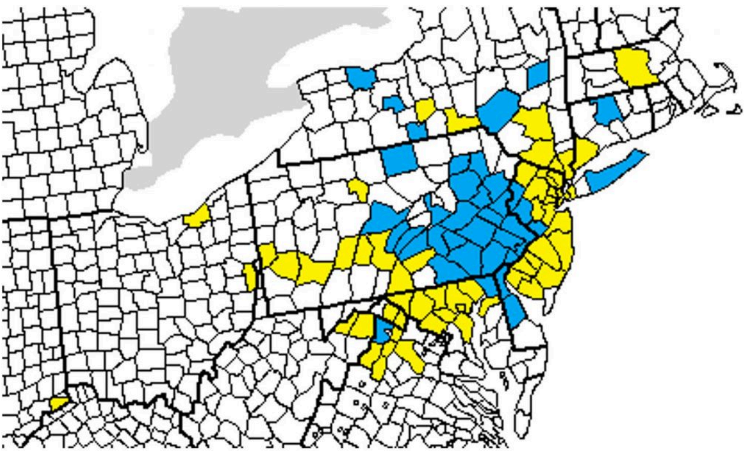

Figure 3. The distribution of the spotted lanternfly in 2018 (blue) compared to the distribution of the spotted lanternfly in 2021 (yellow and blue).

Other current methods of slowing the spread of the spotted lanternfly include the use of traps on host plants. One of the most common traps used against the spotted lanternfly uses a glue-covered band placed around the trunk of host trees (Francese et al., 2020). The traps target the lanternfly in its nymph stage, as the insect will often lay its eggs on the trunks of its host trees. The newly hatched spotted lanternflies will climb up the tree and will get stuck to the band. The bands also use a compound called **methyl salicylate**, which is commonly found in the spotted lanternfly's host plants, to attract the spotted lanternfly to the trap. However, while this currently is the most widely used trap, it suffers from the same low effectiveness as the pesticides being used. The traps are only effective at capturing younger nymphs, while older nymphs and adults avoid capture entirely by avoiding areas covered by the band of glue on the tree. Adult nymphs have even been known to pull themselves off the glue band to avoid capture. The glue used in the traps can also change randomly without the makers knowing due to manufacturing differences, and the traps must be changed frequently due to other insects and particles becoming trapped (Francese et al., 2020).

To combat the growing issue of the lanternfly, this project poses two research questions. These questions were formed with the mindset of finding a proposed solution to the current predicament that many people in the northeastern United States currently face (see Figure 2 for reference). The first question asks why the lanternfly is so dangerous, specifically looking at aspects such as how quickly the lanternfly can spread over vast distances of land. The second question asks what broader threats and side effects the lanternfly brings with it, such as pesticide use. In order to answer these questions, historical data will be reviewed to track the spread of the spotted lanternfly, examining exactly how the spotted lanternfly travels so quickly (Porter, 2021). Researchers in Pennsylvania, where the spotted lanternfly **infestation** is at its worst, have also researched the financial impacts of the spotted lanternfly, including damage to buildings (Warnert, 2020). Research of the spotted lanternfly done by experts will be compared to research done on similar invasive species to determine the potential side effects of each proposed solution. Using the answers to these research questions, this project can hope to offer a potential solution that could help limit the spread of the spotted lanternfly as a species, especially in the local area of Central Massachusetts.

The expected outcomes from this research project are to have a plausible solution to some of the many problems created by this invasive species and to fully understand the scope of danger that the spotted lanternfly poses to the ecosystems it invades. This project's various dimensions, such as its social, economic, political, cultural, and ecological aspects, will be integrated through the research that tries to both understand and find a solution for the numerous problems caused by the spotted lanternfly. This is because this invasive species creates so many problems that they cover all the previously mentioned areas. For example, the spotted lanternfly feeds on over 70 distinct types of plants, many of those being **economically beneficial** crops (Urban, 2020). The fly also produces an **excrement** which encourages fungal growth on plants that prevents **photosynthesis** and damages or kills the crop (Urban, 2020). These two aspects of the spotted lanternfly alone have negative economic, cultural, and ecological impacts due to the destruction of economic crops and plants in various **ecosystems**. Furthermore, the spotted lanternfly has primarily ravaged the northeastern region of the United States but is quickly spreading to other states and is projected to spread to a global scale, making the issue more pressing than many would believe (Leach & Leach, 2020).

Methods

In order to collect the data necessary for this project, recently (within the past few years) written articles were a necessity. The issue at hand was a relatively new issue, especially in the United States where the spotted lanternfly has only been present since 2014. This resulted in an extremely limited timeframe for relevant sources on the current spread of the insect. None of the sources related to the project that were written before the issue came to light were discounted, but they were looked at with more scrutiny. The solutions that would later be proposed had to be based on pure evidence and grounded in facts, meaning there was little room for **bias** or untrustworthy sources. Based on these parameters, the main sources used would have to come from scholarly articles, government-sponsored sites, and a few trusted news articles. Some examples of this included government articles that educate the public on the threat and potential solutions, scientific studies that examine the effectiveness of pesticides, and population spread diagrams (such as Figure 3). The problem was fairly new to the United States, but other invasive insects such as the **Asian long-horned beetle** have caused extensive environmental damage (Haack et al., 2010). This led to some sources that were written about other species/scenarios that could be applied to the issue at hand. Information from other countries, such as South Korea and Japan, was also reviewed due to their experience with having the spotted lanternfly as an invasive species before it arrived in the United States.

The five main steps in the research process were as follows: The first step was looking at current statistics and information on the lanternfly in the northeast. The next step was examining what current methods are being employed to help mitigate the spread of the lanternfly, along with their effectiveness. After that, research was done that looked at other potential solutions and their theoretical effectiveness. Another important aspect to review was the detrimental effects that both the problem and solutions were having on the surrounding environment. The last step was validating the claims that were made, preventing the spread of misinformation.

Most of the data collected were information on potential solutions to the lanternfly and similar issues. This mostly involved scholarly articles written before this issue came to light. The other half of the research was finding current data about the lanternfly itself, such as migration patterns, population maps, chemical effectiveness, mitigation methods such as traps, and life cycle. Some of this information came from articles, but more of it came from government websites and sponsored publications. The government websites include the Mass.gov website and Penn State University's website from their environmental department. The Mass.gov website also provides resources and links to other websites that are working closely with the environmental impacts of the spotted lantern fly (Mass.gov, 2020).

Pesticides

One of the potential solutions to the issue of the spotted lanternfly is pesticide use. There are many places around the world where pesticides are used to protect agriculture from pests, and they have been proven to work very well in certain cases. In New England, farmers have turned to pesticides to attempt to stop the spotted lanternfly from getting to their crops. The two chemicals most effective for this are thiamethoxam and bifenthrin. Thiamethoxam is the main ingredient in a few pesticide brands and affects a broad range of insects. It works by attacking specific receptor sites of the insect's nervous system, stopping the insects from being able to eat the plant any further. It is applied to the plants while they are still growing from a seed, so some foresight is necessary in order to implement this pesticide (Environmental Protection Agency, 2021). Bifenthrin is a **pyrethroid**, a synthetic version of **pyrethrin**, which commonly comes from chrysanthemum flowers. This pesticide is also widely used in many agricultural areas and works in the same way as thiamethoxam, attacking the nervous system of insects and stopping them from getting to the crops (National Pesticide Information Center, 2011).

Each of these chemicals is largely harmless to humans due to their much larger body size and temperature, but other insects are less fortunate. Almost every species of insect in agriculture, including the beneficial ones, get affected by these pesticides. One such species is the *Anthophilia* species, more commonly known as the bee. Bees and other helpful insects will also die if exposed to these chemicals, causing harm rather than good to the plants

(Environmental Protection Agency, 2021). Of all pesticides tested on the spotted lanternfly, thiamethoxam and bifenthrin are the only two that have made a significant impact on the issue. Both have around a 50% **effectiveness rate**, which is not remarkably high as far as pesticides go (Leach et al., 2019). Because of their low effectiveness and the issues that they pose to the environment at large, pesticides do not seem to be a satisfactory solution to the spotted lanternfly problem.

Other Species

Another potential solution to the abundant spotted lanternfly population is the introduction of a natural predator. One of the spotted lanternfly's most effective natural predators is the parasitic wasp known as *Anastatus orientalis*. This wasp is an **egg parasitoid** that is known to keep spotted lanternfly populations in check in their native Asiatic regions. While there are other natural parasitic predators to the spotted lanternfly, *A. orientalis* has proven to be one of the most effective as its parasitism rate on spotted lanternfly eggs reaches as high as 69% in some areas (Manzoor et al., 2021). The wasp operates by using the egg masses of the spotted lanternfly as a host to lay its own eggs. The eggs then develop into larvae which feed on the spotted lanternfly eggs before they have a chance to grow (Broadley et al., 2021). The introduction of a natural predator to the spotted lanternfly would be one of the ideal solutions. It lacks some of the harmful effects caused by solutions such as pesticides, and it serves as a long-term method to keep the spotted lanternfly populations in check. Despite all of these benefits, this solution is still undergoing necessary research and testing as all of the consequences and side effects are still unknown. Although this may seem like an ideal solution to the problem, it cannot be implemented until it is proven that the benefits will outweigh any consequences.

Governmental and Individual Efforts

The governments of the states affected by the spotted lanternfly have also developed their own methods for dealing with the insect. In Pennsylvania, one of the most common methods is the use of **quarantine zones** in affected areas. When an area is under quarantine, most vehicles, both personal and commercial, must be checked daily along with different types of commercial shipments. This may include any lumber shipments, agricultural supplies such as full plants or crops, or any other shipping container that eggs may have been laid on. This method so far has been relatively ineffective due to the overall lack of public knowledge of the problem. As this method requires everyone to check for lanternflies daily, it would only take a single mistake for the lanternfly to escape the quarantine zone. As the problem has become more severe, many local governments have also implemented **egg watches** to encourage the public to limit the spread of the lanternfly. In states such as Pennsylvania, the public has been encouraged to identify the egg masses of the lanternfly and scrape them off surfaces. Individuals are also encouraged to contact the local government about the location of the lanternfly and to destroy the egg mass by dropping them into a bucket of water filled with soap (Tawny Skimisky, personal communication, November 19, 2021). In other states, such as Massachusetts, individual reporting of spotted lanternflies is used instead of widespread egg watches. Under this protocol, individuals are required to identify lanternflies, and to capture and preserve the individual insect if possible. The local government will then survey the area for more insects, set up traps, and even chip the surrounding trees if they are infested. Like the quarantine zones, the individual identification of the lanternfly requires everyone in the surrounding area to be aware of the problem, and its efficacy relies on how aware the public is about the issue.

A major issue with the spotted lanternfly is the lack of public awareness. Even though the government cannot do much to limit the spread of the spotted lanternfly at this time, there should be money and efforts going towards a strong PR campaign aiming to educate the public about it. As mentioned before, the Asian long-horned beetle is another invasive species in central Massachusetts, and its spread has been limited through the education of the public, where each individual who knows about the beetle does their part and reports any sightings (Haack et al., 2010; Warnert, 2020). From signs to pamphlets, Worcester County has made sure the public is educated about the Asian long-horned beetle, and it is recommended the state and city governments do the same for the spotted lanternfly before the species becomes widespread. Due to its ability to cover long distances quickly and reproduce in large masses, preemptive action is essential to the eventual permanent containment of the spotted lanternfly. At the time of writing, only a small descriptive paragraph about the lanternfly and a link for reporting sightings exists on the Mass.gov website (Mass.gov, 2020).

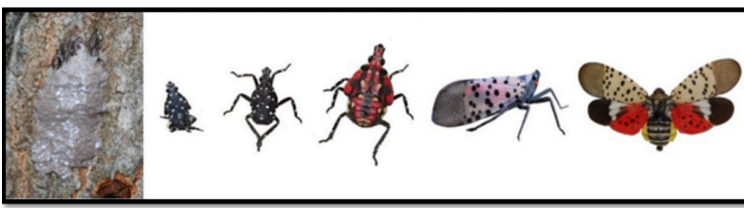

Figure 4. "Spotted Lanternfly Life Stages" by Massachusetts Department of Agricultural Resources is licensed under CC BY 3.0.

Conclusion

Taking into account all of the potential solutions to the lanternfly problem and their broader impacts/prerequisites, there is no clear solution. This is not to say that the issue can't be solved, only that there is no solution that will do it. Instead, a combination of all solutions must be employed. This will involve participation from the local and state level governments as well as personal involvement. On a governmental level, one of the things that can be done is to continue to support research into the viability of parasitic wasps as an option (Broadley et al., 2021). This research is critical, as it could potentially lead to one of the most potent solutions currently available. Along with this research, quarantine zones must be implemented in all affected counties, regardless of the state that they are in. This, in conjunction with a proper website and database for documenting sightings of the lanternfly, will go a long way in ensuring that people stay on top of the issue and do not let it spread any further. For the time being, the best thing that can be done is to spread public awareness (Cornell College of Agricultural and Life Sciences, 2021). The reason that the lanternfly has gotten as far as it has is that the public is largely unaware that the lanternfly is even an issue. Egg masses can look like spots of mud or dirt, leading to them being largely overlooked by drivers. Knowing what they are and what they look like can be the difference that stops them from spreading to a new state.

The public also has an obligation to help solve this issue. Government PSAs and tracking websites can only work if the public knows what is going on and remains vigilant. One car with a single egg mass can be the difference between the lanternfly population spreading or remaining contained. One of the best ways to raise awareness of the issue is public signage. There are already many signs around New England roadways that educate the public about the Asian long-horned beetle, so there is no reason that the same cannot be done for the spotted lanternfly. If each of these solutions is properly implemented and further research is conducted, then the issue of the spotted lanternfly will become a thing of the past.

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PART III

CONSERVATION

Effective conservation requires access to resources to design, monitor, and face the challenges of ecosystems and the communities that live or depend on their resources. This section explores human responses and challenges in the conservation of soil biota, the eagles in the Amazon rainforest, the Mexican long-tongued bat, mountain gorillas, American pikas, Puerto Rican parrots, the I'iwi, Kemp's Ridley and Galapagos green sea turtles, and the rusty patched bumble bee. Across these chapters, reconciling the conservation of non-human species with human needs emerge as critical elements in addressing and designing current and future conservation practices.

Prescribed burn at a pine barren site to restore habitat for a complex suite of declining species (plants, pollinators, reptiles, birds, and mammals) that rely on this specific habitat. "Back burn" by Ross, licensed under CC BY-NC-SA 2.0.

13. Appreciate What Lives Beneath Your Feet: Soil Biota, the Microbes that Rule the Earth

RYAN MALONE; TREVOR BUSH; SARAH FENTON; AND HANNAH GILMORE

Abstract

This specific chapter delves into various facts about the biodiversity of soil microbes—bacteria, actinomycetes, fungi, algae, protozoa, and nematodes—such as their population, status, and various ecological and economic roles. Many ecosystem services are reliant on soil biota, as they have a vital role in the regulation and cycling of nutrients and the decomposition of organic matter; even so, they are often not included in environmental protections. In general, there are multiple soil conservation efforts currently in practice, such as alternate agricultural practices that reduce fertilizers, pesticides, or tillage. However, due to the expanse of these organisms, it is difficult to determine either the long-term effectiveness or broad usage of these methods.

"Amanita Muscaria" by Adam is in the Public Domain, CC0

General Information, Diet, and Reproduction

After a long day of work, you return to your house nestled in a woodsy hill, take a deep breath of fresh air, sit down at your kitchen table, eat some fruit, and wash it down with a glass of fresh spring water. If soil microorganisms ceased to exist, none of this would be possible. Microbes provide structure to the soil and carry nutrients to roots for their expansion—without them, the hill you live on would erode away. Soil biota is essential in creating the wooden table you sit at, producing the food you eat, cleaning the water you drink, and cycling the air you breathe.

Soil microbes—which include **bacteria**, **actinomycetes**, **fungi**, **algae**, **protozoa**, and **nematodes**—are organisms typically found in the top layers of soil in most biomes. They live in mostly isolated **microcolonies** or **biofilms** on mineral particles, organic matter, and roots, where their habitat is composed of 45% minerals, 25% water, 25% air, and 5% organic matter (Doula and Sarris 2016). Due to the differing capabilities of soil microbes to withstand certain levels of soil disturbance, they inhabit various soil types. On average, however, one gram of soil can contain over ten thousand unique species of microorganisms and millions of individual microorganisms (Parker 2010). Bacteria, actinomycetes, and protozoa tend to live in **tilled soils**, as they can withstand more soil disturbance. Fungi and nematodes, on the other hand, reside in untilled soils (Hoorman and Islam 2010; Young and Ritz 2000). Nematodes, specifically, can be found everywhere except for isolated islands in the Antarctic (Williamson and Gleason 2003).

Nutritionally, soil microbes rely mostly on the active component of soil organic matter (SOM) which includes living and dead plant and animal matter (Hoorman and Islam 2010). Likely because of this, soil with higher amounts of organic matter tend to have higher populations of soil microorganisms (Bhattarai et al. 2015). Additionally, nematodes can feed on other microscopic organisms or parasitically feed from the cellulose of plant roots and fungi solely decompose decaying matter (Treseder et al. 2014). In soil habitat, there is a competition between abundant groups of diverse organisms for nutrients, space, and moisture (Gentry and Zuberer 2021), as can be seen in Figure 1. The distribution of organisms in normal soil—containing 4% organic matter—are: protozoa, 100 kg/ha; nematodes, 2-100 kg/ha; bacteria, 5000 kg/ha; actinomycetes, 1500 kg/ha; and fungi, 5000 kg/ha (Bhattarai et al. 2015). The unit ha stands for hectare which is a unit of area that is equivalent to a square with sides measuring 100 meters. In terms of percentage of kg per ha, protozoa comprise 0.9%, nematodes comprise 0.02-0.9%, bacteria- 42.7%, actinomycetes- 12.8% and fungi- 42.7%.

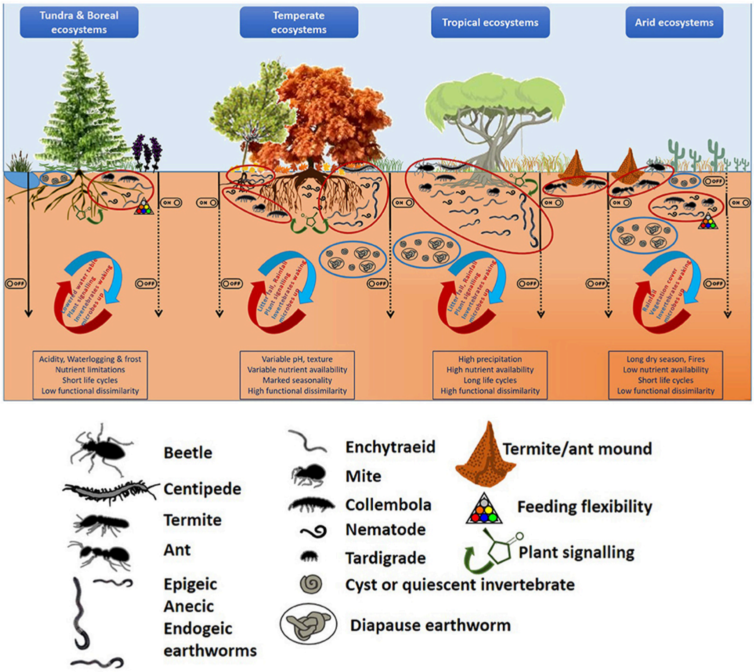

Figure 1. Various climates and some of the soil organisms and microorganisms that inhabit each one. "Soil fauna, climatic gradients and soil heterogeneity" by M. Briones is licensed under CC BY 4.0

While the majority of soil microbes and fungi reproduce **asexually**, there are many exceptions. Nematodes lay eggs that are fertilized after a form of sexual reproduction, and many of the single celled organisms use mitosis. Some fungi can reproduce sexually, but most reproduce asexually through zoospores or budding. Zoospores create a swarm of offspring that travel a short distance before turning into their own organism (Treseder et al. 2014). Budding, on the other hand, involves a small piece of the main fungi breaking off and growing independently.

Biodiversity and Threats

Soil biodiversity can be measured via species diversity, which measures species richness and evenness, or **soil biological activity**. There is currently a lack of research in connecting species abundance with soil function and the subsequent quality of regulating ecosystem services provided. Additionally, soil biological activity can vary widely, especially in different ecosystems, due to differences in water, temperature, vegetation, and changes in weather and climate (Breure 2004). Soil microbes depend on the **soil pore network**, and the habitats of soil microbes are greatly affected by climate, other living organisms, topography, subjection to weathering (Doula and Sarris 2016), erosion, plant cover, and agricultural practices (Pascual et al. 2000).

There are various threats to soil microbes that vary based on what the soil is used for, but intensive human exploitation is regarded as the leading factor in reducing soil biodiversity. Soil used in agriculture faces the intensification of land use and the influences of crops, fertilizers, tillage, pesticides, and pollution (Breure 2004). Additionally, pesticides and herbicides reduce the ability of some soil microorganisms to continue their basic function because the chemicals in these substances slow the growth and reproduction of the soil biota, negatively affecting the overall processes of nutrient cycling (Thiour-Mauprivez et al. 2019). Non-agricultural soil is affected by human activities and by-products, such as construction and waste. This includes, but is not limited to: **habitat fragmentation**, **temporal** and **spatial heterogeneity** (Breure 2004), soil organic matter decline, **soil sealing**, climate change, erosion, **soil compaction**, GMO pollution, plastics, **liming**, salinization, loss of available nutrients, and changes in soil temperature and moisture (Tibbett et al. 2020).

There are numerous efforts towards the conservation of soil; however, some have proven inadequate for the continuation of microorganism biodiversity. For example, company use of chemical fertilizers and pesticides is regulated by only one scale. This scale, called N-Mineralization, only judges the effect of nitrogen within the soil on soil health as a whole and is unable to gauge the effects on most microorganisms (Thiour-Mauprivez et al. 2019). However, some farmers have begun implementing no-till or conservation tillage methods, to reduce soil disturbance and maintain the habitat, structure, moisture, and organic matter of soil microbes (Quinn 2016).

Ecological, Societal, and Economic Role

Soil microorganisms are a key factor in most ecosystem services that humanity relies on (Aislabie and Deslippe 2013). Atmospherically, soil microbes provide regulating services for carbon, which are detailed in Figure 2. They are the only organisms capable of several nitrogen regulation processes, including **DNRA** (dissimilatory nitrate reduction to ammonia), **nitrification** and **denitrification**, **nitrogen fixation**, and **anammox**. Since nitrogen is recognized as a limiting factor for plant production, and processes such as nitrogen fixation increase soil fertility (Barrios 2007), soil microbes have great control over the productivity of an ecosystem (Aislabie and Deslippe 2013). They also improve **nutrient cycling**, a process that is vital for all organisms' survival in their respective ecosystems (Saccá et al. 2017). Additionally, soil microbes can control pathogen diseases, increase resistance to invasive species, and create diverse soil microbial populations through **antagonism**, competition, and **interference** (Saccá et al. 2017).

Bacteria and fungi can be both harmful and beneficial to an ecosystem (Singh et al. 2019). On top of nitrogen fixation, bacteria and fungi can improve plant productivity and accelerate carbon sinking, and play a role in altering plant and animal community structures by providing decomposed nutrients for growth. Bacteria and bacteriophages (bacterial viruses) can be detrimental to plant health by causing blights, root wilt, or overgrowth. Fungi can also kill plant cells through fungal diseases. These effects are sometimes used by humans to control the populations of different plants by using a bacteriophage or fungal disease to target a plant species for destruction. Plants that withstand harmful bacteria or fungi can result in a community that has an increased tolerance to stressors (Singh et al. 2019). Bacteria and fungi are essential in the **land-atmosphere carbon exchange**, but this cycle is threatened by the intensification of land use (Saccá et al. 2017).

Without the various services soil microorganisms provide, agriculture and resulting civilizations would not have been able to properly develop. Soil microbes play a big role in making arable soil for plants like maize, rice, and other culturally significant crops through their role in water recycling and purification. Additionally, soil microbes have large roles in replenishing an ecosystem that has been overexploited for human use (Singh et al. 2019). This includes detoxifying environmental pollutants, waste recycling (Aislabie and Deslippe 2013), sustaining ecological restoration, degrading toxic compounds such as **heavy metals** (Singh et al. 2019), and filtering pollutants (Ledin 2000). As technology improves, they gain more applications for products including food, water, fiber, fuel, genetic resources, chemicals, medicines, and pharmaceuticals (Figure 2; Saccá et al. 2017).

Actions need to be taken to protect the health and proficiency of soil microbes, but seed technology and farmer profits can have large impacts on the likelihood of significant conservation efforts. Soil conservation policies can have many positive impacts both ecologically and economically, and can help reduce greenhouse gas emissions. Microbes prefer no-till soil, and implementing these methods can result in healthier soil from the increased breakdown of organic matter and soil structure by soil biota. However, these methods can have larger up-front costs to farmers, which creates hesitancy in implementing these soil maintenance methods. To discover the most cost-effective practices for soil health, more research needs to be conducted in the future in regards to how costly it is for farmers to implement no-till methods in comparison to the long-term profit margin of better soil practices (Bowman et al. 2016).

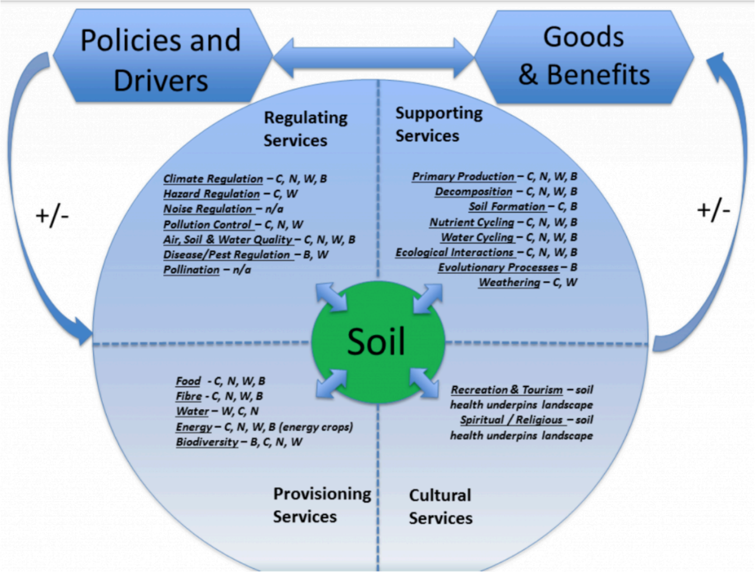

Figure 2. "[Schematic representation of where soil carbon, nutrient, and water cycles, and soil biota underpin ecosystem services (adapted from Smith et al., 2014)]" is licensed under [CC BY 3.0]

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14. Protect the Nest: Conservation of the Amazon Rainforest and the Harpy Eagle

ADRIANNA NILES; BROOKE STRUBLE; AND ANNA WIX

Abstract

The Protect the Nest research project examines the detrimental impact **deforestation** has on the Brazilian Amazon with a concentration on the harpy eagle (*Harpia harpyja*). Through analyzing deforestation rates, habitat patterns, nesting tendencies, reproductive cycles, and prey abundance, a better understanding of the negative effects deforestation has on the eagle was collected. In order to restore the harpy eagle population and the forest, our solutions include a breeding program, an education program, and a sustainable logging method.

Figure 1. *"[Bird Harpy Berlin Zoo]" is in the [Public Domain, CC0]*

Background on Amazonian Deforestation and the Harpy Eagle

Throughout history, deforestation in the Amazon has been a prominent issue. The Protect the Nest research project focuses on the effects deforestation has on Amazonian birds. Specifically, we will be examining the impacts deforestation has on the harpy eagle population. The harpy eagle is a species of large tropical **raptors** that only nest in huge emergent trees. Emergent trees are the larger trees in the rainforest that make up the canopy. In the past, the harpy eagle occupied extensive parts of southern Mexico, northern Guatemala, southern Belize, eastern Panama, and Brazil; however, many **extirpations** have occurred throughout their distribution range. Specifically in Brazil, the distribution of the eagle is greatly restricted and they have disappeared completely from the southernmost areas like Rio Grande do Sul (Schulenberg, 2020).

Currently, the harpy eagle is considered near threatened and their population numbers exhibit a decreasing trend (BirdLife International 2017). The two major threats to the harpy eagle's survival include deforestation and humans (Figure 2). Unfortunately, many people are uneducated in regards to the bird. People fear that the bird will attack them or their family, and are also curious to see what they look like up close; as a result, many eagles are killed by shootings (The Peregrine Fund, n.d.). However, in the case of indigenous tribes of the Brazilian Amazon, they believe the bird is the personification of tribal chiefs and symbolizes eagerness and prowess (WWF, 2006). In general, extending the perspective and knowledge of the indigenous people to the public will improve the conservation efforts directed toward the Harpy eagle.

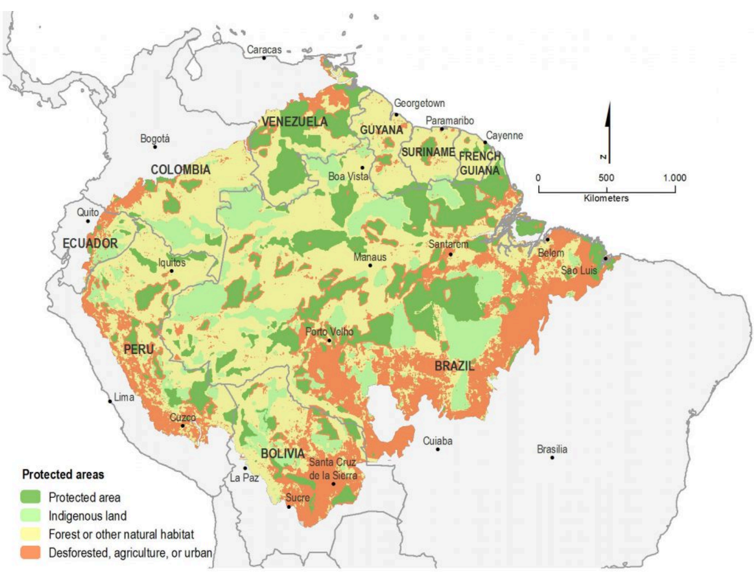

Figure 2. Deforestation and other threats in Amazon. "*Fig. 2. Current Amazonian situation, threats, and management forms. Source: Modified from Neugarten et al. (2017).*" *in Agudelo et al. 2020 is licensed under* CC BY-NC 4.0

On the other hand, deforestation threatens the harpy eagle and the other inhabitants of the Amazon. harpy eagles are extremely selective in their choice of **nesting trees**, as they only nest in about 28 of the 10,000 tree species found in the Amazon (Miranda et al., 2020; Figure 3). Unfortunately, of the 28 species, a substantial portion of the trees are commercially targeted by the timber industry. harpy eagle nests are commonly found in ceiba (*Ceiba pentandra*) and courbaril (*Hymenaea courbaril*) trees, which are both negatively impacted by logging (Miranda et al., 2020).

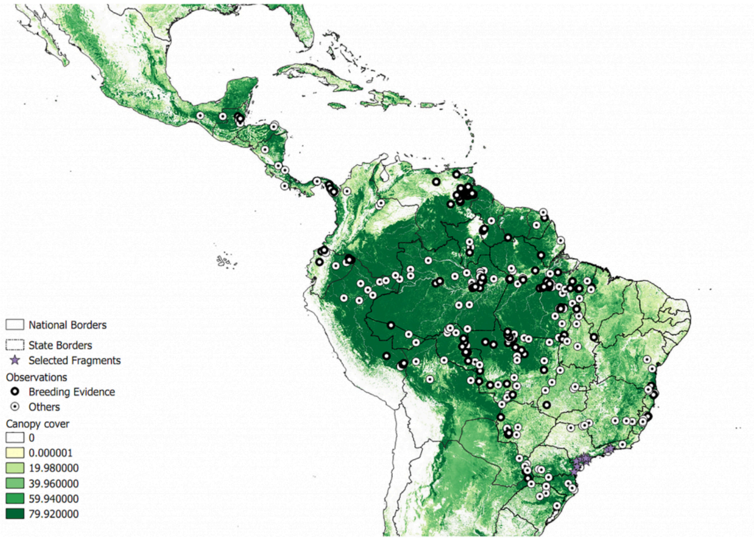

Figure 3. The black circles on the map portray nests of harpy eagles; use Figure 2 as a reference to see where the nests and deforested areas overlap. "[Fig. 2](#)" *from* [Miranda et al. (2019)](#) *is licensed under* [CC BY 4.0](#)

Throughout history, deforestation has obliterated the Brazilian Amazon. The rates of deforestation have fluctuated tremendously over the years. Figure 4 depicts the annual deforestation rates in Brazil, which shows various spikes and trends. Though the rate of deforestation has decreased drastically, it is important to note that the amount of deforestation is still immense. In 2009, deforestation in Brazil had one of its lowest rates; yet, an estimated 600,000,000 million trees were removed from the Amazon (Ometto et al., 2011). Although compared to past years, 2009 had one of the lowest deforestation rates, the severity of deforestation is put into perspective due to the number of trees that were still cut down. Unfortunately, in present-day Brazil there has been a lack of change in the deforestation rate. The lack of change is important to draw attention to because the same methods that worked to diminish the rate in the 2000s no longer work. Outside factors such as **economic recession** and political turmoil in Brazil have stunted the progress in maintaining the decrease of deforestation. By analyzing the trend of deforestation, scientists predicted that by 2020 the deforestation rate in Brazil would hit zero (Boucher & Chi, 2018). Unfortunately, due to insufficient economic leadership and political chaos, the goal was not achieved.

Figure 4. A graph of the annual deforestation rates in Brazil (km2/yr). "Figure 1" from Boucher and Chi (2018) is licensed under CC BY-NC 4.0.

Deforestation and the removal of trees from the Amazon forest damages the **habitats** of species, therefore diminishing **biodiversity** and resources. Locally, deforestation in the Amazon directly impacts local species populations, hence why we chose to focus on the harpy eagle. The removal of trees contributes to habitat loss and loss of many species since they are forced to find new land and habitats to survive in. Additionally, the harpy eagle's **selective breeding preferences** create even more complications for the species since there is decreasing availability of breeding grounds with the increasing demand for deforestation (Miranda et al., 2020). Considering the ecological dimensions on a global scale, when trees die or are removed they release mass amounts of carbon that they had been storing, which leads to increased levels of carbon in the atmosphere and causes the Earth's temperature to rise. Especially considering that the Amazon is the largest rainforest in the world, deforestation within it can have major effects on global warming today. Moreover, deforestation has a major impact on atmospheric and oceanic circulation, further contributing to climate change since it decreases rainfall (Nobre, 2009).

For many years, the Brazilian Amazon has continuously been decimated by mining, logging, cattle ranching, and soy farming (Vale et al., 2008). On top of this, the harpy eagle is considered an umbrella species, meaning its conservation will help protect other species (The Peregrine Fund, n.d.). The Amazon rainforest is comprised of ecosystems with the highest biodiversity in the world. By helping protect the harpy eagle, its prey, and its nesting trees, the biodiversity will continue to remain high.

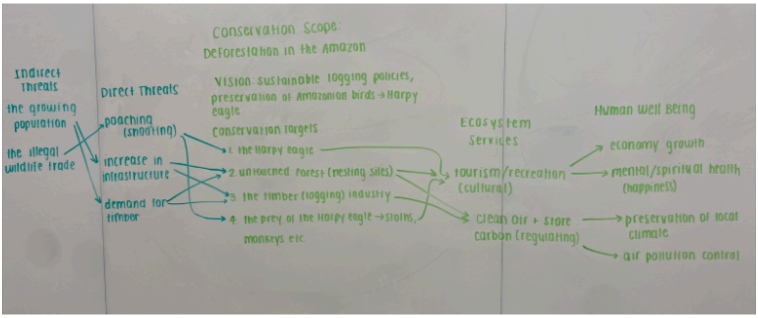

Figure 5. Protect the Nest Situation Model. Created by chapter authors.

The Focus of the Protect the Nest Project

The guiding research questions of this project are: How are Amazonian birds, specifically harpy eagles, affected by habitat loss/ deforestation? Are rates of **extinction** among the harpy eagle increasing? What is the relationship between deforestation and country development?

As stated above, this project is going to focus on the Amazon Rainforest in South America; specifically Brazil. To reiterate: deforestation has been a prominent issue in this area for many years. The State of Rondonia in Western Brazil is a tragic example of the expansion of deforestation in the rainforest. In 1978, about 4,200 square kilometers of forest was cleared (NASA, n.d.). By 2003, 67,764 square kilometers of rainforest was cleared, which is approximately ⅓ of the total forest that once existed in the area (NASA, n.d.). Similar levels of deforestation can be seen in the Amazon rainforest throughout Brazil. This project is looking to diminish the increasing levels of deforestation in the Amazon in order to conserve biodiversity and harpy eagle populations.

This project utilized a variety of methods to answer the research questions proposed above. There was research done on the reasons for deforestation, specifically **overharvesting** from the logging industry, to allow for an analysis of the issue in order to create a solution. Changes in harpy eagle populations were also researched, along with causes for those changes to see how they connect to deforestation; this included nesting site changes for the harpy eagle and changes in **prey** population. All these research points helped to shape the project and the direction it was taken in.

There are several main goals and expected outcomes of the Protect the Nest research project. First and foremost, the project worked to find a sustainable logging method for the timber industry in the Amazon rainforest and, in turn, conserve harpy eagle populations. This project also explored the inverse relationship between harpy eagle populations and deforestation, which will show the necessity for the sustainable path the project produced.

Cultural Significance

There are various cultural dimensions related to deforestation in the Amazon and its effects as well. One of the most notable ones relates to research that compares the land use and methods of indigenous tribes and migrants, further exhibiting the inconsistency between the two cultures. To explain, indigenous tribes and even settlers from the early 20th century appear to have brought and used their agricultural knowledge in order to properly value and utilize the forest and its resources (Hoelle, 2018). Therefore, this culture prioritizes the deeply held philosophies regarding the conservative use of land in order to properly coexist with nature without depleting it of its resources. Additionally, the traditional knowledge of raptors, such as the harpy eagle, that indigenous tribes possess potentially allows for advancements in conservation efforts. Whether it regards raptors' migration flight paths, landscapes, or any other local knowledge, indigenous tribes in the Amazon have strong correlations to our efforts with the harpy eagle (Panopio, 2021). On the other hand, the migrant culture seeks value in development and growth, which often overpowers conservation-related efforts (Hoelle, 2018). By putting so much emphasis on improvement and progress in society, land changes such as deforestation are seen in a positive light since it provides greater economic and commercial opportunities.

Methods

Our research analyzed a variety of sources and methods to shape our project. To explain, we made an effort to find sources that included empirical facts, such as an article that discussed the population changes of the harpy eagle over time. **Empirical facts** were important to include because they solidified our claims, as well as provided numbers and proof for how harpy eagle populations were affected by deforestation. Additionally, we evaluated academic literature that mentioned background on deforestation in the Amazon, the harpy eagle, and related cultural ties. The use of academic literature expanded our knowledge of our topic and subtopics so we could form a complete understanding of our project.

The steps for our research plan are as followed: First, we looked into the background and reasons for deforestation. Next, through the use of maps focusing on their range in Brazil, we collected and examined the location of harpy eagle nests and the type of tree they nested in. Through the utilization of deforestation maps, we were able to analyze and show the overlap of harpy eagle nesting areas with the growing rate of deforestation. We further examined these areas before and after deforestation and how the nesting tree species overlapped with the timber industry. Then we gathered data on the mating pairs in the region, including how often they reproduced and the number of chicks that survived, along with prey populations of the harpy eagle. We also interviewed Everton Miranda, a professor and biologist who has studied the harpy eagle populations in Brazil, to gather his insight on the issue. Lastly, we analyzed sustainable logging methods and conservation efforts and found a plan that diminished deforestation and conserved eagle populations along with overall biodiversity in the Amazon rainforest.

Effects of Deforestation on the Harpy Eagle

Through our research and methods, we were able to determine two major impacts deforestation has on harpy eagle populations. One of the more obvious effects, habitat loss, has significant consequences. Currently, most logging industries pursue clear-cutting techniques, meaning that in order to harvest timber, large plots of land are cleared completely of trees (Sist & Ferreira, 2007). Moreover, timber industries typically target the few timber trees harpy eagles nest in, leaving little to no land or trees for the eagle to reside in (Miranda et al., 2020). While the harpy eagle can tolerate habitat disturbances, it can only survive with a sufficient area of the forest intact. Therefore, with increasing demand for deforestation and logging, the harpy eagle faces threats of extinction/extirpation so long as timber industries continue to target nesting trees for clear-cutting (Miranda et al., 2020). Not to mention, the harpy eagle's prey of choice is also impacted by logging and habitat loss, therefore indirectly contributing to the decline in harpy eagle populations. Around 35% of the harpy eagle's prey is primarily sloths, and they typically target monkeys as well (Aguiar-Silva et al., 2015). Unfortunately, sloths and monkeys are also threatened with extinction in the Amazon, and by being some of the main sources of prey for the harpy eagle, their declining population creates yet another complication for the harpy eagle (BirdLife International, 2021). Consequently, deforestation and logging have and continue to impact harpy eagle populations in the Amazon, but some modifications in logging and breeding can aid in preventing such large-scale impacts.

Solutions: Conserving Eagle Populations and the Amazon Rainforest

Figure 6. *"[Harpy Eagle Chicks](#)" is in the [Public Domain, CC0](#)*

Our research showed a variety of solutions that could help restore eagle populations along with conserving the Amazon rainforest. One part of a solution would be to create a **breeding program** for the harpy eagle. During the interview with Everton Miranda, he mentioned two existing breeding programs that exist for the harpy eagle in Brazil (Everton Miranda, personal communication, November 18, 2021). One of these programs is located at the Itaipu Binacional's Wildlife Breeding Center in Brazil (Itaipu Binacional, 2015). They created their first couple in 2005 and had their first successful offspring in 2009 (Itaipu Binacional, 2015). In 2015, the breeding program grew to include a flock of 21 birds that contained both adults and chicks (Itaipu Binacional, 2015). This program is going strong and is the largest breeding program of harpy eagles in captivity in the southern region of Brazil (Itaipu Binacional, 2015). Breeding in captivity gives the birds an environment they can thrive in, so they can be released back into their native habitat when they reach maturity. This gives them a better chance of survival and will allow wild populations to increase.

In hand with a breeding program, an education program in Brazil focused on the harpy eagle would also be beneficial in conserving its populations. The locals' fear of the harpy eagle would negatively impact any conservation efforts set in place. As stated before, people in the area shoot the birds because they are afraid the eagles will hurt their livestock or children, or because they are curious as to what they are and want to "feel [them] with their hands" (Everton

Miranda, personal communication, November 18, 2021). Having an education program in place will diminish the mystery around these birds, making the locals comfortable with them. This will allow them to coexist peacefully with the harpy eagles which will help the populations to increase.

Figure 7. *Area that has undergone selective logging*
"*[Selective Cut north of Mt Hood](#)*" *by* *[Sam Beebe](#)* *is licensed under* [CC BY 2.0](#)

Another part of the solution could be following a sustainable logging method, specifically selective logging. Selective logging is the practice of only cutting down a few trees in an area while leaving the rest of the forest intact. It is a way of preserving forest while still allowing some logging. An example of this method can be seen in Figure 7. It has become an important type of land use in the Amazon (Asner et al., 2009). Studies have shown that moderation in logging techniques can decrease damage to residual stand and surrounding grounds and soil by 50% (Sist & Ferreira, 2007). Selective logging can help the harpy eagle because this method will not clear-cut a forest leaving the harpy eagle some habitat. These eagles can't live in areas that have been clear-cut (Miranda et al., 2020). Even areas that have been selectively logged hurt their habitat, but it is better for them than clear cutting and allows for logging to continue, which is a more realistic solution rather than attempting to stop logging altogether. Moreover, this part of the solution will work to create stricter regulations on logging and work to eliminate all illegal practices since 40-50% of logging throughout the Amazon is done illegally (Miranda et al., 2020). All these efforts from the timber industry and the Brazilian government to have breeding and education programs, along with stricter logging regulations and practices, will work to conserve eagle populations and the Amazon rainforest while still allowing logging to continue.

Conclusion & Broader Impacts

From our research within this project, we were able to conclude that there are several strategies to reduce the impact of logging and deforestation on the harpy eagle. As previously mentioned, we can proactively work to restore the harpy eagle population with the creation of or support of already existing breeding programs. These programs could be funded purely by donations, or possibly by government funding, and could have several ethical and social benefits to society. Not only would they aid in restoring the populations, but also they could be an important resource for local people or others to learn more about the importance of keeping the harpy eagle alive. Moreover, one of our other solutions involved seeking out more sustainable logging methods to preserve the forest for harpy eagle populations, as well as other species. Methods such as reduced-impact logging not only reduce waste and better preserve the Amazon forest and habitats, but it also has proven to be more cost-effective as well (Holmes et al., 2000). Economically, reduced impact logging typically has a lower cost per cubic meter as opposed to conventional logging systems by being more productive and producing less waste (Holmes et al., 2000). Not to mention, reduced impact logging also has ecological benefits since it reduces damage to residual stands and surrounding grounds (Holmes et al., 2000). Both of these solutions could prove to be more than adequate solutions to restoring harpy eagle populations over time considering their cost effectiveness and ecological benefits.

Considering the implications and impacts of our project and solutions, there most definitely are other places or situations that can utilize a similar solution approach or method as ours if proven effective. For example, there are plenty of bird species in the

Amazon threatened by deforestation much like the harpy eagle, and similar methods can aid in the preservation or restoration of certain species and their habitats.

The problem of deforestation in the Amazon is a concern to a wide range of people. First and foremost, the Brazilian government should be at the forefront of working to combat the issue of logging and the harpy eagle. Unfortunately, as mentioned before, this is not the case. The ones that have the most power to cause change are not doing their part to help with the solution. An audience that is actually concerned about the harpy eagle is the indigenous people in Brazil. The harpy eagle is an important part of their culture as it can symbolize eagerness and prowess (WWF, 2006). They can help with the solution by sharing their ways of life and how they learned to coexist with the land. This will show sustainability is possible and that people can live in peace with these birds. Another group of people who truly understand the danger that the harpy eagle is in are scientists and researchers, such as Everton Miranda (Everton Miranda, personal communication, November 18, 2021). They can appreciate the uniqueness and value these birds add to an ecosystem. Researchers can add to the solution by helping to raise awareness through their work. Not only will this help more people to care about this issue, but it might earn the attention of the government since their research could bring money to the country (Everton Miranda, personal communication, November 18, 2021). The more research is done on the harpy eagle, the more attention they will get, which will help in the conservation efforts for them. The combined efforts of these groups will aid in the restoration of the Amazon rainforest and harpy eagle populations.

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15. The Mexican Long-tongued Bat: The Pollinator with a Sweet Tooth

HANNAH ALLEN; MORGAN OWEN; PAIGE AGOSTINI; AND ZOE SWARTLEY

The Mexican long-tongued bat (*Choeronycteris mexicana*) is an incredible species of **nectivorous** bat that plays a significant role in the pollination of multiple key plants. Some of these plants are major regional cash crops in Mexico and the Southwestern United States. In addition to the ecological and economic services these bats provide, they are also symbolic for several indigenous groups and are undeniably a very meaningful and influential species for the region. Unfortunately, reduced resource availability and various forms of human-induced disturbances have led to a decline in the bat population. This has led to their designation of "**near-threatened**" by the IUCN. There are a handful of conservation efforts in place to increase their numbers, though more research and work are required to restore this species.

“Mexican Long-tongued Bat, Choeronycteris mexicana Tschudi, 1844” *by* Misenus1 *is licensed under* CC BY-NC-SA 2.0

It’s the dead of night in Arizona; a myriad of animals take advantage of the lack of desert heat to hunt, forage, and find food. A small brown figure about the size of a human hand hovers around a flowering **agave plant**. As it approaches the flower, its wings flutter quickly, allowing the animal to float in place. As the creature gets closer and closer, it pushes its small head into the yellow flower. Then, unexpectedly, a long, pink tongue, double the size of the creature's body, darts into the center of the agave blossom, giving the fuzzy animal access to the plant's nectar. When it is done feeding, the being emerges from the flower, covered in bright yellow pollen. You just watched the nectivorous Mexican Long-tongued Bat feed on a blooming agave plant, and boy are you lucky! These little critters are hard to track and even harder to observe. This little bat will make its way to other agave plants, where it will spread the pollen from its face to these plants, allowing for the next generation of agave plants. As adorable as these **pollinators** are, they play an important role in the ecosystem of the US and Mexican deserts.

The Life History of the Mexican Long-tongued Bat

The Mexican long-tongued bat is a medium-sized **nectarivore**. It is concentrated along the Pacific Mexican coast to Central and Southern Mexico with some populations residing in the southwest United States and Baja California (Couoh-de la Garza et al. 2006). The species is a small **mammal**, typically weighing about 25 grams, and averaging a total length of 85 millimeters (Schmidly and Bradley 2016). Their fur shading ranges from brown to a sooty gray hue, and their most noticeable feature is their long snout and protruding nasal appendage (see Figure 1). This appendage is likely used during echolocation to direct the frequencies they make (Buchmann [date unknown]). **Echolocation** signals are used to find the bat's food source (flowers) and detect predators (Brown and Rainey 2018).

Figure 1. *"Nectivorous bat" by [Leah] is licensed under CC BY-NC-ND 2.0*

This bat has formed a **mutualistic relationship** with its food source due to the pollination it inadvertently does in between plants (Cryan and Bogan 2003). This species is well known for its consistent diet of **columnar cacti** plants, agave plants, and occasionally insects that bother their source of nectar (Cajas-Castillo et al. 2015). The bat's long tongue, which can extend to one and a half times its body length, allows for easier access to the nectar of the cacti (Charron 2002). As the bats immerse their heads into flowers to feed on their nectar, they often become covered in pollen, which they then transfer to the next plant they feed on. The more plants the bats visit, the more pollination occurs.

These critters are **seasonally migratory**, where they tend to be in their southernmost habitat in winter months and northernmost habitat in summer months as seen in Figure 2 (Burke et al. 2019). They follow the **nectar corridor**, where plants in their diets tend to bloom in sequence with their migration (see Figure 2) (Migratory...

[date unknown]). Their reproduction cycle also tends to follow their migratory patterns. They will reproduce in the northern areas of their migration range from late June to early July (Cryan and Bogan 2003), though their reproduction cycle is reported to start as early as April and extend as late as September (Choeronycteris… 2015). Each litter remains small, typically with only one pup born per mother per reproduction season (Cryan and Bogan 2003).

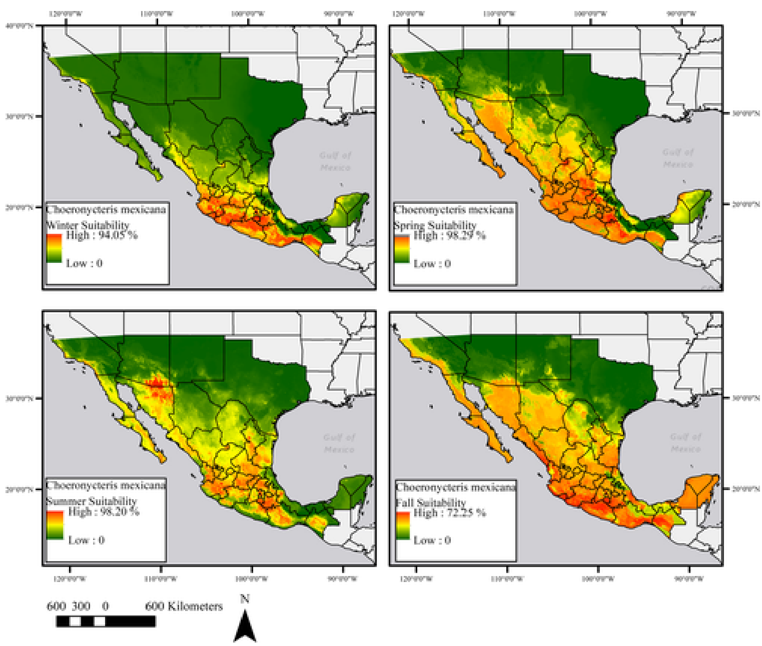

Figure 2. *[“Seasonal distribution models for Choeronycteris mexicana: winter (top left), spring (top right), summer (bottom left) and fall (bottom right)”] by Burke et al. (2019) in [Diversity and Distributions] is licensed under [CC BY 4.0]*

The bats tend to **roost** in small groups of less than 50, and stay in the same approximate areas every year after migration (Choeronycteris… 2015). They make their home in the woodlands, forests, and deserts. They are commonly found in shrublands, mountain canyons with dense vegetation, and old mines (Choeronycteris… 2015). The bats are also known to inhabit deep canyons and roost near the entrances of caves and mines, which allows them to remain alert to time changes and increase their sensitivity to disturbances wrought by human activity (Solari 2018). Like our friend in the beginning, once it becomes dark, the bats habitually leave their sites following the sunset to feed.

Because of their roosting style, it tends to be difficult to get an accurate population count of Mexican long-tongued bats. These creatures roost in small groups, change the location of where they roost often, and only roost with members of their own sex (Texas Parks and Wildlife Department [date unknown]). As a result, the population of the Mexican long-tongued bat is currently unknown. However, they are consistently found to have widespread low population levels, as shown by the lightest blue color in Figure 3, even though the exact population size is inconsistent (Arita and Santos-Del-Prado 1999). Due to their size, **nocturnal** activity, and small population, more research about the life history and habits of these nectar-loving bats needs to be conducted, making viewing one of these winged beauties a once-in-a-lifetime event.

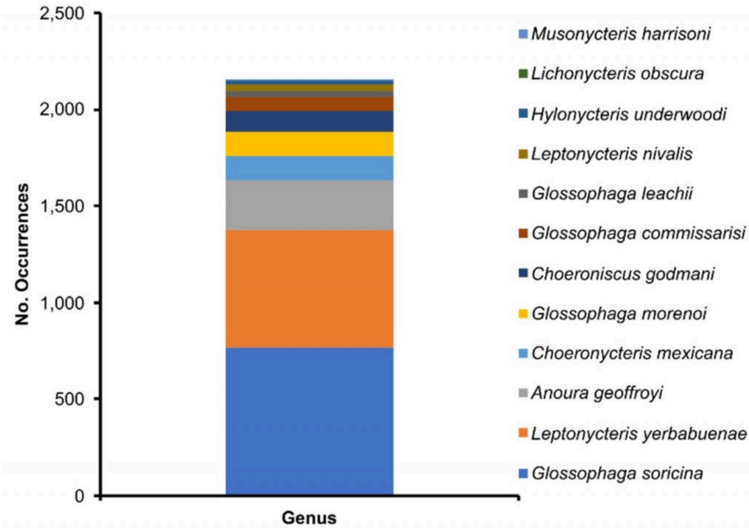

Figure 3. *"Number of occurrences recorded in GBIF/iNaturalist for pollinator bat species in Mexico from January 2001 to October 2020" by Urbán-Duarte et al. (2021) in Sustainability is licensed under CC BY 4.0*

Bats in Media: an Age-Old Tale

Most everyone is familiar with the typical trope surrounding bats; they're bloodsucking, rabies-infected animals that live in haunted houses and only come out around Halloween. Of course, this is an inaccurate portrayal, but it is interesting how often bats appear in folklore, pop culture, and the media. Bats appear numerous times in Indigenous tales and oral histories. For the Navajo people of the southwest U.S., it is believed that the bat was one of the first species to exist, and is the mentor of the night. The Pomo Indians of California have stories of bats chewing and swallowing **obsidian** and spitting out perfectly crafted arrowheads (McCracken 1993). This tale could also be associated with the California leaf-nosed bat, which is similar in appearance to the Mexican long-tongued bat, as they share the feature of an arrowhead-like nose (McCracken 1993) In Southern Mexico, a group of people known as the Zotzil uinic, or batmen, believe that their ancestors discovered a stone bat and they claimed it as their deity.

While countless Indigenous cultures view bats in a significant and positive light, a large majority of U.S. citizens as well as other Western nations see bats as more of a symbol of horror and disease. Exacerbated by Halloween films and media, in addition to the widespread knowledge of rabies in bats, these creatures are continuously painted as unwelcome. The COVID-19 pandemic has also influenced how people view bats. The **SARS-CoV-2** virus is thought to have been derived from a form of **bat-CoVs** virus, which was spread to humans in wet markets and close contact with bats. Due to this association, bats have been viewed as dirty nuisances, which could lead to persecution of bats, lowering their already declining populations. While this negative connotation toward bats is unproductive for maintaining their populations, it is still recommended that unnecessary contact with them and other wild mammals are avoided to avoid the spread of other viruses (Colunga-Salas and Hernández-Canchola 2020). For a virus to become zoonotic, certain mutations have to occur in the genome of the virus. These mutations occur completely by chance due to a variety of genetic and environmental factors. Meaning, a virus can potentially become **zoonotic** at any time. When humans come closer and closer into contact with a wild species, the probability of a person coming into contact with a zoonotic virus significantly increases. This is likely how the SARS-CoV-2 pandemic was initiated. For these reasons, it is important for humans to try and avoid invading the habitats of wild animals as much as possible and remain cautious around them. However, it is also just as important to recognize the essential role that bats play in the functioning of our ecosystem.

Threats to Existence: The Causes of the Low Bat Population

While these lively pollinators seem to be consistent and adjusted to their way of living, threats linger beneath the surface. The IUCN categorizes this bat as "near-threatened", meaning it is not endangered currently but has the potential to be soon (Solari 2018). The main threat to the decline of the Mexican long-tongued bat is its dependence on the agave plant. The agave populations are frail, as they are subject to prescribed fires and intense **grazing**. Due to the bats' dependence on the nectar of the agave plant, this, in turn, affects the populations of the bats. Not only are their food sources threatened, but the bats' roosting sites are also at risk of decline. The bats primarily roost in caves, which continue to be infringed upon by miners and tourists. This renders these sites uninhabitable, as bats are sensitive to disturbance. The pups of these bats are also sensitive to the disturbance of roosting sites directly after birth and when they first learn to fly. If disturbed, the young bats can become startled and fall to their deaths (Choeronycteris… 2022). Additionally, the use of the pesticide imidacloprid has been shown to reduce the ability of bats to echolocate, making it more difficult to find food and avoid predators (Solari 2018). Finally, North American bats are dealing with the fungal disease called **White-nose syndrome**, as displayed in Figure 4, which is another potential threat that the Mexican long-tongued bat could face in the battle to increase its population (White-nose…2021). Along with all these direct threats, the Mexican long-tongued bat, like all bats, faces being hunted by larger birds of prey in their daily lives, in conjunction with dealing with the invasive habits of humans (Beyond Pesticides 2017). With all the ecological services these bats fulfill, they are more than worthy of being protected, and work must be done to ensure their population isn't threatened any longer.

Figure 4. *"Bats display common symptoms of white-nose syndrome." Photo by Government of Alberta is licensed under CC BY-ND 2.0*

Agave: the Cashcrop Powered by Bats

Many people know agave from the products they consume regularly. Agave syrup, and more recognizably, tequila, are just a few of the important functions of agave within our economy (Bat Pollination 2000). Agave plants also have many medicinal, **antimicrobial**, and **antifungal** benefits, and contain many useful compounds. The availability of agave is made possible in part by the Mexican long-tongued bat. Our bats are pollinators, which means that when they feed on the agave plants, they are actually helping to keep them alive and maintain the desert ecosystem. The bat's long tongue gives it an advantage, allowing it to reach far into the plant to access its nectar, as shown in Figure 5. Research has shown that these bats are responsible for an additional 300 different plant pollinations and around 60 of them are of the agave species (Lopez-Romero et al. 2017). With agave being such a large industry, it is obvious that conserving the Mexican long-tongued bat has not just ecological benefits, but economic benefits, too.

Figure 5. *"*[*Mexican long-tongued bat*](#)*" by* [*Stephen Buchmann,*](#) *USDA is licensed under* [PDM 1.0](#)

Conservation and the Effort to Save the Mexican Long-tongued Bat

In order to keep desert ecosystems healthy, the preservation of this species, among others, is necessary. Areas such as Pima County, Arizona are working on conservation efforts and population tracking of the bats to try and save their declining populations (Gicklhorn and Murray 2020). Residents of this county have hung hummingbird feeders that the long-tongued bats will eat from, and have been recording sightings of the bats (see Figure 6). They also monitor the roosts of these bats as well as other threatened bat species (Gicklhorn and Murray 2020). Bat experts and researchers, such as the company Vesper Bat Detection Services, have also been working to train graduate students, other experts, and enthusiasts about acoustic monitoring and echolocation species identification so that more data can be collected about bat populations in general, including the Mexican long-tongued bat (Vesper 2020). Additional ideal conservation acts to improve bat population involve land and water protection. As these bats are currently threatened by habitat loss, it is important to protect their habitat and resources (Solari 2018). More research and monitoring are needed on the species to track population trends and threats, as the current research on the species is lacking. This will also allow people to make better decisions on how to conserve the species (Solari 2018). With the preservation of this species comes the flourishing of desert plant species, and the overall improvement of desert ecosystems.

Figure 6. *"Lesser Long-nosed Bat. Leptonycteris yuerbabuenae OR Mexican Long-tongued Bat . (Choeronycteris mexicana)" by gailhampshire is licensed under CC BY 2.0*

As important as the Mexican long-tongued bat is, their numbers are slowly dwindling down. Being such an important pollinator in the ecosystem of the U.S. and Mexican deserts, it falls on us to make sure the future generations are able to observe these adorable fuzz balls as they continue their long-time tradition of pollinating the plants of the deserts. So if you ever see a small brown bat with an absurdly long tongue in the desert, just know how lucky you are.

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16. It Takes a Village to Raise a Mountain Gorilla

An Investigation into How Indigenous Peoples of Eastern Africa Are Interacting with Endangered Mountain Gorilla Populations

CLAYTON HANLON; SOPHIA JOHN; ELIZABETH VIVEIROS; AND MICAH VARGAS

Abstract

The mountain gorilla (*Gorilla beringei beringei*), originating in Eastern Africa, is a recently recovered species from the **critically endangered** species list. Now an **endangered** species with a population of around 1000 individuals, these gorillas play a significant ecological role in their environment and even impact human economic systems as well. Conservation efforts concerning mountain gorillas have been largely made possible by the **ecotourism** they attract. Their intelligence, group structure, and unique habitats make these gorillas a very interesting species. Right now, however, the mountain gorillas are facing a very serious problem—the possibility of going extinct. They are now faced with a crucial dilemma: how can they exist in a human-centered and economically driven world, and is there a true solution to the population challenges they face?

“*Rwanda Mountain Gorillas*” *by youngrobv is licensed under* CC BY-NC 2.0.

Background

Mountain gorillas have an average standing height of 4-6 feet tall and are covered with very thick fur compared to other great apes, as it helps them retain body heat in their higher elevation environment (Tranquilli et al. 2012). They possess specialized teeth, having narrower **central incisors** and higher **shearing crests** than those of western lowland gorillas due to their differences in diet (Doran and McNeilage 1998). Mountain gorillas are classified as an endangered species, residing in **protected areas** in higher elevations between 8,000-13,000 feet (Tranquilli et al. 2012). The Virunga National Park of The Democratic Republic of the Congo, where mountain gorillas are most commonly found, is not their only home, as they also have habitats in Rwanda and the Bwindi Forests in Uganda (Figure 1).

Mountain gorillas are primarily **herbivores** who prefer vegetation with high protein content and adequately high sugar content (Ganas et al. 2008). Their diet consists of five main types of vegetation: leaf, stem, pith, root, and shoot (McNeilage 2001). The most frequent species of vegetation consumed are Cleavers (*Galium* spp.), *Carduus nyassanus*, and *Peucedanum linderi* (McNeilage 2001; Akayezu et al. 2019). The observed dietary diversity within mountain gorilla groups suggests that they can live within a large range of elevation. Fully grown, mountain gorillas will weigh around 440lbs and their diets are generally consistent but will vary by altitude. It was also observed that their diets change based on the time of year, specifically during the bamboo season when bamboo is readily available (McNeilage 2001). Mountain gorillas will even be selective about the part of each plant that they eat (Nyungwe Forest National Park 2022).

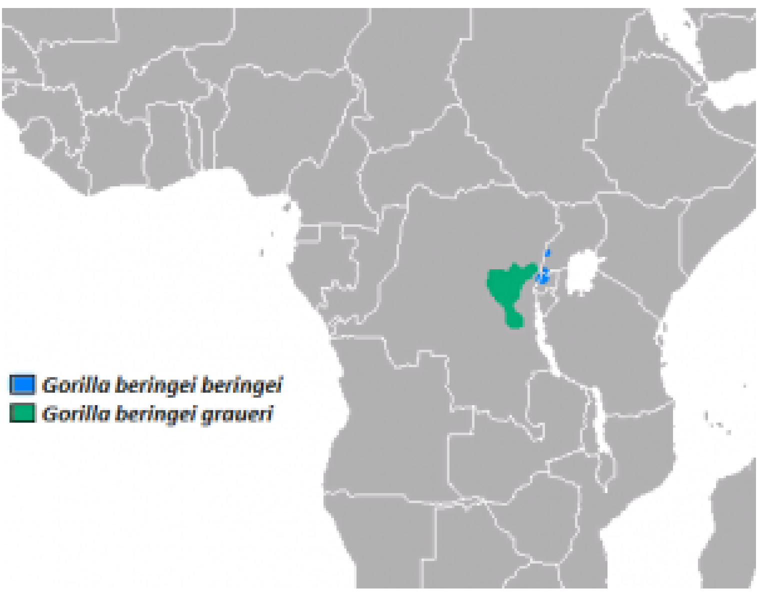

Figure 1. *Range Map of the Mountain Gorilla. "[Eastern Gorilla (Gorilla beringei) range]" by Chermundy is licensed under [CC BY-SA 3.0]*

Mountain gorillas organize themselves in groups called troops (or bands) typically consisting of around 30 individuals led by a single **silverback**. The rest of the troop will be composed of young males, some females, and their children (Figure 2). The silverback wards off challengers with aggressive moves (chest-thumping, charges, etc.) and fiercely protects females and infants in their groups.

Figure 2. *An Adult Mountain Gorilla in Virunga National Park "Virunga National Park" by Fanny Schertzer is licensed under CC BY 3.0*

Interactions between troops are commonly over resources like food. Other driving factors include competitive ability and intergroup relations (Mirville et al. 2018). The majority of these interactions were found to be non-physically agonistic (57%), with peaceful and aggressive interactions being less common (18% and 25% each) (Mirville et al. 2018). Such aggressive acts were commonly begun by young silverbacks, solitary males, or when a troop entered another troop's territory. In cases of group-on-group interactions, when the bands were of similar size, escalation was common as they had similar competitive viability. Peaceful interactions were seen in cases where there was a familiarity between the two bands. Another factor in violent interactions, however, was the presence of **migrant females** as they were sought after as potential mates. Solitary males' aggression would frequently occur over the chance to find a mate/migrant female (Mirville et al. 2018).

Similar to a human mother, a female mountain gorilla is pregnant for almost 9 months before giving birth, after which the children are still heavily reliant on their mother for two to three years (Nat. Geo. 2010). Young gorillas are seen to act and interact with one another similarly to human children: playing, swinging, climbing, and chasing one another (Nat. Geo. 2010). This parental dependency, paired with a relatively long gestation period, is a contributor to the slow growth in population numbers. The mountain gorilla population has been found to have a growth pattern of about 3% per year. Additionally, it is estimated that the global population is at least 1000 mountain gorillas with the Bwindi Impenetrable National Park containing 639-669 individuals (Granjon et al. 2020).

As a troop, mountain gorillas work together to build stable shelters to help alleviate constant stress factors such as temperature and intense humidity levels in their habitat. They create nests made out of available vegetation, which provide them with effective protection from the harsh cold temperatures experienced in their mountain habitats. Mountain gorillas build their nest in areas surrounded by vegetation that will mitigate the impacts of weather conditions too, such as wind and rain (Eckardt et. al 2019).

Threats to the Species

Posing as an even greater threat to mountain gorillas' survival than their environment is human presence. Humans have rapidly pushed mountain gorillas to endangerment, as they are vulnerable to human diseases, charcoal production/burning forests, accidents involving traps meant for other animals, and **poaching**. Other threats include farming, mining, and the ever-so-looming climate change. Part of the reason gorillas face danger is because they use a wide range of terrain and rely on large stretches of land. Thus, the need for constant migration leads to an increase in the probability of mountain gorillas coming into contact with humans. This causes the population growth to be stifled by the human-made structures surrounding these areas, as they serve as a barrier against animal movement (Petrželková et al. 2021). This population density increase has led to a correlating increase in disease among mountain gorillas (Ekott 2021). Apes in general are vulnerable to human **pathogens** due to their immense genetic similarity with humans. This results in mountain gorilla populations being highly susceptible to human virus breakouts that can cause fatal respiratory diseases. Because of this, there has been a large concern about how the SARS-CoV-2 virus would affect mountain gorillas. In the past, diseases like human measles and **human metapneumovirus** have been known to create an outbreak among mountain gorillas. Another main factor that spreads viruses to mountain gorillas is ecotourism (Gilardi et al. 2021). Additionally, poaching and illegal activities still pose a serious concern to the conservation of the already endangered mountain gorillas (Tranquilli et al. 2012).

Another cause for concern to the mountain gorillas is the prevalence of unauthorized uses of resources (such as bushmeat, firewood, medicinal plants, honey, basketry materials, and building poles) by the poor households that reside close to the park boundaries, but far from the roads and trading centers. These families were suffering from the inequity of revenue sharing and employment, in addition to crop loss from wild animals. The Integrated Conservation and Development Projects (ICDs) were proving to be effective as a form of rural biodiversity conservation, as well as other law enforcement in the area. However, ICDs are best used in direct contribution to the poorest people, to provide benefits and reasonable alternatives to them. Currently, they are aiding the act of unauthorized resource use in the area by allowing the harvest of medicinal plants and basketry materials.

Conservation Efforts

Conservation efforts in the protected areas where mountain gorillas reside have led to steady growth in their population. However, the only place where they can now be found is in those protected areas. Consequently, mountain gorillas have gone from being classified as critically endangered to endangered. This is a result of conservation methods that have been adopted; wearing masks to help prevent viral infections including COVID-19, having large ranges where mountain gorillas are protected and the chances of human-gorilla contact are minimized, and having ample resources to help protect mountain gorillas from illnesses and treat injuries (Gilardi et al. 2021). Although ecotourism can have negative effects on ecosystems, such as the introduction of foreign foods and substances to the area, damage to the plants and animals with vehicles, and affecting reproduction in the area (Sabuhoro et al. 2021), the revenue from mountain gorilla tourism motivates both the public and the government to protect them, which is ultimately beneficial to the mountain gorilla as a species. From 1999 to 2014, numbers have only been increasing steadily in the number of tourists who visit and, with that, revenue. For instance, in 2014 alone, revenue from ecotourism in U.S. dollars was 15,076,916 (Sabuhoro et al. 2017).

To better understand the impacts and effectiveness of mountain gorilla conservation, the indigenous peoples who border two protected lands (Volcanoes National Park in Rwanda and Mgahinga Gorilla National Park in Uganda) were interviewed and surveyed during a 9-year period (2007-2015) regarding the number of illegal activities (use of protected land for agriculture, hunting of protected land etc.) in the parks. The results of the surveys suggest that while most illegal activities were not targeting mountain gorillas specifically, the land supposedly set aside for conservation was still being exploited for its resources (Sabuhoro et al. 2020).

One of the most notable conservation efforts is the Dian Fossey Gorilla Fund, a charity founded by conservationist Dian Fossey. She had worked with gorillas and their habitats for years and her main goals were to protect gorillas, conduct science, train conservationists, and help communities for multiple species in addition to gorillas. From habituating the mountain gorillas to recognize and exist in harmony with humans and other species, to collecting basic information about their habits, births, deaths, and more, this organization's work has had far-reaching effects on the world around these gorillas, and beyond, promising hope for the future.

The Rwandan government has used mountain gorilla tourism to benefit local communities through **pro-poor tourism**. The goal of this strategy is to bolster local low-income communities through revenue and livelihood opportunities. The areas surrounding the national parks have some of the highest population densities in the world (700 people per square kilometer). Seventy-five percent of Rwandans live under the international poverty line. The Parc National des Volcans (PNC) in Rwanda employs 180 individuals. Since 2005, local communities have seen about 5% of tourism revenue invested back into the communities surrounding the park by the Rwanda Development Board (RDB). The RDB has also used about 60% of total revenue to provide 10 schools, 88 water tanks, and funding for community organizations. This strategy has some benefits, as Rwanda has emerged from its violent and conflict-driven past, and we can see the mountain gorilla population rebound. A large part of this reason is due to pro-poor tourism. It is possible to have well-defined conservation efforts for the mountain gorilla populations while also involving local communities.

Pro-poor tourism is not the only significant improvement being made in the area. A new payment model using benefit-sharing schemes with locals (a bio-economic model) would be able to resolve exploitation in habitats, being done in areas bordering reserves without access to roads or trade centers (Harrison 2015). The current model does not directly incentivize the growth of gorilla stock and, as such, intrusive human behaviors remain. While the current system has had an effect, a greater conservation effort could be made in conjunction with making local communities co-owners of wildlife by directly connecting payment to population growth (Mukanjari 2013).

Research Question

The policies put into place regarding the conservation of land and the coexistence of mountain gorillas and indigenous people can be beneficial and harmful to both parties. This raises the critical question: how can national parks be run in sustainable ways that make them profitable and beneficial for the local communities, while also taking proper precautions in protecting the mountain gorillas and their habitat?

Mountain gorillas are essential to their local environments, as they're one of the largest **grazers** to inhabit the mountains of the DRC, Rwanda, and Uganda. Mountain gorillas roam large expanses of land throughout the day, constantly searching for their next meal. Primarily vegetarians, they play a key role in maintaining biodiversity amongst the local vegetation species. Mountain gorillas are also known to change their diet, namely during the bamboo season. This is an important ecological role in the balance of biodiversity in their habitats because, without these primary consumers of bamboo, the environment could be quickly dominated by the fastest growing plant on the planet. The mountain gorillas that live around tropical rainforests, the "lungs of the planet", play an important role in keeping up these services provided by plants by dispersing various seeds (Why Gorillas Matter 2020). There are also many other endangered species that reside in the same habitat, which depend on the gorillas as an “umbrella” for protecting ecosystems on a larger scale.

Mountain gorillas show signs of using imitation learning in the diverse ways in which they prepare their food and consume it. Mountain gorillas are known to learn from **genetic predispositions**, meaning they retain information learned and acquired during development. It has been observed that Mountain Gorillas possess characteristics of low vulnerability to stress, low aggressiveness, and low neurotic tendencies. They also demonstrate characteristics of generally being emotionally stable, introverted, and calm. Mountain gorillas are predicted to have calming characteristics due to the low competition for food and the stable environment in which they reside. Male mountain gorillas are more dominant in a structured hierarchical society than females, however, female mountain gorillas are more social than males (Eckardt et al. 2015).

Mountain gorillas affect those around them in more ways than other plants and animals in their habitat. They are serving their own conservation efforts and supporting local communities by attracting many eager tourists (Nowak 1995). Their generated revenue has caused the locals to be much more concerned with their conservation, thus raising more awareness of the pressing issue. The International Gorilla Conservation Program has no longer been the only source of funding for the conservation of mountain gorillas since they opened the Ugandan National Parks with gorillas for viewing.

Ultimately, all hope is not lost for the mountain gorillas. As more awareness of their endangerment is raised, more funds can be dedicated to supporting conservation efforts for mountain gorillas. Moreover, the continual advancement of research efforts and sustainable technologies show promising routes of hope for providing effective solutions that reap both environmental and economic benefits for preserving the species. The pursuit of understanding mountain gorillas—their behaviors and lifestyles, ecological impact, and biology as a species—is a vital part of sustaining and boosting conservation efforts.

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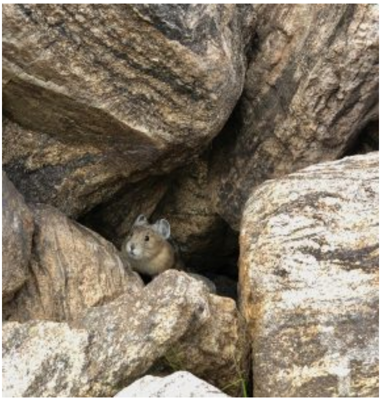
17. Look Closely: The Elusive American Pika

AMELIA SADLON; KALEIGH WALSH; CRAIG DUNN; AND NICOLE RANNIKKO

Abstract

American pikas (*Ochotona princeps*) are small mammals that live in cold, **alpine** ecosystems, spending most of their time in and around rocky slopes in the western United States. They can be found scurrying to collect vegetation to store for the winter, which creates decaying hay piles that benefit future plant growth in their environment. Researchers struggle to find funding for research into this "least concern" species, turning toward **citizen science** to help gather information while debates about the threat status of the American pika continue. Despite this, some conservation strategies for the American pika do exist.



"North American Pika in Rocky Mountain NP" by shannonbuttimer is licensed under CC BY-NC 2.0.

Introduction

Many species across the planet are well-known through extensive research that reveals their unique characteristics and the important roles they have in their environment, among other things. Often, this results in a positive feedback loop of increased research and attention on these species. The American pika is a species that is struggling to reach this limelight, likely in part due to a lack of funding for research as well as their elusive habits. This is despite initial research into the species that shows compelling evidence of **fragmented populations** decreasing in size, behavior informing climate research, and activities that benefit the health of their environment. There is much to be learned and appreciated about the American pika.

Natural History

Physical Traits

American pikas are small mammals that weigh about 121 to 176 grams and are about 15 to 20 centimeters long (Oregon Wild 2019; Peri 2012). These animals have thick, gray to brown fur (depending on the season) and round bodies, with round ears and no visible tails (Oregon Wild 2019; Peri 2012), as can be seen in Figure 1. Since American pikas live in a cold climate, they have furry paws that provide the necessary surface area for them to move across the snow, as well as a high metabolic rate that contributes to their **thermoregulation** (Oregon Wild 2019; Peri 2012). They are typically **monomorphic**; however, in some **populations**, males are larger than females (Peri 2012).

Figure 1. An adult American pika in its natural habitat. "pika" by Phil Myers is licensed under CC BY-NC-SA 3.0.

Life History

American pikas are **monogamous** by nature and will produce up to two litters per breeding season, which can consist of two to four young (Peri 2012). The timing of breeding follows the seasons, occurring as winter shifts into spring which allows more available vegetation for the mothers of the new litters (Smith and Weston 1990). Female pikas will not release eggs until breeding has occurred, which is referred to as **induced ovulation** (Peri 2012). Then, it will take around thirty days for the offspring to develop (Smith and Weston 2012). American pikas tend to reach sexual maturity around one year old and will live approximately three years in the wild on average (Peri 2012).

Basic Needs

The American pika is a rock-dwelling species that typically inhabits **talus** near meadows. They prefer to live at high elevations in cold areas (Oregon Wild 2019), such as the **alpine tundra**, **taiga**, and mountain **biomes** (Peri 2012), which adds to their elusive nature. Some American pikas live in cool caves, like the ice tubes in California's Lava Beds National Park (NWF 2019), as well as log piles or human-made habitats such as road cuts (Smith and Beever 2016). American pikas typically create hay piles in the summer and later use them as a primary food source in the winter, as they do not hibernate (Dearing 1997; Peri 2012). They often leave stems intact so that they can easily carry the plants in their mouths to the hay pile for winter storage, while they eat the other portions of the plant in the warmer months. These hay piles can compensate for decay and prolonged food scarcity during unseasonably long winters (Dearing 1997). The American pika's diet consists of plants such as thistle, sedges, wildflowers, and grasses (Oregon Wild 2019). Alternate early winter and fall food sources depend on the specific environment but could include lichens (Dearing 1997).

Range and Distribution

American pikas live in mountainous areas across the western United States and Canada. They are believed to have evolved from Siberian ancestors that crossed the **land bridge** spanning from continental Asia to Alaska. American pikas once lived all across North America, but have since retreated to a smaller range over the previous twelve thousand years. Now the American pika is only found from British Columbia to southern California (NWF 2019). Their distribution is discontinuous and their habitat is patchy by nature (Smith and Beever 2016), as seen in Figure 2. Within this region, the American pika's preferred habitat is found above the treeline within

alpine terrain, reaching elevations of 4,175 meters (Smith and Beever 2016).

Figure 2. Distribution of American pikas (Green) in the US and Canada. "American Pika (Ochotona princeps) range" by Chermundy is licensed under CC BY-SA 3.0.

Role of the American Pika

Ecological Roles

Despite their small size and elusive nature, American pikas play a significant role in their environment. The species is an **ecosystem engineer**. Specifically, American pikas function as **allogenic engineers**. By creating hay piles, the American pika influences nutrient availability for plants and increases nutrient abundance in a localized area. American pikas do not eat all of the hay piles and the species' feces is often found in the hay pile; the leftover biomass decomposes alongside the American pika's feces which can increase the nitrogen in the soil. In the **alpine** environment, where the American pika lives, nitrogen is the limiting nutrient. Therefore, by increasing the nitrogen content of the soil, the American pika increases plant growth and productivity (Aho et al. 1998).

American pikas are part of their ecosystem's food chain, as they are known to have several predators including coyotes, long-tailed weasels, ermines, and American martens (Peri 2012). When American pikas see potential predators they hide and may camouflage with their surroundings, usually sending an alarm call to other American pikas to inform others of their presence (Peri 2012).

Societal and Economic Roles

The American pika has been labeled by some as a **climate change indicator** species, which makes them important for climate-related research (De Jong 2011). However, due to debate surrounding the American pika's current generally unthreatened status, there is no significant funding that is available for research into the species. This only furthers the lack of knowledge or understanding of the American pika. In order to continue the collection of valuable information about American pika **populations**, researchers have turned to **citizen science**, which helps to reduce costs through volunteers. This usually involves groups being led by professionals to look for signs (hay piles, scat, vocalizations, sightings) of the American pika in the wild (Figure 3). Bringing civilians into American pika research not only motivates individuals to get into the outdoors, but it also spreads knowledge about the American pika to individuals that may not normally be aware of the species (Moyer-Horner et al. 2012). It is also difficult to conduct research into the American pika due to their high-elevation habitat and elusive behavior (Smith and Beever 2016).

Figure 3. A civilian researcher looking for signs of the American pika in a talus slope. "[Scanning a talus slope for signs of pikas (Citizen Science)]" by [GlacierNPS] is in the [Public Domain].

American pikas are not an **economic driver**. Hunting and trapping of the American pika are illegal, which is further reinforced given that the species is small, making hunting for fur or meat not desirable (Smith and Beever 2016). Additionally, American pikas cannot be obtained as pets, given that there are no known cases of domestication and that they are highly adapted to their **alpine** habitats, which would make ownership difficult. Since animals are unfortunately often valued by their availability as food, trophies, or pets, the American pika does not present as a species that brings money into the regions they occupy.

The Road to Conservation

Status

Since 1996, the American pika has been listed as **least concern (LC)** by the **International Union for Conservation of Nature** (IUCN). This classification is supported by the rulings of the U.S. Fish & Wildlife Services (2010) and California Fish and Game Commission (2010, 2013), which determined that this species is not qualified for protection under the U.S. Endangered Species Act or the state's Endangered Species Act, respectively (Smith and Beever 2016; FWS 2010). This is despite specific attempts to have the American pika designated as more threatened (Reis 2010). There are sub-species of the American pika whose **populations** may be under more threat as shown by their higher **extirpation** rates (Peri 2012). However, according to the FWS, the threat of **extirpation** is still supposedly not likely to endanger the species, subspecies, or distinct **populations** in the foreseeable future (FWS 2010).

Population Data

Although the numbers for all American pikas are not available (Smith and Beever 2016), specific **populations** have been studied, which reveal local numbers and trends. One study found 266 pikas in Glacier National Park (Moyer-Horner et al. 2016). American pika **population** density is also estimated to be around 20 pikas per hectare in prime **talus** habitat, as shown in Figure 4 (Smith and Beever 2016). Because American pikas have specifically vulnerable states at the beginning and end of their average lifespans, there is a higher concentration of them around three or four years old within these **populations** (Peri 2012). Trends show that many **populations** of American pikas are decreasing in areas such as the Great Basin, southern Utah, and northern California—mostly due to climate change (Smith and Beever 2016; Beever et al. 2016). Studies also show certain American pika **populations** struggling to inhabit all the areas they were previously detected.

Figure 4. An American pika in its ideal habitat, with available vegetation and sun cover in the talus. "Calling All Pikas" by Will Thompson is in the Public Domain.

Some areas did experience above 90% occupancy in previous zones of detection; however, many other areas with smaller **fragmented populations** experienced much lower occupancy compared to the past (Smith 2020). For example, there has been a 44% loss of American pikas in the Great Basin, according to historical records (Beever et al. 2016).

Figure 5 provides some insight into the past and present locations of the American pika. Additionally, the figure depicts locations in which the American pika has shown activity post-**extirpation**, cross-referenced with viable summer habitats. Summer habitats are the focus of many American pika **extirpation** studies since it is when **extirpation** tends to occur. The **alpine** habitat conditions are most volatile during the summer months; therefore, if the summer habitats are stable, then the pika population will find even greater stability during the winter months. Thus, the study of summer habitats is of the most value when investigating American pika **population** volatility and extirpation. This cross-referenced figure indicates that, while loss of habitat is a threat to stranded subspecies, there are habitats readily available and suitable for the species to inhabit (Figure 5). This raises even more questions surrounding the misunderstood American pika—what is stopping them from inhabiting these suitable zones?

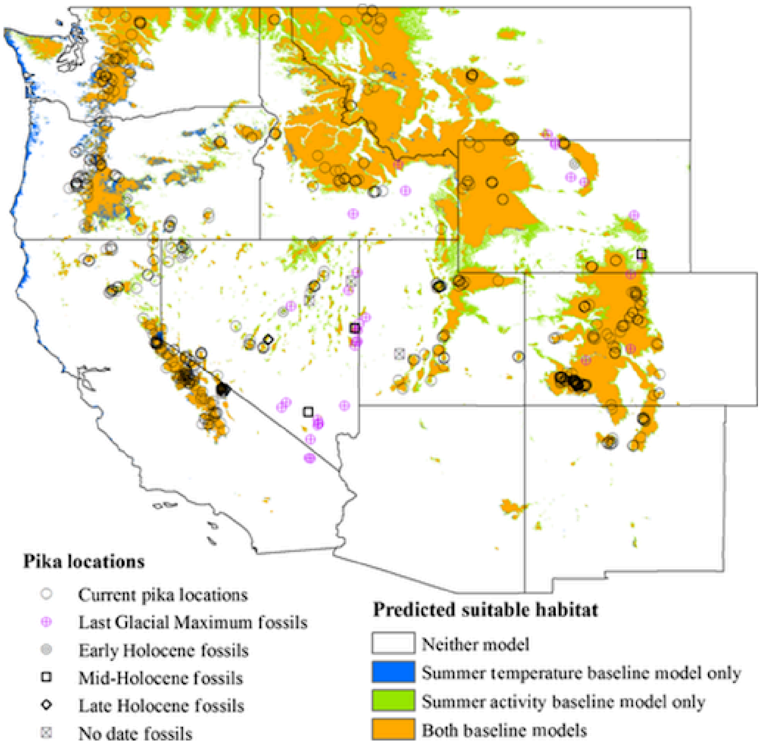


Figure 5. Map detailing American pika populations in the western United States as well as fossil records to detail former American pika habitat locations. Printed with permission from P. Mathewson.

Threats & Conservations Efforts

Threats to the American pika include habitat shifting and alteration due to climate change, livestock farming, and nomadic **grazing** (Smith and Beever 2016). Since **alpine** mammals like the American pika live in high elevations and cold temperatures, it is predicted that they are some of the most threatened by climate change (Beever et al. 2016). Climate change leads to extreme temperatures (abnormally hot or cold days), higher than average summer temperatures, and changes in the duration of snow cover (FWS

2010). The American pika is sensitive to temperature changes and since they already live on the tops of mountains, there is nowhere colder to go (Beever et al. 2016). **Grazing** can also threaten the American pika on the local scale but does not significantly impact its status. When livestock is present, American pikas must compete for food with a much larger species, so they tend to stay closer to the **talus** and are forced to graze on poorer vegetation (Smith and Beever 2016). **Invasive species**, fire suppression, disease, predation, and roads do not currently pose threats to the American pika, according to U.S. Fish and Wildlife Services (2010).

Efforts to conserve the American pika include the installation of water containers for hydration, as well as added sun cover, such as dead logs (Wu 2019); these can generally help with the loss of resources that American pikas experience due to human activities and climate change. Another strategy for conservation is assisting in the migration of the American pika **populations** to new and previously inhabited areas, given that certain **populations** are so dispersed now (Wilkening et al. 2015). **Assisted migration** is especially difficult for **alpine** animals as the disappearance of this terrain across the globe is the initial cause of **extirpation** (Mathewson 2016). American pikas are fortunately protected in national parks and other protected areas occurring within their range. Additionally, hunting and trapping of them is not allowed within their range (Smith and Beever 2016).

Ecologists have also proposed that efforts be tailored to the different **populations** of the American Pika since the needs of the **populations** can vary based on their abilities to adapt and react to the changing conditions of their environments. Researchers found that some American pika **populations** have learned to forage nocturnally, avoiding heightened temperatures during the day, which shows that these **populations** may not require increased sun cover compared to other **populations** (Smith 2020). However, this shift from diurnal to nocturnal activity leads them to be most exposed to nocturnal predators, which is another aspect to consider in their conservation. The tailored conservation efforts would be benefited if more funding was available for American pika research, as the nuances of the American pika could be revealed, understood, and targeted to help their **populations** stabilize.

Conclusion

The American pika shows signs of being an informative species for several types of research, though the feedback loop of lackluster research funding because there is not a clear understanding of the species does not help. Initial evidence points to this small mammal's sub-populations experiencing stressors related to human activity, which may lead to increased **extirpation** events. It is vital that more focus be placed on the American pika in order to support one of the many species contributing to this world's biodiversity.

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18. Soaring to New Heights: The Rebirth of the Puerto Rican Parrot

LUKE GEBLER; CONNOR NORTON; NATHAN SARACHICK; AND JACKSON HAUMAN

Abstract

"[The Puerto Rican Amazon](#)" by [vivtony00](#) is licensed under [CC BY 2.0](#)

The Puerto Rican parrot (*Amazona vittata*) lives almost exclusively in the **Luquillo mountains** and greater El Yunque rainforest (United States Department of Agriculture, 2019). Puerto Rico has been through many spells of isolation and colonization throughout the years by the Spanish and Americans. The rainforest sparked particular interest due to its unique flora, fauna, and natural resources. In 1876, Spanish King Alphonso XII declared the forest to be a reserve and for all lumber and tree removal to be regulated. In the 1900s, President Theodore Roosevelt proclaimed the forest again as a **reserve** but overseas war generated charcoal production and gold mining in the area. Water was also diverted to the now growing populations of locals and the edges of the forest were stripped away. These habitat disturbances have caused the native parrot to be critically endangered for many years; however, restoration efforts

have been moderately successful in restoring a wild population (United States Department of Agriculture, 2019).

An Emerald Beauty

Habitat, Physical Characteristics, and Diet

The parrots are found in ***Dacryodes excelsa* forests** around the island, where they commonly nest in the Palo Colorado tree. They generally prefer the **lowland forests**, but due to human interference, populations have shifted to higher elevations of 200-600m (Collar et al. 2020). Their current **habitat** is shown in Figure 1. They are known for their colorful plumage with the majority of their feathers displaying a bright green color, as well as hints of blue and red feathers on their heads and accenting their wings (US Fish and Wildlife Service 2012). Males and females show little differences in their feathering, with the exception of some males having a wider red band around their heads. Young Puerto Rican parrots also have the same bright green, blue, and red feathers when they are born (US Fish and Wildlife Service 2012). On average, adults grow to about 29-30 centimeters in length and about 300 grams in weight. The Puerto Rican parrot feeds on fruits, seeds, leaves, flowers, and bark of many plant species, such as *Prestoea montana*, royal palm, and guava. Despite having the entire island to roam, these birds are sedentary. Individuals communicate and mark their territory via different screeches and high-pitched calls (Collar et al. 2020). Specifically during flight, these birds make a distinct "kar…kar" sound that echoes across large distances (US Fish and Wildlife Service 2012).

Figure 1. "[Range map of Puerto Rican Amazon (Amazona vittata)]" by [Cephas] – Adapted from: BirdLife International. 2020. Amazona vittata is licensed under [CC BY-NC 4.0]

Reproduction and Mating

Puerto Rican parrots live, on average, for about 40-50 years and reproduce once a year between the months of January and July. Unlike most parrot species who typically change partners seasonally, the Puerto Rican parrot mates for life. Each year, female parrots will lay between two to four eggs which will then incubate for 24 to 28 days up in natural tree cavities. Newborn parrots typically take 60-65 days to **fledge**, and after three to five years, they will become full adults (US Fish and Wildlife Service 2012). The reproduction rate of these parrots has drastically decreased over the past century. The issues which likely cause this decline can be attributed to a multitude of problems. These problems include but are not limited to: sexual inexperience due to lack of social interaction, asynchronous breeding conditions, improper **imprinting**, and infrequent mating (Clubb et al. 2015).

Population Problems

Natural History

The first documentation of the Puerto Rican parrot was around 1493 when Christopher Columbus sailed to the Caribbean. Back then, it had been estimated that millions of these birds populated the rainforest. Since then, the population has only decreased until recent conservation efforts have been implemented. Their high population numbers plummeted down to only 13 birds by 1975, causing the Puerto Rican parrot to be considered critically endangered by the International Union for Conservation of Nature (Birdlife International 2020). The population remains small even now, as shown in Figure 2. When they were numerous, they spread out across the entire island, but recent populations have become isolated due to habitat loss and **fragmentation**. This fragmentation has only been made worse through both Hurricane Hugo back in 1989 as well as the recent Hurricane Maria in 2017, eliminating around 90% of the parrot population with only two wild parrots surviving (Associated Press 2018). Conservation efforts have been instrumental in harboring a new generation of birds both in captivity and eventually into the wild again.

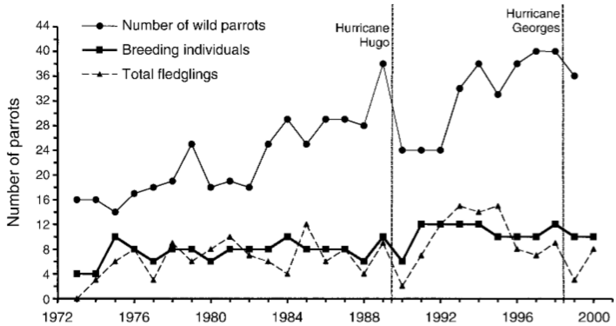

Figure 2. "[Puerto Rican Population Trends]" by Beissinger et al. 2008, [U.S. Department of Agriculture] is in the [Public Domain].

Environmental and Genetic Risk Factors

The population of the Puerto Rican parrot is still nowhere near their pre-European numbers, despite modern conservation efforts. Having such a low population makes the parrots more susceptible to random changes in their environment and genetics. Small changes in the tree populations necessary for nesting or feeding can cause detrimental effects on the few parrots in those regions. Oftentimes these changes occur via natural disasters, like Hurricane Hugo and Maria, as described in the history section. Likewise, these small populations are susceptible to diseases and **inbreeding depression** (Earnhardt et al. 2014, Beissinger et al. 2008). Figure 3 summarizes several other random genetic and environmental processes that currently impact the population size.

Predatory Risk Factors

Outside of **intraspecies** issues, Puerto Rican parrot populations are kept low due to predation by various birds of prey, like the red-tailed hawk (the most prominent threat), peregrine falcon, and pearly-eyed thrasher (Burgos 2011). Once the red-tailed hawk was introduced to the island, the Puerto Rican parrots were preyed on immediately and continuously (Engeman et al. 2003). This is further amplified in the winter when peregrine falcons migrate to the area (Engeman et al. 2003). While these hawks have been responsible for the loss of eggs and chicks, they come nowhere near the real danger to these parrots—parasites. These **ectoparasites** have been responsible for the majority of failed offspring, around 56% of the total losses (Arendt 2000). Additionally, mammalian predators, such as black rats, brown rats, roof rats, feral cats, and mongooses, stalk the ground and trees to feed on the eggs and young birds.

		Factors maintaining the bottleneck			
Stochastic processes	Species or environmental attribute	Inbreeding	Failure to nest	Nest failure	Survival
Genetic	hatchability	low			
	hatchability after mate change for members of pairs with previously low hatching success	increase			
	deformities of chicks	frequent			
Genetic, demographic	percentage of birds nesting		low		
	rate of mate replacement		high		
Demographic	sex ratio		skewed		
Environmental	cavity availability		low	high	
	nest failure rate (nongenetic)		low	high	
	annual survival of juveniles				low
	annual survival of adults				low
Environmental, catastrophe	rainfall			high	negative
Catastrophe	hurricanes			high	reduced

Figure 3. "Factors Potentially Maintaining the Puerto Rican Parrot Population Bottleneck" by Beissinger et al. 2008, U.S. Department of Agriculture is in the Public Domain.

Conservation Efforts

Conservation efforts for the Puerto Rican parrot have occurred for more than four decades, ever since the reported population of 13 in 1975 (Earnhardt et al. 2014). A multitude of programs have been put in place in order to guarantee to keep the species alive. The main strategy being implemented is the breeding and harboring of a portion of the population that has now grown far past the wild population. Another program that has been established is the **reintroduction** program in order to help these birds breed and return to their wild habitats. Many studies have been done in order to help determine the optimal reintroduction strategy, heavily leaning on past attempts for other bird species (Earnhardt et al. 2014). Thankfully, many of these efforts have had a huge amount of success with the wild population hovering around 30 and the captivity population reaching upwards of 400, hopefully pointing towards a future where these birds will no longer be critically endangered.

Why Does It Matter?

Ecological Role on the Island

The Puerto Rican parrot feeds off many of the endemic plants on the island of Puerto Rico. By combining their mobility and scale of habitat, seeds eaten by the parrot are dropped in various areas around the island. This makes them very important for starting new populations of the island's endemic plant species (Christian et al. 1996). To humans specifically, the Puerto Rican parrot and its conservation efforts have helped uncover fundamental Puerto Rican animal behaviors and ecosystem functions. The techniques used in their conservation are now applied to improve other bird populations. Years of study have developed ways of conserving various other ecological resources needed to sustain these animals. Finally, Puerto Rican parrots attract a lot of birdwatchers to the island which helps with **ecotourism** (Burgos 2011).

Economical and Societal Roles

The Puerto Rican parrot, also called **"**Iguaca**"** by the locals, is a central part of the natural and cultural history of Puerto Rico. Since it is only endemic to Puerto Rico, many people use the parrot as a symbol of national pride much like a flag. It is also used as a symbol of conservation, especially because of its low population numbers (U.S. Fish and Wildlife Service 2014). Various artworks have been inspired by their beautiful green plumage, as shown in Figure 4. In terms of economic impact, these birds have been a focal point of major conservation efforts, having given lots of opportunities for research and education on critically endangered species and how to help. This species, so far, has been a successful restoration story and can be used as a blueprint for future efforts.

Figure 4. "Puerto Rican Parrots" by Walter Alois Weber, National Park Service U.S. Department of the Interior is in the Public Domain

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19. I'iwi: The Ruby-Red Gem of Hawaii

GRACE SOLOD; SAM BEZANSON; CHIARA SMITH; AND LAUREN MCILHENNY

Five thousand miles away from Worcester, Massachusetts, there is a hidden gem hidden high up in the forests. Among the busy buzzing and blooming tropical mesic forests of Hawaii, the I'iwi (*Drepanis coccinea*) gently chirps, "eeeee-eeeee." The I'iwi (pronounced ee-ee-vee), a ruby-red honeycreeper with a long and thin beak, resides on five out of the eight islands of Hawaii, sipping sweet nectar from the scarlet-red ōhi'a flowers and golden mamane blossoms. Because of the I'iwi's beautiful color, many Hawaiians collect its feathers to make clothes; decorated clothing was a symbol of social ranking. According to legend, the Hawaiian demigod Maui was the only one who was able to hear and see the I'iwi, and he was fascinated with its beauty. He boasted about its beautiful plumage and was so proud to have it live on his islands that he made a big reveal and showcased the I'iwi to all the villagers, so they could appreciate the I'iwi as much as he did. Unfortunately, this treasure is very difficult to find in the wild because it is extremely vulnerable due to devastating diseases and the destruction of its habitat, with only about 600,000 individuals). However, in 2017 the I'iwi was recognized as threatened by the US government and several tactics are being employed to keep this species stable, including forest conservation, working with national partners, removing ungulates, and controlling invasive plants. There are even private island tours hosted and the money donated goes to local organizations dedicated to protecting the I'iwi. If you ever get the chance to go to Hawaii, try to look for this little crimson bird–it might be the last chance to ever see it.

Sketch of the I'iwi. "I'iwi" by Isabell Schulz is licensed under CC BY-SA 2.0

Physical Traits and Adaptations

The I'iwi is a medium-sized **honeycreeper** that is approximately 15 cm in length. The adults are bright red with black wings, a small white patch, and a tail, as seen in Figure 1 (Fancy and Ralph 1998). The young fledglings are much smaller and have black, yellow, and tan feathers. The I'iwi is endemic to Hawaii (living mainly in Maui, Hawai'i, and Kaua'i with very tiny populations on O'ahu and Moloka'i) and have adapted a specialized bill that curves downward to reach ohi'a, lobelia, and mint flower nectar ('I'iwi 2020). The I'iwi has adapted to living in higher elevation forests along the mountains (4300-6200 m) because of the decreased prevalence of mosquitoes carrying malaria and other diseases ('I'iwi 2020). Sadly, the I'iwi's ability to avoid predation is currently threatened due to changing environmental conditions (Cummins et al. 2020).

The I'iwi is mainly targeted by non-native organisms such as black rats, cats, and mongooses. These predators hunt eggs and chicks due to their vulnerability, but larger birds such as the barn owl, short-eared owl, and Hawaiian hawk also prey on adults. The I'iwi's large bill, protective nature, and movement to areas containing fewer predators (such as higher elevations) allow it to escape these threats and thrive (Fancy and Ralph 1998).

Figure 1. The I'iwi in its natural habitat in Hawaii. "I'iwi – Vestiaria coccinea," by USFWS, is in the Public Domain

Eating Habits

The I'iwi is a primarily **nectarivorous** species and prefers to feed from the flowers of the 'ōhi'a (*Metrosideros polymorpha*) tree. The

I'iwi is recognizable for its long flights through the forest canopy in search of 'ōhi'a trees but is also known to feed on any flowers of lobehoid plants (*Campanulaceae*), as well as spiders and insects on occasion. While foraging underneath the canopy of trees, the I'iwi sings, known for its loud call. To feed, the bird will pierce the tubular **corollas** on the flowers and feed for a few seconds before moving to another flower rapidly (Fancy and Ralph 1998).

Habitat

The I'iwi mainly inhabits five of the Hawaiian Islands (U.S. Fish and Wildlife Service c.2022). Their population is the largest on the islands of Hawaii, Maui, and Kaua'i (Fancy and Ralph 1998). The I'iwi inhabits the forest interior of the Hawaiian islands, primarily in high elevations and **closed canopy environments**. Additionally, Hawaii has been experiencing **fragmentation** in which its ecosystems have experienced extreme losses of biodiversity and pollution, and directly felt the effects of increasing global warming. I'iwi **activity patterns** have seen significant changes. Because plants (their main food source) are less adaptive to changes than insects, the I'iwi must change their established routines to find food and survive (Smetzer et al. 2022).

Breeding

The I'iwi breeding season falls between February and June, coinciding with the ohi'a plant's peak flowering season (Fancy and Ralph 1998). The species spends its breeding season nesting in the same wet and **mesic** forests that they inhabit throughout the year, and oftentimes female birds become quite protective and aggressive of their specific nesting area (U.S. Fish and Wildlife Service c.2022).

During the mating season, the I'iwi song plays an important role in communication as well as courtship. The male's call is "flute-like," "harsh," and "strained" while the female's call sounds like baby fledglings (Fancy and Ralph 1998). The call sounds like "eeeee-eeeee," just like the first part of the name. There is a high number of unique syllables which males use to court females which highlights the variation among the population. The species is **sexually monomorphic**, therefore the male's song plays an important role in determining whether or not it will find a mate and reproduce. The birds usually have partially **monogamous** relationships, and these partnerships produce, on average, about two eggs per **brooding season** (U.S. Fish and Wildlife Service c.2022).

Population Size and Status

Most species of the endemic Hawaiian honeycreepers (*Passeriformes drepanididae*) today have either gone extinct, have reduced population numbers, or have been restricted to small portions of the forest (Liao et al. 2017). The estimated total population size for the species is between 550,972–659,864 individuals (as of 2013), with specific island populations detailed in Figures 2 and 3 (Paxton et al. 2013). In 2020, a national assessment of I'iwi's population concluded that the species was highly threatened and the IUCN Red List of Threatened Species classifies the bird as **vulnerable**, a step down from **endangered**, yet they still face devastating population losses (Birdlife International 2020). Due to their critical dependency on the forest ecosystem, populations are predicted to decrease by 30-50% over the next 10 years (Birdlife International 2020) and 92% over the next 25-year period based on surveys from 200-2012 (Paxton et al. 2013).

Island/region	Area (ha)	Mean abundance	Lower 95% CI	Upper 95% CI
Kaua'i	5,436	2,551	1,934	3,167
O'ahu		[2]50		
Maui, east	13,201	59,859	54,569	65,148
Maui, west	1,887	[1]176		
Moloka'i	1,800	[1]80		
Hawai'i (all regions)	174,840	543,009	516,312	569,706
Hawai'i, north windward	24,926	277,055	258,075	296,035
Hawai'i, central windward	40,773	71,524	62,662	80,386
Hawai'i, Ka'ū	33,680	28,325	23,138	33,512
Hawai'i, south Kona	12,489	3,489	2,059	4,918
Hawai'i, central Kona	25,441	139,829	124,649	155,009
Hawai'i, north Kona	21,231	22,787	18,444	27,130
Kohala Mountains	5,600	[1]802		
Mauna Kea	4,200	[1]482		
[3]Species total		605,418	550,972	659,864

[1] Estimates from Scott and others (1986) surveys

[2] Estimate from BirdLife International (2012)

[3] Total estimates do not include Scott and others 1986 estimates and O'ahu estimate

Figure 2. I'iwi population estimate numbers referenced in the text are circled in red. Modified from"Table 1," by Sally Jewell and Suzette Kimball is in the Public Domain

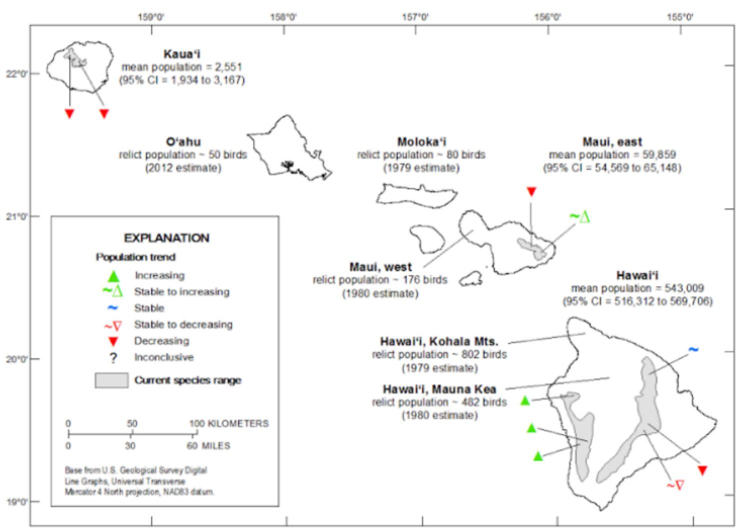

Figure 3. I'iwi population trends in 8 locations. "Figure 3. Distribution, mean population size (95-percent confidence interval), and population trends by region for 'I'iwi (Vestiaria coccinea) across its range in Hawai'i," by Sally Jewell and Suzette Kimball is in the Public Domain

Trends, Distribution, and Abundance

To avoid **vector** mosquitoes, 90% of I'iwis live at an elevation of at least 1300 m. The I'iwi population at both low and high elevations is decreasing. For example, in Kaua'i, the I'iwi population is in severe decline because the population lives at low elevations and the habitat size and range have significantly decreased due to human actions. One region of Kaua'i had a 97% decline in population over a period of 25 years. In Mau, however, the population inhabiting the island's northeast size is declining while the population inhabiting the southeast side is increasing. In O'ahu and Molokai, the I'iwi populations still inhabit lower elevations, making them more susceptible to malaria and, therefore, population decline. O'ahu consists of less than 50 birds while Moloka'i has less than 140 birds (Figure 2). The mainland of Hawai'i has the highest population size (540,000)–specifically on Mauna Kea and Kona because the mamane tree blooms are most abundant there (see Figures 2 and 3). During the breeding season, there is a lower density of I'iwis because they migrate to lower elevations closer to their food source. Overall, the low elevation populations are declining rapidly and the higher elevation populations are declining slowly (Jewell and Kimball 2013).

Ecological Impact

The I'iwi holds a key role in its ecological system, acting as a food source for other animals, as well as a consumer itself (see Figure 4). Non-native mammals are its key predator, therefore, as I'iwi populations decrease, these organisms must find other food sources, disrupting the established **food chain** and throwing off other ecological balances (The 'I'iwi…2017). On the other hand, because their food source is nectar, they help pollinate native Hawaiian flowers. The birds' tendency to efficiently spread nectar and pollen from plant to plant is very helpful for the plant species because they don't have to rely solely on seed dispersal for effective reproduction. Although it is not a **keystone species**, the bird is a key consumer of the ʻŌhiʻa trees, with the nectar and plant providing necessary food and shelter (The ʻI'iwi…2017). A decrease in Iʻiwi populations has led to an increase in the **autotrophic** organisms it consumes, demonstrating its importance in maintaining a balanced predator-prey relationship.

Figure 4. Traditional I'iwi food chain connecting non-native mammal predators and native autotrophic organisms such as 'Ohi'a lehua. "Pueo Asio flammeus. Location: Maui, Kanaha Beach", "Metrosideros polymorpah (Ohia, lehua, ohia lehua)" *and* "Sophora chrysophylla (Mamane): *by Forest and Kim Starr is licensed under* CC BY 3.0. "'I'iwi – Vestiaria coccinea" *by USFWS is in the* Public Domain.

Cultural Impact

The I'iwi has had a strong cultural influence throughout history (Cultural Significance 2018). Because of the birds' vibrant colors, Hawaiians have a long tradition of detailed featherwork to make ʻ*Ahu* ʻ*ula* (feather capes), *lei po*ʻ*o* (head lei), and *kāhili* (nobility rank) (Larson 2019), with an example in Figure 5. These articles could depict a person's high rank in society. To make them, they would use a net of olona fibers from plants as a framework. To capture birds for feather collection, bird catchers, also called *kia manu*, used sticky materials from local trees and smeared them on branches so that when the birds landed, they would stick. The *kia manu* would then collect a couple of feathers from the I'iwi, release them back into the wild, and sew the feathers onto the framework. Initially, only men would wear these, but eventually, women were included after the daughter of the first Hawaiian ruler wore a feathered cape (Cultural Significance 2018).

Figure 5. "ʻAhu ʻula (feather cape), Hawaiian, late 18th-early 19th century, O'o (Moho spp.), ʻi'iwi feathers (Vestiaria coccinea), olona bark, Honolulu Museum of Art" by Hiart is in the Public Domain

In traditional Polynesian culture, religion and nature intersect commonly in religious legends to explain natural phenomena. A typical legend told by Polynesian elders ("kupuna") is that, in the "olden" days, many birds would fly around villages unseen, even though their calls could be heard. Only Maui, a demigod, could see the birds, including the beautiful I'iwi with its vibrant plumage. One day, another god came to the island and the two spoke of the uniqueness and incredible colors of their islands. To prove his point, Maui, proud of his island, called to all the birds who filled the sky and baffled the visiting god. In his joy, Maui lifted the veil and the birds became visible to everyone, led by the fiery I'iwi (Cultural Significance 2018).

Economic Impact

Hawaii has a unique abundance of biodiversity and native species, encouraging ecotourism to see various species that can not be seen anywhere else in the wild, including the I'iwi. Hiking trails and state parks in Hawaii advertise the native wildlife, including endemic birds such as the I'iwi to increase interest for visitors and ecotourism (The Hawai'i Forest 2022). To display this avian beauty, Hawaii has made birding trails that total 180 miles across the island that allow tourists to spot and observe various species of birds like the endemic Hawaiian honeycreepers. The Hawaiian government's website includes a comprehensive list of birds that can be found along the trails which are on the islands of Hawai'i and Maui, including the I'iwi (The Hawai'i Forest 2022). The organization, The Hawaii Forest & Trail, aims to support local communities and conserve Hawaii's natural habitat. Donations to this organization (booking tours, etc.) help conserve ecosystems and illuminate Hawaiian culture (The Hawai'i Forest 2022). This is a form of ecotourism that involves finding the I'iwi along the driving trails (The Hawai'i Forest 2022). Donating to conservation organizations such as this one helps to fight population decline among native Hawaiian bird species so that future generations have the ability to witness such beautiful species.

Threats

The primary threats to I'iwi include disease, climate change, non-native **ungulates**, plants, and predators, as well as habitat loss and degradation (Marshall et al. 2012). The main disease threat is **avian malaria**. This parasitic disease is transmitted through mosquito vectors and has the ability to kill 90% of I'iwi fledglings after only one bite (Marshall et al. 2012). The disease's transmission rate varies depending on the environment and the time of year, but remains relatively high year-round in the warm, lowland forests and relatively low in cooler, high-elevation environments (Liao et al. 2017). This environmental restriction poses a difficulty for the I'iwi, who are forced to travel far distances to find a source of food (Marshall et al. 2012). Like many species, climate change is also a major threat. Global warming is causing higher altitude climates to become inhabitable by mosquito vectors, which poses a higher risk for avian malaria transmission (Paxton et al. 2013). The introduced prevalence of ungulates and **invasive** plants also pose a risk to the I'iwi because they contribute to habitat destruction and the overuse of natural resources, like the lobelia plant, which the I'iwi needs to survive (Marshall et al. 2012). Finally, industrialization also contributes to habitat loss. Humans inhabiting the islands and building over natural habitats pose a significant threat to the I'iwi and many other native Hawaiian species.

Conservation

There are few conservation plans specifically for the I’iwi species; however, other efforts to conserve the avian populations of Hawaii have benefitted the I’iwi. These include efforts such as habitat and forest conservation, removing ungulates from critical habitats, increasing nectar availability in a wider range of habitats, and controlling invasive plants. Some of the few conservation efforts that have been taken include a petition sent to the U.S. Fish and Wildlife Service in August 2010 to list the species as endangered, which was backed up with population data and passed in January of 2012 (Marshall et al. 2012). In 2017, however, the U.S. Fish and Wildlife Service (USFWS) only announced the ‘I’iwi as threatened under the Endangered Species Act. More recently in 2021, the Center for Biological Diversity filed a lawsuit against the federal government in an attempt to help conserve the I’iwi population as well as its primary food source, the ‘ōhi’a tree (Honroe 2021). The forests that the I’iwi inhabits are protected by organizations such as USFWS (in Kona forest), National Park Service (regions of Hawaii Volcano National Park), The Nature Conservancy (Kona preserve), and Natural Area Resource System (nature preserves in Hawaii). These protections allow the mamane flower, a key resource for I’ iwis, to thrive at many elevations, thus increasing the I’iwi population. Now, scientists are planning to study the I’iwi to see if they have developed any resistance to malaria and find if there are genes that make them more resistant to disease, in order to make new populations (Marshall et al. 2012). Other possible solutions and conservation efforts are sterilizing the mosquito population to limit the spread of disease; however, this solution is seen as a long-term plan (Honore 2021). See Figure 6 for a full list of conservation action plans (Marshall et al. 2012).

Summary of 5-year Actions, 2013-2017:

Conservation Action	Years	Annual Cost	Total Cost
Complete regulatory compliance for additional fencing in the Alaka'i Wilderness Preserve, Kaua'i	1	$80,000	$80,000
Fence and remove ungulates from 3,000 acres in the Alaka'i Wilderness Preserve, Kaua'i	2-5	$900,000	$3,600,000
Invasive plant control in the Koke'e-'Alaka'i area, Kaua'i	1-5	$250,000	$1,500,000
Complete fences, remove ungulates, and restore habitat in Kahikinui FR+Nakula NAR	1-5	$350,000	$1,750,000
Fence repair/replacement, inspection, and maintenance at Hakalau Forest NWR	1-5	$200,000	$1,000,000
Remove feral pigs from fenced units of Hakalau Forest NWR	1-5	$500,000	$2,500,000
Control invasive plants at Hakalau Forest NWR	1-5	$200,000	$1,000,000
Build fence (~35 km) in Ka'u FR	1-3	$1,100,000	$3,300,000
Remove feral ungulates from Ka'u FR and begin habitat management (~4,850 ha)	2-5	$450,000	$1,800,000
Remove feral ungulates from Kona Forest NWR	1-3	$150,000	$450,000
Control invasive plants at Kona Forest NWR	1-5	$85,000	$425,000
Remove ungulates from Pu'u Wa'a Wa'a FBS	1-3	$75,000	$225,000
Control invasive plants at Pu'u Wa'a Wa'a FBS	1-5	$85,000	$425,000
Continue habitat restoration at TNC Kona Hema Preserve	1-5	$150,000	$750,000
Restore forest in the Kanakaleonui corridor on Mauna Kea	1-5	$300,000	$1,500,000
Mosquito surveys and disease monitoring on Kaua'i	1-2	$200,000	$400,000
Mosquito surveys and disease monitoring on Hawai'i	1-2	$300,000	$600,000
Range-wide surveys for 'I'iwi on each island, 1 island per year	1-5	$50,000	$250,000

Figure 6. Five-year action plan to increase I'iwi population size 2013-2017. "Summary of 5-year Actions, 2013-2017," by Robert Marshall et al. 2012, with permission from the Hawaiian Bird Conservation Action Plan

Conclusion

Although this bird is rare in abundance, its bright colors and distinctive call make it almost impossible to miss if you are to come across one of the few remaining in the rich Hawaiian vegetation. Like so many other species native to this land, increases in human activity and climate change have threatened its populations, bringing what was once a thriving population to dangerously low numbers. The I'iwi's rich history spans back to ancient Polynesian times, as the bird's uniqueness has been forever a symbol of Hawaii's beauty and biodiversity. Fluctuations in population have mirrored changes in its natural habitat, demonstrating the direct effects of Hawaii's popularization and push to become the ultimate "travel destination". As a key species, this bird maintains the balance in its tropical ecosystems by acting as a consumer of many common plants and vegetation, yet the introduction of many non-native mammals has threatened this delicate food chain. It is clear that this species requires immediate conservation efforts, with environmental protection agencies jumping to ensure that strict laws and protected areas are plentiful. With these protection measures comes the hope of the restoration of a thriving population, bright in color as well as future.

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20. Kemp's Ridley Riddle: A Look at Conserving the Kemp's Ridley Sea Turtle

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Abstract

Kemp's Ridley Sea Turtle hatchling. *"Crawling toward the sea, close-up" by TurtleDude is licensed under CC BY-NC 2.0*

Forgotten and on the edge of extinction, Kemp's Ridley sea turtles (*Lepidochelys kempii*) have been fighting for their lives since the mid-1900s. Native to the Gulf of Mexico, this species only has a single subpopulation, which has seen enormous fluctuations since 1947–including dropping to less than 1% of their past population size. Significant conservation efforts have been made to protect this vulnerable creature, but progress has halted, leaving the Kemp's Ridley sea turtle critically endangered. The species is fighting for its survival against several predators (including feral hogs, sharks, and shorebirds), fishing equipment, and human interference. Climate change and pollution have also significantly harmed the population and continue to prevent species recovery. Will conservation be enough to save this dwindling species as climate change worsens?

Natural History

As the smallest sea turtles in the world, Kemp's Ridley sea turtles have a unique appearance. They are known for their greenish-gray circular carapace, pale yellow **plastron**, and triangular-shaped head, as seen in Figure 1 (Reyes-López et al. 2021). They have four flippers in total; the front flippers each have one claw, while the back flippers have one to two claws each (NWF 2020). The color of the **carapace** depends on the age of the turtle. Hatchlings are dark on both sides, while juveniles have a dark gray carapace and a whitish plastron (NWF 2020). By adulthood, Kemp's Ridley sea turtles develop a carapace as wide as it is long with five pairs of **costal scutes**. Adults weigh about 100lbs, with a carapace measuring 24 to 28 inches (NWF 2020). These turtles are also **sexually dimorphic**, with the males exhibiting longer tails and back flippers (LeBlanc et al. 2012).

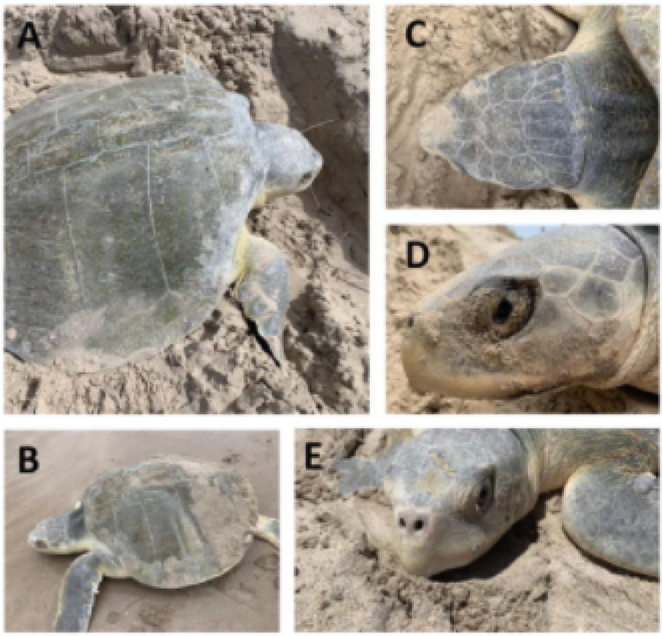

Figure 1. Kemp's Ridley Morphology, A. General view of shell B. General view of whole body C. Aerial view of triangular-shaped head D. Lateral view of head E. Frontal view. "[Pictures showing general morphology of Kemp's ridley](#)." by Fátima Y. Camacho-Sánchez is licensed under [CC BY 3.0](#)

These sea turtles typically spend most of their adult lives in a **neritic habitat** where sunlight reaches the seafloor. The adult population's geographic range is between the Gulf of Mexico and the northeastern United States, as illustrated in Figure 2. Juveniles have a very different habitat. After birth, the young swim towards the open ocean where they passively drift, sheltered by Sargassum seaweed (USFWS 2011).

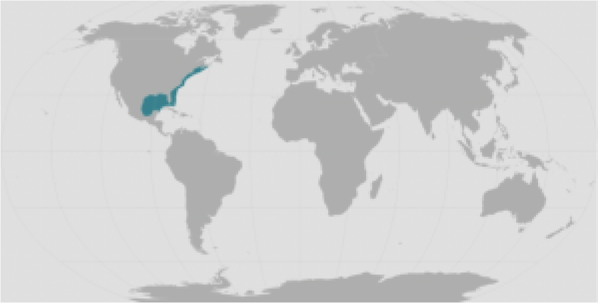

Figure 2. Kemp's Ridley sea turtle is a resident range of the Gulf of Mexico and migrates to the North-East of the United States. "World map providing approximate representation of the Kemp's ridley turtle's range." by NOAA *is in the* Public Domain

The turtles have a diverse diet consisting of crabs, shrimp, shellfish, and sometimes jellyfish (TPW 2005). What they eat depends on the availability of resources and the region they spend time in throughout the year. Within the **neritic zones**, the turtles prefer to stay low to sandy or muddy bottoms where they forage for food (USFWS 2011). It is important to note that the consumption of waste and debris that has been mistaken for food is one of the most significant threats to this species.

Life History and Reproduction

Kemp's Ridley sea turtles begin their life as eggs typically in sandy dunes, where they incubate for 50 days before hatching (Putman et al. 2013). Recent hatchlings are most vulnerable to predators, such as sharks and shorebirds (Burke et al. 1994), when they swim out to sea and stay in the open ocean for 1-2 years, before returning to the Gulf of Mexico to reach maturity around 12 years of age (USFWS 2011). During this **maturation period**, several populations migrate north and can be found in the northern Atlantic Ocean (Burke et al. 1994).

They usually lay eggs in the Gulf of Mexico in sandy dunes near lagoons (TPW 2005; USFWS 2011). The entire process of digging and laying the eggs takes about 45 minutes before the female can return to the ocean (TPW 2005). The males stay in the water during this process and do not participate in egg-laying. (TPW 2005).

Like elephants and alligators, sea turtles' life spans are about 30 to 50 years, but there is little information about this exact number (TPW 2005). Towards the end of their lives, they tend to stay near the coast of the Gulf of Mexico, where food is readily available (Putman et al. 2013).

Kemp's Ridley Population and Conservation Research Summary

Unfortunately, the current Kemp's Ridley sea turtle population is just a fragment of what it used to be. The species used to have a robust population, but between 1947 and 1985, the population dropped an estimated 99.4%, with annual nesting numbers decreasing from 121,000 to 702 (Wibbels and Bevan 2019). This decline was a result of many threats, most notably human involvement. In years before this precipitous decline, the Kemp's Ridley sea turtle was protected, but as these protections were lifted, poaching eggs and female turtles played an enormous role in their decline. Human interference caused approximately 90% of nests to be destroyed the day they were made during this period (NPS 2020).

Additional human activities continue to affect Kemp's Ridley turtle populations. Turtle **bycatch** in fishing nets has resulted in many turtles drowning, and over-shrimping has caused food scarcity for the Kemp's Ridley sea turtle, preventing reproduction due to a lack of resources (Caillouet et al. 2018).

Climate change has also had a large impact on sea turtle populations due to them being **ectotherms**. Water and sand temperatures are critical to Kemp's Ridley sea turtles – a warmer climate increases the eggs' **incubation** temperature, resulting in a female bias in hatchlings (Martins et al. 2020). As a result, rising temperatures drastically affect sea turtle sex ratios. Furthermore, these changes have reduced juvenile survival rate to **sexual maturity** and negatively impacted hatchling **fitness** and survival (Martins et al. 2020). Changes to **migration patterns** and distribution have also altered survival, leading to a steady decrease in the population (Griffin et al. 2019).

Even with the odds against them, this decline did not lead to extinction. In the years following 1985, the Kemp's Ridley population began to rapidly recover, reaching 21,000 nests a year in 2010 (Wibbels and Bevan 2019). This sudden increase was due to strong efforts by a **binational coalition** between the United States and Mexico, called the Kemp's Ridley Sea Turtle Restoration and Enhancement Program (KREEP) (NPS 2020). The program started by performing beach surveys and posting guards to protect turtle nests, and now monitors the entire sea turtle's range (Wibbels and Bevan 2019; NPS 2020). This initiative is vital since nest destruction was a large factor in the species' decline.

Another important aspect of conservation was the creation of sea turtle breeding sites. In 1985, breeding was done almost exclusively in Rancho Nuevo, Mexico, and it was only through relocation programs that this spread to other places such as the Padre Beach reserve (NPS 2020). An essential part of this was moving eggs to beaches with colder climates to preserve the standard **sex ratio** amid climate change (Martins et al. 2020). Alongside this, the United States has put laws into place to reduce the **bycatch** of turtles, including banning certain shrimp exports and monitoring popular fishing brands (NOAA 2022). Laws requiring modified nets safe for turtles, such as the one seen in Figure 3, have also been implemented (NOAA 2022).

The population increases are certainly promising, but there are still challenges to solve regarding their conservation. One of these is the threat of oil spills. Since Kemp's Ridley turtles occupy such a small region, environmental disasters impact them significantly. This was seen in the Deepwater Horizon oil spill in 2010, which caused the female **carrying abundance** of the sea turtles to drop significantly (Caillouet et al. 2018). This event is attributed to many reproduction setbacks that have caused the upward trend in population to halt.

Other challenges exist as well. For example, even in captivity, there is only a 63.2% hatchling emergence success rate (Shaver 2020; NPS 2020). These factors, combined, have caused the turtle's current population to fluctuate and generally decline – only 12,000 nests were recorded in 2014 (Wibbels and Bevan 2019). In the end, despite all these efforts, the turtle remains on the IUCN critically endangered list, and their current population trend is unknown, demanding further conservation efforts to protect this fragile species (Wibbels and Bevan 2019).

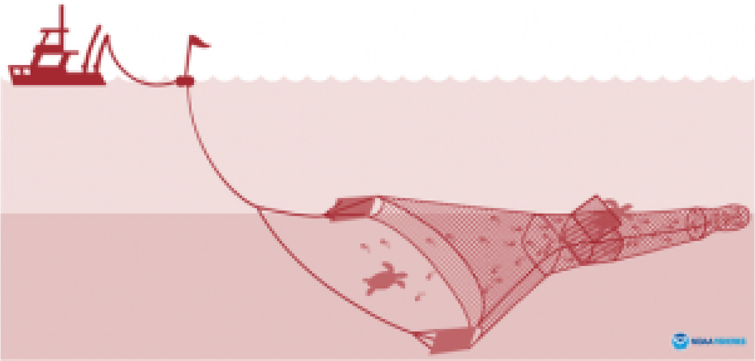

Figure 3. "Turtle excluder devices" allow sea turtles to escape fishermen's nets and prevent bycatch. "[Illustration of a turtle excluder device](#)." by NOAA is in the [Public Domain](#)

Kemp’s Ridley Ecological, Societal and Economic Factors

Ecological

The decline of the Kemp’s Ridley sea turtle has harmed the aquatic ecosystems they lived in, creating an unstable environment incapable of supporting groups of sea turtles (Bjorndal and Bolten 2003). This decrease has made ecosystem recovery necessary when considering conservation (Bjorndal and Bolten 2003). These measures are linked to some of the **ecosystem services** the turtles offer in their **neritic habitats**. First, they help reduce the competition with fish for food by preying on jellyfish. Since fish populations are more abundant when jellyfish populations are under control, a decline in fish populations would affect humans and marine wildlife. Furthermore, their crustacean diet increases **nutrient recycling** and improves sand **aeration** by hunting close to the ocean floor (Lomas et al. 2021).

The feral hog (see Figure 4) is another enemy the sea turtles face. This **invasive species** has significantly impacted sea turtle nesting and egg **incubation**. Specifically, in North Island, South Carolina in 2005, feral hogs began threatening Kemp’s Ridley sea turtles (Engeman et al. 2019). In 2010, nest monitoring showed a total loss of young turtles worth over $1,000,000 from the feral hogs, causing a 6-year extermination process that has eradicated the island’s feral hog population (Engeman et al. 2019). In this way, Kemp’s Ridley turtle recovery is linked closely to the environment they live in and has shown how predators of protected species are affected by conservation (Engeman et al. 2019).

Figure 4. Invasive feral hogs are one of the biggest predators to hatchlings. "[Feral Pig and Piglets](#)" *by* [Craig ONeal](#) *is licensed under* [CC BY-NC-ND 2.0](#)

Societal

Besides the many ecological issues listed above, societal and governance challenges impact Kemp's Ridley sea turtles. In 2020, conservationists created an index to predict the conservation of sea turtles, which labeled the Gulf of Mexico as least concerned according to the **Human Development Index (HDI)** (Barrios-Garrido et al. 2020). The Gulf was the only region in the study that the Kemp's Ridley turtle occupies, which is good for conservation initiatives. However, despite a good HDI value, there are still challenges to conservation in the Gulf of Mexico, such as the 2010 Deepwater Horizon oil spill (Barrios-Garrido et al. 2020).

Economic

There have also been conflicts with fisheries because the conservation of sea turtles affects the economic success of fisheries. Throughout the 2000s, sea turtle **bycatch** has been on the rise, resulting in many regulations being put in place to protect them (Putnam et al. 2020). However, these regulations have decreased fishery harvests by approximately 50% in the eastern United States (Putnam et al. 2020). In this regard, conservation poses a significant economic challenge to fisheries. Furthermore, since sea turtle populations are growing, fisheries are tasked with finding more sustainable solutions to avoid **bycatch** (Putnam et al. 2020). On the more positive side, sea turtle tourism plays an economic role in some parks, providing a financial motivator for conservation.

Conclusion

While human activities and their production of waste are unlikely to come to a halt, there are many strategies available for conserving these sea turtles. With fisheries implementing excluder devices in their nets, and conservationists keeping a watchful eye over nests, Kemp's Ridley sea turtle populations are likely to increase in coming years. Most importantly, the survival of this species is anchored in environmental awareness. Humans must become aware of the impact of their activities, and recognize the importance of sea turtles species to ecosystems. These tiny turtles are persistent creatures and there remains much hope for the future of the species. The combined efforts of these groups will surely aid in saving the turtles!

Acknowledgments

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21. Galapagos Green Turtle

JACOB FLEISCHER; KELLY MAKECHNIE; MALVINA PIZIAK; HOPE HUTCHINSON; AND OLIVIA GUIMARAES

Abstract

Galapagos green sea turtles (*Chelonia mydas*) have been on the endangered species list since 1978. Human activities and climate change have disrupted their ability to lay and hatch eggs, find adequate feeding grounds, survive poaching, and follow migratory routes. Their population has only continued to decline over time. Conservation efforts by organizations such as the Galapagos National Park, which enforces restrictions for fishing and extractive activities in the Galapagos, and The Charles Darwin Fund, researching to design a system to avoid boat strikes, need to continue and be expanded to eventually remove the Galapagos green sea turtle from the endangered species list.

Figure 1. *The Galapagos green sea turtle swimming in the water.*
"Galápagos green turtle" by doevos is licensed under CC BY-NC 2.0.

Introduction

Picture this: you go on vacation to the gorgeous Galapagos Islands, which are filled with the most beautiful clear water and several animals you have never seen before! These animals are all over the island, walking, swimming, and having fun. You go snorkeling to see the animals you can't quite see from the surface of the glistening water. As you are swimming, a bright green turtle swims by you. The jetstream behind this turtle sets you back a couple of feet in the water as it swims by! You look in the direction it swam, surprised by the size and speed of the turtle. This turtle was half your height, several times larger than you, and zoomed by so quickly that you almost missed them. That turtle you saw was a Galapagos green sea turtle.

Location and Physical Characteristics

Seeing these turtles in the Galapagos is a pretty common experience but they can also be found in a few other locations. The Galapagos green sea turtle is a migratory turtle found in both tropical and **subtropical regions**. They are the only green sea turtle species found in the Galapagos and have the largest nest in the **Eastern Pacific** (Galapagos…c2021). The reason for the high nesting amounts of these turtles in the Galapagos is that these Islands contain important feeding grounds for green turtles, particularly around the archipelago's western islands of Isabela and Fernandina (Green and Ortiz-Crespo 1982). These locations are **high productivity areas** due to local **upwelling** (Carrión-Cortez et al. 2010).

These turtles have a very distinct physique: Galapagos green sea turtles have larger fins and lighter **carapaces** than other turtle species, allowing them to swim at speeds up to 35 mph (Galapagos…c2021). Due to the design of their shells, they cannot tuck their heads in for protection (Galapagos…c2021). In terms of size and weight, the Galapagos green sea turtle can grow to be 1.5 meters long with an average weight of 440lbs or 200kg (Galapagos…c2021). These turtles also have a unique way of regulating bodily salt concentrations; they are capable of shedding salt tears from **salt glands** located behind their eyes (Galapagos…c2021). Their diet also impacts their appearance; Galapagos green sea turtles are herbivores whose diets consist mostly of **seagrass** and **algae**, which provide the characteristic green hue of their fat.

Diet

The **diet** of the green sea turtle can differ by location and availability of food sources. The primary food sources for green sea turtles, as mentioned above, are **algae** and **seagrass**. Specifically, *Ulva lactuca*, *Polysiphonia* sp., *Hypnea* sp., *Dictyota* sp., and the red mangrove (*Rhizophora mangle*) make up the majority of their diet. A smaller portion of their diet consists of cnidarian (jellyfish) matter and other invertebrates. Younger sea turtles consume an omnivorous diet consisting of animal matter and seagrass, which then shifts almost exclusively into algae as the turtle matures into a herbivorous diet (Howell et al. 2021). **Forage preferences** can, to some extent, alter the diet composition of a green sea turtle (Carrión-Cortez et al. 2010). An example of forage preferences can be seen between green sea turtles found off the Pacific coast of California and in the Great Barrier Reef of Australia. In California, the diet consists of an equal mixture of algae and seagrass, but in the Great Barrier Reef, seagrass is the predominant food source (Carrión-Cortez et al. 2010).

The longevity of this species allows for the reshaping of reefs and landscapes over a long period through their herbivorous diet. These turtles predominantly stay near coasts and in shallow waters, and are considered an **indicator species** in these locations with regards to environmental health (Mashkour et al. 2020). While adult turtles spend their time on the coast, juveniles spend many years "lost" in the current. Hatchlings move from the beach to specific regions in the water where they will be taken by the currents, either accidentally or by choice. These currents sweep them to shallow waters, where they abide until they grow in size and strength. These areas for younger turtles are rich in algae and seagrass, which are staples in their diet. This demonstrates the different ways this species can influence the environment (Mansfield et al. 2021).

Reproduction and Hatchlings

Female Galapagos Green turtles reach sexual maturity between 25-35 years, after which they make reproductive migrations every

2-5 years, which each span anywhere from 2 weeks to several months (Herrera et al. 2021; Fig 2.; Green…c2022). During these migrations, they return to the same general area from which they hatched. The **breeding season** of Galapagos turtles runs from late spring to early summer.

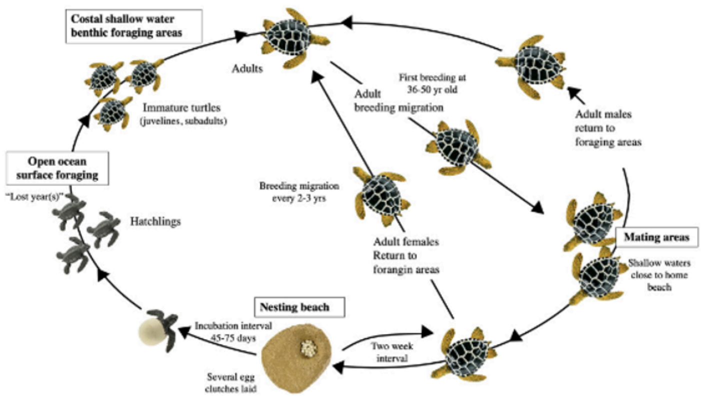

Figure 2. *Life cycle of the Galapagos green sea turtle. "[Fig. 1. Schematic diagram of the Chelonia mydas life cycle]" in [Herrera et al. 2021] is licensed under [CC BY 4.0].*

Females dig nests above the **high tide point** and lay their eggs at night (Galapagos…c2021). The females finding nesting spots on the beach can be seen in Figure 3 below.

Figure 3. *Female Galapagos green sea turtles going onto the beach to nest eggs. "Basking Green Sea Turtles (Chelonia mydas)" by Douglas Mills is licensed under CC BY-NC-ND 2.0.*

Clutches can range from 50-200 eggs. Once eggs have been laid, the female uses her rear fins to cover the nest in the sand before returning to the water. Eggs are threatened by tides, crabs, beetles, boars, and other predators (Zárate et al. 2013). During the mid-trimester **incubation period**, the sex of the embryo is influenced by the temperature of the egg. A higher temperature results in a higher likelihood of a female hatching (Galapagos…c2021). At 29.4℃, there is an equal chance that either gender could be hatched (Herrera et al. 2021). Eggs have a 34-46% success rate at hatching (Zárate et al. 2013). Upon hatching, the turtles attempt to make their way to the sea. Very few survive due to predation by birds, sharks, and **frigatebirds** (Galapagos…c2021).

Population Threats

Diet, **embryonic mortality rate**, and an unequal ratio of males to females are three major pressures in early life for these sea turtles.

Adult sea turtles compete with other herbivores and omnivores, such as marine iguanas, for **algae** and **seagrass**. Sea turtle eggs and hatchlings serve as prey for various insects, mammals, birds, and lizards (Heithaus 2013). Heavy predation can have a profound impact on population size. Hatchlings and young juveniles are also at risk of predation by sharks, birds, squid, and teleosts, with an average of 46% being taken by predators within two hours of reaching the water. Most adult and large juvenile sea turtles do not experience natural predation but instead are put at risk by human threats (Heithaus 2013).

The ratio of males to females is influenced by the altering of **nesting location**s and rising temperatures in the sand at beaches, producing a higher female to male ratio (Wei et al. 2021; Laloë et al. 2020). In a study that looked at hatchling survival across several Galapagos nesting beaches, increased hatching success correlated directly to the cover of large bushes and trees (Zárate et al. 2013). Embryo mortality was attributed to predation, submersion, erosion of nesting sites by the tide, and plant root invasion. The most prevalent predators found in the study were the beetle *Omorgus suberosus* (killed 31.6% of embryos), the feral pig *Sus scrofa* (killed 7.4% of embryos), and the ghost crab *Ocypode gaudichaudii* (killed 5.4% of embryos) (Zárate et al. 2013).

The population of green sea turtles has been decreasing, as evidenced by the decline in population increase from 11.4% to 7.4% from year-to-year (Summers et al. 2018). Part of the reason for this is **poaching** and other unnatural predators. Green sea turtles serve as consumers, competitors, and prey in food chains, as well as pathogen hosts (Heithaus 2013). The results of one article that looked at the survival rates of sea turtle eggs when different predators were nearby found a high sea turtle egg survival rate when mesopredators, such as brown rats, kukri snakes, and rat snakes, were present in the environment. Brown rats and kukri snakes are both primary prey of rat snakes, which are preferred over turtle eggs. This multiple-predator dynamic increased green sea turtle survival rates by favoring mesopredator predation (Cardona et al. 2022). Green sea turtles are also pathogenic hosts, and harmful human pressures have led to dormant or inactive diseases flaring up. This has led to turtles now having much more difficulty in fighting off typical illnesses such as fibropapillomas that cause the turtle to grow **papillomas** on their body. There is a real link between immunosuppression and vulnerability to this disease to the rate of increase of anthropogenic pollutants. This poses a huge threat to ecological balance, the severity of the illness, and increasing **pathogen survivorship** (Mashkour et al. 2020).

Another major threat to turtles is boat strikes (Summers et al. 2018). A 2018 study showed that mating females put themselves at a higher risk of being hit by a boat when they rest, swim, or mate on the surface of the water (Reducing…2022). Boat strikes are a huge threat as they can deform turtle's carapaces and fins by cutting or scratching them, which can be so deep that they cut fins off (Denkinger et al. 2013). Boat strikes largely affect the feeding grounds and **nest locations** of these turtles, as do tourism and human activities, by scaring off the turtles as they generally avoid close human contact (Wei et al. 2021). The Charles Darwin Fund is conducting research on the identification of marine animals from boats to create a detection system to avoid collisions (Reducing…2022). This organization also conducts community outreach to increase public awareness of the threats facing this species (Reducing…2022).

As mentioned above, tourism affects feeding and nesting locations. Research was conducted in an ongoing turtle census where data was collected on Tortuga Bay in the Galapagos, which has a high tourist visitation rate (Carrere 2021). During the COVID-19 pandemic, beaches closed, halting tourist and boat activity. With this reduction in human traffic, 300 turtles could be seen lying on one beach together. It was also observed that when they swam, they did so in a more spread-out fashion (Carrere 2021). With the return of tourists more recently, the Galapagos sea turtles have resumed grouping together near the far end of the beach and swimming close together, away from tourists, as was common prior to beach closure (Carrere 2021). To mitigate this negative effect of human presence on beaches, the Galapagos National Park made a plan to restrict fishing and extractive activities for 12.4% of the water surrounding the Galapagos Islands (Cirilla et al. 2021) and define the number of tourist groups that can be in the same area at the same time (Carrere 2021). The restrictions placed on fishing and other activities on main migration routes for this species increased the turtle population and, in turn, tourism, which is a major source of economic gain for these islands (Cirilla et al. 2021). These restrictions benefitted animal migration routes as fewer boats and people are allowed to swim and travel through them. This decreases the chance that turtles will get hit by a boat or scared off by a tourist when swimming on their routes.

Pollution and climate change have also been connected to multiple health crises for green sea turtles. Over the past few decades, there has been an increased occurrence of **papillomas**, found on Galapagos green sea turtles close to shore. Signs of systemic disease and active inflammatory responses were found in 44% of turtles that foraged near the shoreline. Furthermore, they saw elevated total white blood cell counts, liver dysfunction, and **acute inflammation** due to the pollution of essential and non-essential elements from agricultural, urban, and military areas (Villa et al. 2017). Rising sea levels due to climate change also reduce the number of safe, suitable locations for turtles to **sunbask**, or haul onto land. Anthropogenic pollutants favor certain species of seagrass and algae over others with new ratios of seagrass growing in the wild. Young turtles are now forced, in times of low food which is frequent, to consume types of seagrass that cause health issues such as a blocked and inflamed digestive tract (Wei et al. 2021).

Biomass refers to the amount of stored energy in a species.

Higher values correlate with a greater impact on the species ecosystem (Lovich et al. 2018). With an estimated 22% population decline of all turtle populations globally, their ecological impact has declined significantly as well. **Figure 4** below shows the dispersal of this energy transfer (Lovich et al. 2018).

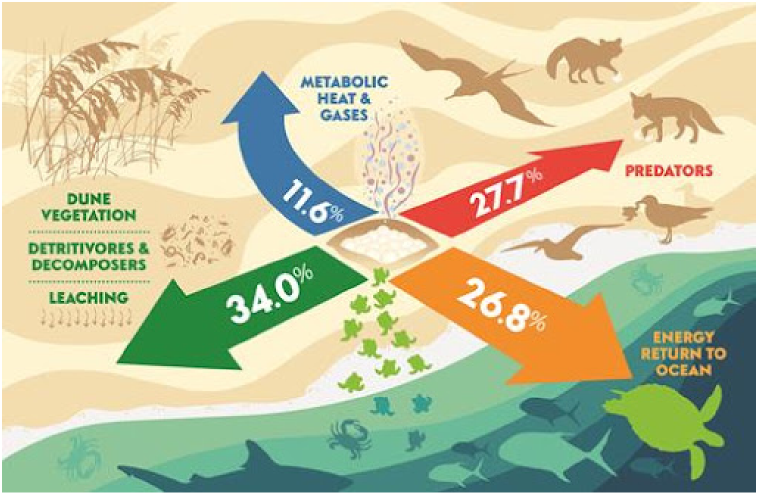

Figure 4. *Dispersal of energy transferred from the ocean to the land by loggerhead sea turtles on a beach in Florida ("Figure 2" in Lovich et al. 2018 is in the Public Domain).*

A 2021 study determined that green sea turtles were usually one of the most abundant species of roving herbivores in the sites studied, but they had lower biomass than fish or sea urchins. They determined that green sea turtles only made major contributions to the total herbivore biomass when the location was sheltered with low **rugosity**, low coral cover, and high algal cover (Liao et al. 2021).

Conclusion

The Galapagos green sea turtle (*Chelonia mydas*) is an amazing species residing in and around the Galapagos Islands. Their lives seem pretty simple at first: their mothers nest on the beach, then they hatch, move towards the light, and into the water. They then grow to be big and strong with a gorgeous, vibrant color; however, they face many hardships throughout their lives. From the threat of predation prior to and immediately following hatching to pollution and climate change, which affect their ability to swim, nest, and feed in certain areas. Luckily, there are organizations that aim to help these turtles not only survive but also thrive in their environment. These organizations have placed restrictions on both tourists and boats to decrease the harming and scaring off of turtles and to protect their nesting, feeding, and migratory routes so they can live in harmony with the growing amount of tourism and marine travel on the island.

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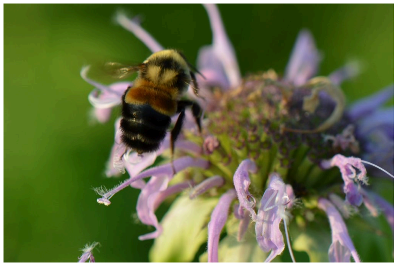
22. Rusty Patched Bumble Bee: The Untold Story of a Disappearing Bumble Bee

HAYLEY WIGREN; MARTIN FORTOU; AND TIONGE NAKAZWE

Abstract

The rusty patched bumble bee (*Bombus affinis*) is a species of bumble bee **endemic** to the northeastern United States and small portions of southeastern Canada. *B. affinis* is one of the earliest bumble bee species to emerge in the spring and one of the latest to go into hibernation. During their active period, they are key pollinators of wildflowers and crops. However, *B. affinis* now faces extinction from numerous threats including pesticides, pathogens, and decreased colony sizes. Although the situation seems dire, there is hope, with various conservation efforts launched to prevent further population loss and raise *B. affinis* populations worldwide.



Bombus affinis worker. "Rusty Patched Bumble Bee" *by* United States Fish and Wildlife Service (USFWS) *is licensed under* CC BY 2.0

Habitat and Diet

B. *affinis* is **endemic** to the northeastern United States and small portions of southeastern Canada. Its range extends from the eastern coast of the United States to the edge of the Great Plains region and extends north to the southern regions of Ontario and Quebec, Canada, as shown in Figure 1 (Thorp et al. [date unknown]; Williams et al. 2014; Hatfield et al. 2015). They mostly reside in woodland habitats and along the Appalachian Mountains, but more recently they have also been observed in urban parks and gardens (Boone et al. 2022). B. *affinis* colonies nest underground in abandoned rodent dens which typically reside 1-4 feet below ground, with nest entrances being approximately 3.5×4.5cm (Boone et al. 2022).

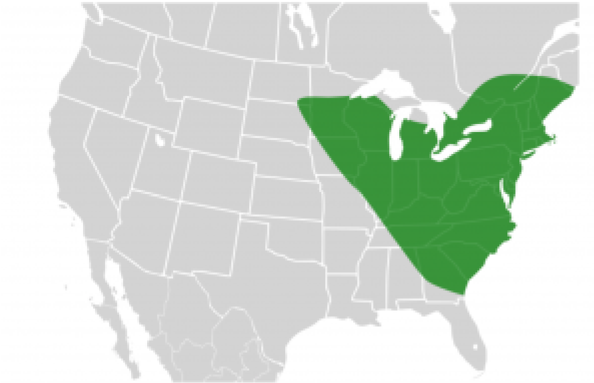


Figure 1. *Bombus affinis historic range. "Bombus Affinis Distribution" by Ninjatacoshell is licensed under CC BY-SA 3.0*

Bumble bee species — including *B. affinis* — forage close to their nests, only traveling within a 1km radius away (Hatfield et al. 2015). Due to this limited foraging range and their preference for woodland habitats, the diet of *B. affinis* consists primarily of the nectar and pollen of open flowering woodland plants (Hatfield et al. 2015). The diet of B *affinis* is surprisingly non-specific and includes a variety of plant species, such as *Aesculus*, *Agastache*, *Dalea*, *Eupatorium*, *Helianthus*, *Impatiens*, *Lonicera*, *Monarda*, *Prunus*, *Solidago*, and *Vaccinium* (Williams et al. 2014; USFWS 2016). This expansive diet makes *B. affinis* less dependent on individual plant species and also makes them a **keystone species** as widespread pollinators (Hatfield et al. 2015; Williams et al. 2014; USFWS 2016).

Physiology and Natural History

As their common name implies, the workers in this species have a rust-colored patch of hair on their second abdominal segment, as well as black hair on their heads and a black patch on the center of the thorax, as seen in Figure 2 (Thorp et al. [date unknown]).

Figure 2. Bombus affinis Worker. "Affinis Worker" by Elaine Evans, Xerces Society is licensed under CC BY-NC 4.0

Like most species of bees, *B. affinis* has distinct **eusocial** classes, consisting of a queen, workers, and reproductive males (Thorp et al. [date unknown]; Hatfield et al. 2015). *B. affinis* is a relatively large bee with the queens ranging in length from 19-23mm on average, and their workers 9-16mm (Williams et al. 2014). The queens are mostly yellow with a small bald patch at the center of the thorax but share the same black hair on their heads as the workers, as seen in Figure 3 (Thorp et al. [date unknown]).

Figure 3. *Bombus affinis Queen. "Affinis Queen" by Elaine Evans, Xerces Society is licensed under CC BY-NC 4.0*

B. affinis have **annual colonies**, meaning each year the life cycle starts anew with one queen. Queens are the only ones who **overwinter** (Hatfield et al. 2015). Mid-July through September marks the mating season, during which the reproductive males and new queens leave the colony to mate (Hatfield et al. 2015; USFWS 2017). The new queens enter hibernation while all remaining members of the colony die (USFWS 2017). Hibernation takes place in small oval-shaped chambers where the queens dig a few centimeters into the soil. In March or April, the queen emerges from hibernation (Hatfield et al. 2015). Notably, the emergence of *B. affinis* queens is earlier than most bumble bee species (Hatfield et al. 2015). Once the queen has emerged, she fertilizes her eggs with sperm that she has stored from the previous mating season through hibernation (USFWS 2017). She takes sole responsibility for foraging and nesting until the first workers hatch. Then, the workers take over the foraging while the queen focuses on growing the colony (USFWS 2017). The cycle continues again when the males and new queens mate and the new queens enter hibernation once again (Hatfield et al. 2015).

Status

B. *affinis* was once highly prevalent across its range, however recent years have seen heavy population declines that earned the species a spot in the Endangered Species Act. B. *affinis* has 926 historical populations, but since 1999 there have only been 103 documented populations across its entire habitat range (USFWS 2017). Healthy B. *affinis* populations consist of hundreds of colonies, each consisting of hundreds of individuals. However, recent population documentation almost always includes 5 or fewer individuals per colony, with the largest current population containing 30 individuals (USFWS 2017). According to the IUCN, B.*affinis* populations are trending downwards with extreme fluctuations in overall population and subpopulations (Hatfield et al. 2015). For instance, their populations have decreased by 33% in Illinois since 2000 while surveys in New York, Toronto, and Maryland have not found evidence of the species since 2003 (Hatfield et al. 2015). In 2017, B. *affinis* became the first bee listed under the Endangered Species Act in the United States due to these population declines and an 87% reduction in its distribution. It is currently listed as critically endangered on the IUCN Red List (Simanonok et al. 2020; USFWS 2017; Hatfield et al. 2015; Colla and Packer 2008).

Ecological and Cultural Role

B. *affinis*, like many bumble bee species, is a **keystone species**. Bumble bees are notable for using an incredibly effective method of pollination called **buzz pollination**. Buzz pollinators vibrate their muscles during feeding to loosen the pollen during foraging, which makes feeding easier for the bees and the spread of pollen more effective for the plants (Ruthenberg et al. 2020). Bumble bees are far more efficient than honey bees in most wild settings due to their ability to buzz pollinate, in addition to their larger sizes. Bumble bees are also less picky about which plants they pollinate while honeybees often avoid less attractive plants. The combination of these three factors explains why bumble bees are responsible for the pollination of 97% of wildflowers (Kingston 2019; Goulson et al. 2008). *B. affinis* is a particularly proficient bumble bee species since its diet is non-specific, allowing it to pollinate a variety of flowering plants (Hatfield et al. 2015). In addition, bumble bees pollinate many plants required in the diets of other species, especially crops for human agriculture (Ruthenberg et al. 2020).

Agriculture relies heavily on pollinator species such as *B. affinis*. In fact, 35% of global food production is made possible by pollinator species (Klein et al. 2006; Allen-Wardell et al. 1998). Generally, there is a positive correlation between pollinator diversity and crop yield (Klein et al. 2006; Allen-Wardell et al. 1998). As a result, the decreasing population trend of *B. affinis* is a concern for many pollinator-reliant crops. Nearly 60% of the world's crops are considered vulnerable to decreased animal pollination as a result of **agricultural intensification** (Klein et al. 2006; Allen-Wardell et al. 1998). For plants with a small number of pollinators—such as tomatoes—this vulnerability is especially prevalent (Klein et al. 2006; Allen-Wardell et al. 1998).

Bumble bees in particular have a major impact on crop production. Forty-two percent of the top 57 global animal-pollinated crops are pollinated by at least 1 species of native bee (Klein et al. 2006; Allen-Wardell et al. 1998). Additionally, bumble bees are one of few species that can pollinate tomatoes. They are also key pollinators of cranberries, blueberries, plums, apples, peppers, alfalfa, strawberries, sunflowers, currants, red clover, and cotton (Ruthenberg et al. 2020; Kingston 2019). As a result, population declines of bumble bee species are likely to affect the production of a variety of crops. Bumble bee population declines also affect non-crop plants, such as Dutchman's breeches (*Dicentra cucullaria*). Dutchman's breeches rely heavily on pollination by *B. affinis*, and animals (such as some ant species) rely on Dutchman's breeches seeds for food. A domino effect is expected where declines in *B. affinis* affect Dutchman's breeches, which in turn affects all species reliant on the plant (Lady Bird Johnson Wildflower Center 2013).

B. affinis provides an integral **ecosystem service** in agriculture given its role as a pollinator. Insect pollinators are responsible for up to $24 billion in the United States economy (White House Office of the Press Secretary 2014), and studies have discovered that 17% of the world's leading food crops show increased fruit or seed with animal pollination, having an economic benefit of €153 billion annually (Ollerton et al. 2011). Without *B. affinis*, many insect-reliant plant species would face severe declines. Because of this, agriculture would become heavily reliant on hand-pollination, which would cost the U.S. approximately $3 billion per year (USFWS 2017). Economically, losing any insect or animal pollinator species, especially a **keystone species** like *B. affinis*, would cost billions of dollars globally; not just for crops for human consumption, but also for specific crops that are directly used in animal feed (Kingston 2019; Goulson et al. 2008).

Threats

Unfortunately, despite the importance of *B. affinis* in ecosystems and agriculture, there are several ongoing threats impacting populations. Pesticides, especially **neonicotinoids**, have been shown to be highly toxic to bees (USFWS 2017; Colla and Packer 2008). The early morning foraging patterns of *B. affinis* align with pesticide spraying, leading to the consumption of pesticide-covered pollen. Additionally, exposure to chemicals trapped in the soil in underground *B.affinis* nests makes individuals more susceptible to pesticides, and reliance on a single queen for colony establishment each year means that if the queens die from pesticide exposure, the colony will not persist (Krischik 2020; USFWS 2017).

Pathogens are another major threat. **Pathogen spillover** is an understudied phenomenon in which viral and bacterial pathogens spread to wild bees from commercially-bred bees (Colla and Packer 2008; Xerces [date unknown]). The full implications of **pathogen spillover** on *B. affinis* are not known because studies have been performed only on the common species—*B. impatiens*. Although the studied threat is found to be sublethal, **pathogen spillover** still deals another blow to bumble bee species (Colla and Packer 2008).

Population declines also cause mating issues due to bumble bee sex differentiation. Bumble bees use **haplodiploid** sex differentiation in which **haploid** males arise from unfertilized eggs and **diploid** females arise from fertilized eggs. If a diploid female mates with a related haploid male, half of her offspring will be diploid males instead of diploid females. Diploid males do not contribute to foraging or reproduction as either they are sterile or their offspring are unviable (USFWS 2017). Decreased population sizes increase the chance of females mating with related males, which greatly decreases the number of viable bees in the next generation.

Conservation Efforts

In order to save this dwindling **keystone species**, strong conservation policies must be enacted. Recovery methods must include preventative measures against population declines as well as methods to increase population size, range, and genetic diversity (Smith et al. 2019). Finding suitable habitats with an abundance of environmental resources and enriching those habitats will allow for population growth and improved colony health. In addition, increased population sizes could help increase genetic diversity and avoid the issues of small population dynamics for **haplodiploid** species (Smith et al. 2019). Minimizing pesticide use in protected habitats could also protect B. *affinis* from further declines (Krischik 2020).

As a starting point for conservation efforts, populations can be split into conservation units that vary by size based on historical values and should be located in a variety of climates and habitats across the entirety of their range, as seen in Figure 4 and Table 1 (Smith et al. 2019). Conservation units allow the protection of subpopulations so that any further population decreases are not detrimental to the overall population. Healthy populations can be defined by 5 or more distinct colonies over a 10-year period, evidence of genetic health over a 10-year period, non-harmful levels of pesticides and pathogens, and high certainty in the population's resilience to environmental stressors (Smith et al. 2019). Training land managers, homeowners, and farmers about the conservation needs of B. *affinis* could greatly benefit populations over time (Krischik 2020). If all conservation criteria are properly followed and funded, delisting can be expected as early as 2059 and will cost an estimated $13.4 million (Smith et al. 2019).

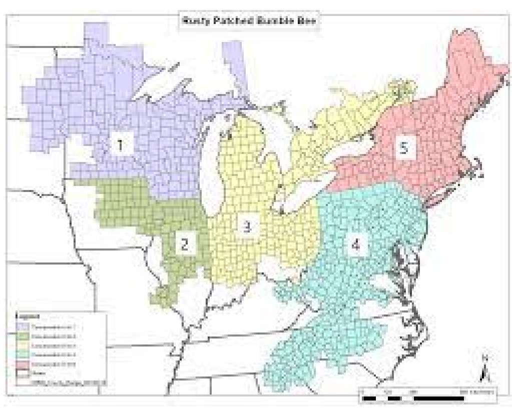


Figure 4. *Map of Conservation Units. [“Rusty patched bumble bee conservation units from west to east”] by [U.S. Fish and Wildlife Service] is in the [Public Domain]*

Conservation Unit	Number of historically occupied populations per CU	Minimum number of populations per CU (Criterion 1)	Minimum number of healthy populations per CU (Criterion 2)
CU1: Upper West	274	32	16
CU2: Lower West	125	14	7
CU3: Midwest	347	40	20
CU4: Southeast	250	29	14
CU5: Northeast	389	45	22
Total	**1,385**	**159**	**80**

Table 1. *Table showing the number of protected populations in each Conservation Unit. "Rusty patched bumble bee Conservation Units table." by U.S. Fish and Wildlife Service is in the Public Domain*

The importance of B. *affinis* in local ecosystems and in modern agriculture cannot be understated, and continuing population decreases of this critically endangered species could lead to detrimental ecological and economic effects. Reducing the risk of pesticide contamination and **pathogen spillover** could be great first steps in maintaining subpopulations in order to strengthen the overall population. Current conservation plans provide hope for the future of this disappearing bumble bee.

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