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Eradication of Invasive Species in the Galápagos Islands

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Abstract:

Invasive species are extremely damaging to island ecosystems. In the Galápagos, invasive goats, donkeys, and pigs have altered ecosystems and community structure, and led to the decline and extinction of multiple endemic and native species. Eradication programs on Isabela and Santiago have removed hundreds of thousands of goats, donkeys, and pigs; as a result, native flora and fauna have begun to recover. These programs prove that large scale invasive species eradication is possible, and their published methodology and results will allow other islands to implement similar eradication and restoration projects.

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Introduction to Island Biogeography Theory

The Galápagos Islands are located over 500 miles from mainland Ecuador; they are home to some of the most unique and interesting wildlife and ecosystems on the planet (Galápagos Conservancy, 2018). Despite their uniqueness, however, they are still governed by the same ecological principles as other islands. Perhaps the most important theory is that of island biogeography, which relates islands' isolation and size (area) to species occurrence, colonization, and extinction. It states that the number of species on an island is determined by the balance of its extinction and colonization rates. Specifically, islands farther from the mainland will have lower colonization rates and support less species, islands closer to the mainland will have higher colonization rates and support more species, larger islands will have lower extinction rates and support more species, smaller islands will have higher extinction rates and support less species, and extinction rates increase as species reach the island's carrying capacity (Ehrlich et al., 1988). The introduction of new species from the mainland is a key part of the theory. However, problems can arise for native species when humans artificially introduce invasive species.

Basics of Islands and Invasive Species

Islands, including the Galápagos, tend to have high proportions of endemic and specialized wildlife and vegetation. Island biogeography theory states that small, isolated islands like the Galápagos have few species, which translates into established species evolving with few competitors and predators. This makes non-native species introduction especially dangerous on islands, as the lack of predators and excess of empty ecological niches provides

them the perfect environment to successfully invade. Species are typically introduced through ship ballast water, cargo containers, food/agricultural products, waste material, military activities, and biological pest-control agents (Convention on Biological Diversity, 2018).

One of the most famous examples of native ecosystem destruction via invasive species is Guam, a small US territory in the Western Pacific. During the second world war, Guam was used as a US military base; over the course of the war, brown tree snakes were accidentally introduced to Guam from other Pacific island military bases through cargo shipments. Because there are no predators, competitors, or diseases controlling the snakes' population on Guam, their numbers have exploded; the current population estimate is 50 brown tree snakes per hectare. They have directly caused the extinction of nine bird species and 3 lizard species, in addition to over $31 million in damages to power infrastructure, and more. The USDA National Wildlife Research Center has estimated that the accidental introduction of the brown tree snake to Hawaii (so far eight brown tree snakes have been found there, all from military shipments) could cost up to $1.7 billion- annually (Hawaii Invasive Species Council, 2017).

Introduction to the Galápagos

The Galápagos consists of 18 main islands, 3 small islands, and over 100 rocks/islets (*Figure 1)*; the archipelago is fairly young on a geologic time scale, estimated to be no more than five million years old. Of these islands, only four are inhabited by humans: Santa Cruz, San Cristobal, Isabela, and Floreana. The islands were first discovered by the Spanish in 1535, but populations have only risen significantly since the 1970s, as tourism boomed and economic conditions on the mainland worsened; they are now home to over 25,000 permanent residents.

This rapid growth brought about many problems, including the introduction of invasive species. However, this issue began much earlier, in the 17th century (Galápagos Conservancy, 2018). This paper will explore the introduction, effects, and eventual eradication of some of these species; the focus will be invasive goats, donkeys, and pigs on the islands of Isabela and Santiago.

Goats on Isabela Island

Beginning in the 16th century, pirates, and whalers introduced domestic goats (*Capra hircus*) to islands across the globe. Goats are extremely versatile generalists, and can survive on grasses, forbs (non-graminoid flowering plants), browse (leaves and stems of woody plants), and sometimes marine algae. Their negative ecological effects are now well-known; they consume and trample native vegetation, which over time modifies community structure. In fact, the World Conservation Union has identified goats as the primary threat to 26% of threatened insular plant species (Lucas & Singe, 1978). 16th to 18th century sailors, however, did not known this- they introduced goats to islands along their routes as a food source for future voyages (Chynoweth et al., 2013).

Pirates and whalers passing by the Galápagos Islands in the 18th century soon discovered that the islands' tortoises suited their needs even better than goats; tortoises could be kept alive without food and water for nearly a year, flipped upside down in their ships' cargo holds. Sailors would offload their goats onto the islands and instead fill their holds with the ever-decreasing-in-numbers giant tortoises. On their return journey, when the men were sick of

tortoise meat, they would stop back at the Galápagos to replace them with goats (Galápagos Conservancy, 2018).

Prior to eradication attempts, Isabela and Santiago had an estimated goat population of over 100,000. The tipping point which finally forced human action on Isabela came in the 1970s, when goats crossed the Perry Isthmus into the northern half of the island (*Figure 2*). Over the course of the next 15 years, their population exploded, and they destroyed everything in their path as their range expanded. The dense forests on the rim of Alcedo, where tortoises once gathered at drip pools formed by the oceanic mists, were transformed into barren grasslands. As the shade and water that the tortoises relied on disappeared, the tortoises began to disappear as well. Bird and insect species were also affected and saw declines in population similar to the tortoises.

In 1997, the Charles Darwin Foundation and Galápagos National Park Service held an international conference to discuss the feasibility of removing invasive goats from the islands. There had been relatively few large-scale goat eradication programs on islands in the past; the methods they engineered were tested on the small boar and goat populations on Santiago (boar eradication will be discussed later), as well as goat populations on other smaller islands. In 2004, goat eradication on northern Isabela began. Project Isabela (the name given to the eradication program) involved high-tech, modern practices such as aerial hunting via helicopters, GPS tracking, and sterilized “Judas goats”. A large number of goats were eradicated from the air via assault rifles and highly-trained sharpshooters. However, as populations began to dwindle, goats began hiding from helicopters; helicopters had become associated with slaughter. This is where the Judas goats (and small amounts of ground hunting) came into play. A small number of goats were captured alive, sterilized, and released back onto

the island with tracking collars. Due to their social nature, these goats would seek out their hiding relatives, leading hunters to their locations. The Judas goats were then captured for reuse while the remaining goats were shot and killed. In addition to being sterilized, some Judas goats were surgically altered to remain in heat for abnormally extended periods of time, increasing their chances of leading hunters to more hidden goats. By 2005 (one year after hunting began on Isabela), goats had been eliminated from Pinta, Santiago, and northern Isabela (Galápagos Conservancy Blog, 2018).

Downsides to Goat Eradication

Unsurprisingly, the mass execution of over 100,000 goats via air assault did not sit well with everyone in the Galápagos. Despite what some disgruntled citizens may believe, all options were considered- one researcher even proposed introducing lions to the islands to eat all of the goats (Schellhase, 2018). The unfortunate truth is that the aerial hunting and Judas goat combination was the cheapest, quickest, and most efficient choice available to protect the ecologically significant islands; in fact, the average cost per hectare (on Isabela Island) for Project Isabela was only $9 (Donlan et al., 2018).

Unfortunately, there have been goat re-introductions since Project Isabela. Many fishermen still rely on the goats as a food source and were angered by the mass slaughter; others threaten goat re-introduction as retaliation for unfavorable fishery restrictions. In total, nine intentional re-introductions have been documented since 2006. To permanently halt re-introductions (both intentional and unintentional) and protect the $10.5 million investment in

island restoration, it has been suggested that goats be removed entirely from the archipelago; otherwise, re-introduction is always a possibility (Donlan et al., 2018).

Effects of Goat Eradication

The effects of goat eradication have been largely positive. Although Galápagos tortoises are still classified as vulnerable, their numbers have increased from 3,000 to 19,000 as a result of Project Isabela (McCarthy, 2016). Native vegetation including highland shrubs, opuntias, and drip pool-forming seedlings increased dramatically; eight critically endangered and endangered endemic plant species have increased in both populations and individuals (*Figure 3*), including the nearly extinct *Scalesia atractyloides* (Donlan et al., 2018). Several species once reduced to craters and other goat-excluded areas returned to their original ranges (Galápagos Conservancy Blog, 2018). On Santiago, endangered Galápagos rails were spotted for the first time since the late 1980s (Donlan et al., 2018).

An unintended effect of goat removal, despite invasive plant control, was the increased spreading and population increase of blackberries (*Rubus niveus*) on Isabela. Previously, the large goat population had been keeping them in check; the Galápagos National Park Service is now researching methods to contain and eradicate blackberry (Donlan et al., 2018). Despite this setback, the positive results of eradication have encouraged researchers; the current goal of the Galápagos National Park Service and Charles Darwin Foundation is to “ensur[e] that ecosystem restoration proceeds towards a more pristine condition… the final result [should be] a Galápagos similar to that witnessed by Charles Darwin in 1835” (Galápagos Conservancy Blog, 2018).

Donkeys on Santiago Island

Like goats, donkeys (*Equus asinus*) have been introduced to islands worldwide and have caused habitat destruction and extinctions as a result of overgrazing. They were first recorded in the Galápagos in 1834, having been introduced from mainland Ecuador for use transporting kegs of tortoise oil. By 1875, there was a large population of feral donkeys on Santiago (and soon thereafter, there were large populations observed on other Galápagos Islands).

377 plant species are present on Santiago, including the threatened *Galvezia leucantha porphyrantha*, *Scalesia atractyloides*, and *S. stewartia*. Goats and donkeys are these species' main threats; the island is uninhabited by humans and mostly off-limits to tourists (and even scientists). Goats and donkeys are believed to be responsible for the extinction of *Blutaparon rigidum*, which was endemic to Santiago, and last seen in 1906; *B. rigidum* is one of only three extinct Galápagos plant species.

Donkeys also have a direct impact on tortoise and land iguana populations; they commonly trample both tortoise and iguana nests. Land iguanas have been extinct on Santiago since at least 1905 (possibly before), despite Darwin reporting their population as abundant only a few decades earlier. This loss can partially be attributed to nest-trampling and grazing competition from donkeys (Carrion, 2006).

Donkey Eradication on Santiago Island

Although donkeys were hunted opportunistically on Santiago during early boar and goat eradication programs as early as early as the 1970s, they were not specifically targeted until 2004 (Santiago's donkeys and goats were used as a test for Project Isabela). Before Project Isabela, they were killed by ground hunters using a variety of rifles; starting in 2004, helicopter-based marksmen used 12-gauge pump-action shotguns to remove donkeys from Santiago. 339 donkeys were eradicated on Santiago over a 30-year period; the last 25 were killed via the aforementioned aerial hunting in a process which took only 80 hours (it has been estimated that if donkeys were the sole focus of the hunt, eradication could have occurred in 20 hours). This final eradication of donkeys from Santiago was confirmed by nearly five years of surveillance. During this time, the last 99 donkeys in northern Isabela were also eliminated via aerial hunting (in conjunction with the previously discussed goat eradication). Aerial hunting was very effective in eradicating donkeys. Unlike goats, they do not exhibit hiding behavior; this made them much easier for the hunters to locate. Although it can be difficult to determine which gains in island restoration can be attributed to donkey eradication (compared with goat eradication), researchers maintain that donkeys "are major drivers of ecosystem change and degradation" and that "they should be routinely eradicated from islands" (Carrion et al., 2006).

Pigs on Santiago Island

Introduced non-native pigs, like goats and donkeys, have threatened native vegetation and wildlife and changed ecosystem dynamics on islands across the globe. Pigs were most likely introduced to Santiago in the 1830s, shortly after Darwin's voyage. By 1875, they had

become widespread. In contrast to their previously discussed invasive counterparts, pigs are omnivores. They have been known to eat the eggs and hatchlings of giant tortoises, lava lizards, green sea turtles, and petrels, as well as other vertebrates, invertebrates, and vegetation.

Pig Eradication on Santiago Island

The Galápagos National Park Service and Charles Darwin Research Station first began a pig control program on Santiago in 1968, less than a year after the park began operations. During this time, hunting was sporadic; there are no written records of hunting effort (which is calculated as number of hunters * days of hunting). Record-keeping began in 1974, when hunting parties used a mix of traps, dogs, and 0.22 caliber rifles, with little success. By 1985, hunting effort increased, and the program's goal switched from control to eradication. 1985 also saw the beginning of a controversial poisoning campaign; goat meat and sea turtle eggs were injected with lethal doses of sodium monofluoroacetate (1080) or warfarin as a supplement to normal ground hunting operations. Pigs consumed just over half of the 1,199 poisoned baits on Santiago in 1985. Hunting effort increased several times over the next decade, as did use and efficiency of poisoned bait traps. Hunters believed the last pig on Santiago was shot in July of 2000, but extensive post-eradication monitoring showed that one survived; it was poisoned and killed in October of 2000. At this time, goats and donkeys still remained on Santiago. Therefore, it was difficult to determine ecological gains related to their eradication. However, the lessons learned (and more importantly, published) from the decades-long pig control/eradication program can be applied to other eradication programs, both in the Galápagos as well as internationally (Cruz et al., 2005).

Controversy Surrounding 1080 Poison

Although the 1080-laced traps used in pig eradication on Santiago have been proven effective in eradication programs worldwide, a moral controversy surrounds their use. 1080 is the common name for sodium fluoroacetate (FCH_2CO_2Na), a colorless salt that acts as a metabolic poison; it is most commonly used in New Zealand to control populations of invasive possums, rats, and stoats (US EPA, 1995). According to New Zealand's Department of Conservation, its solubility in water and inability to bio-accumulate make it safe to use. They claim there are few risks to humans (it has the potential to move through soil and contaminate groundwater, but has not yet been detected), and the risks to native wildlife are outweighed by the benefits gained by removing invasive species (New Zealand Department of Conservation).

Despite this government endorsement, many pro-animal and conservation organizations (including PETA) are opposed to the use of 1080. The World League for Protection of Animals describes 1080 as "cruel and indiscriminate"; they believe that poisoned animals "[suffer] a prolonged and horrific death", with "shivering or shaking forelimbs and unsteady balance" and convulsions (World League for the Protection of Animals, 2018). The moral debate surrounding poison and the ethical treatment of invasive species is likely to continue for quite some time. Regardless, 1080 was successfully used in the eradication of pigs from Santiago and remains a useful tool in many eradication programs worldwide.

Conclusion

The eradication programs on Isabela and Santiago have been very successful. In total, over 200,000 invasive goats, donkeys, and pigs have been removed from the islands. These programs have proven the feasibility of large-mammal eradication from large islands and demonstrated how a mixture of hunting methods (aerial, ground, traps, GPS/GIS, etc.) can lead to a successful campaign in a short amount of time. In addition, results and methodology published from these programs will allow similar campaigns to succeed worldwide (Campbell & Donlan, 2005). Although there are some who disagree with the methods or the eradication in general, most researchers believe that the results achieved outweigh the potential risks (New Zealand Department of Conservation, 2018); many native species once threatened by the growth of invasive species populations on Isabela and Santiago are now recovering (Galápagos Conservancy Blog, 2018).

Figures

Figure 1: A satellite map of the Galápagos archipelago showing names of major islands (Wikipedia, 2018).

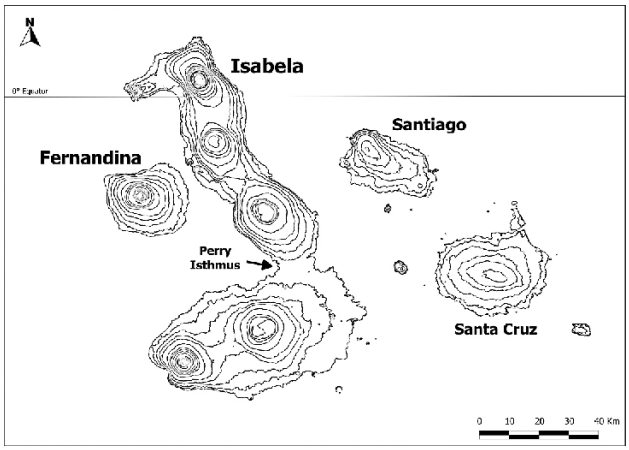

Figure 2: A contour map highlighting the location of the Perry Isthmus on Isabela Island (Anchundia et al., 2018).

Figure 3: A side-by-side view of the Galápagos highland ecosystem before and after goat eradication (Galápagos Conservancy Blog, 2018).

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