
Evolution and Conservation in the Galápagos

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Source: https://galapagosconservation.org.uk/wildlife/galapagos-penguin/
Abstract

Since the thorough monitoring of Galápagos Penguins began in the mid 1900s, their populations have shown severe fluctuation and general decline; in light of these fluctuations as well as a small population size and limited range, the IUCN lists the Galápagos Penguin as endangered (IUCN 2017). As with many species, the increasing severity of climate change poses a threat to the vitality of the Galápagos penguin. As a highly vulnerable species, it becomes increasingly important to understand and attempt to address the threats facing these organisms as climate change continues to worsen. Through literature, this paper attempts to show that some of the largest threats to the Galápagos penguin are anthropogenic in nature and are preventing the population from rebounding. The results of this paper indicate that current human activity in the islands and throughout the world continues to pose a threat to the penguin population and that actions to reduce human impact on the islands should be taken.

Introduction

The Galápagos penguin is one of the rarest penguin species in the world– there are less than 2,000 individuals and current estimates place their population numbers close to 1,500 individuals (Vargas et al. 2005). Descended from the Humboldt Penguin, they are the only species of penguin that lives in the equatorial region and the nature of this environment limits its range (Vargas/De Roy 2009). The species has evolved a mix of behavioral, physical, and physiological adaptations that allow this cold-climate organism to survive in the intense sun of the tropics. Their population is concentrated on the western side of the archipelago where large amounts of coastal upwelling provide cool ocean temperatures and abundant food during most years.
Adaptations

Some of the penguins’ adaptations include opportunistic mating habits, small body size, larger amounts of bare skin relative to other penguin species, and small changes in behavior. This species of penguin is the second smallest in the world– its small body size increases the bird’s surface area to volume ratio which makes it more efficient at dissipating heat and keeping cool in the warm conditions of the islands; they also tend to seek out shaded areas, nesting in cooler areas such as lava tubes that provide optimal conditions for incubating young. (Vargas/De Roy 2009).

One of the most significant adaptations is their opportunistic mating behavior; while many penguin species have defined mating seasons and cycles, this species only mates when resources allow for it (Vargas/De Roy 2009). This behavior gives the penguins a high reproductive capacity. During a good year, they can produce three clutches per year, each with two eggs; during years of low food availability, there is significantly less mating in the population (Durham 2018). The periods of mating are correlated with ocean temperatures with more mating observed during times when temperatures are about 23º C or less (Boersma 1974). This is likely because cooler waters tend to contain higher concentrations of food.

The penguins also have foraging behaviors that allow them to remain cool during the warm daytime temperatures. They forage mostly during the day and tend to hunt very close to their nests often not venturing beyond 10 km from the nest and spend most of their time above a depth of 6 m (Boersma et al. 2013). They feed mostly on species found close to their nesting sites. These feeding behaviors are well-suited to years of high food concentrations and also function as a way for the penguins to cool down as the ocean offers a cool oasis in the equatorial sun.
While effective, some of these adaptations have become vulnerabilities in the conditions of the changing environment. As the climate warms, an opportunistic mating behavior dependent on colder temperature will prove disadvantageous as cooler temperatures become less frequent. Furthermore, the limited range and small population size of the Galápagos penguin make the species extremely vulnerable to environmental change. Their foraging behavior is also detrimental to the penguins during El Niño years and in a warming climate. Since they tend to stick close to their nests and forage in shallow waters, they will be hard pressed to find food in easily accessible areas. Their foraging range also leaves them vulnerable to by catch and competition with fisheries. As a species dependent on cooler temperatures and the unique convergence of currents in the islands, El Niño and climate change pose massive threats to the survival of the species.

*Population Trends*

Some of the initial population censuses of Galápagos penguins were done by Boersma and prior to 1983, she estimated the population to be between 6,000 and 15,000 individuals (Boersma 1987). These numbers were likely a large overestimate of their true numbers but after the massive El Niño of 1982-1983, their population was decimated. Some have estimated a population decrease of up to 80% (Rosenberg, Harcourt 1987). Since then, the population has not reached pre-1983 numbers. All of the surveys done since the 80s have given estimates of between 1,000 and 5,000 individuals at max. The population numbers have fluctuated greatly over the years and the overall trend has shown little improvement. The figure below from Vargas et al. 2005 demonstrates the estimations of penguin populations from 1970-2003 showing a large drop off in the population in 1982-83 and in subsequent El Niño years (more on this later).
Since population numbers of the Galápagos penguin is highly dependent on environmental conditions, it serves as an indicator species for the ecosystem health of the Galápagos and more widely, the world. It is therefore important to monitor the health of the penguin population and work to mitigate any dangers facing the species as they are ultimately a danger to the wider ecosystem. This paper seeks to identify the largest threats to the Galápagos penguin preventing the population from rebounding; it analyzes the effects of El Niño, fisheries, introduced species, and disease on the Galápagos penguin population.

**Hypotheses**

1.) El Niño events negatively impact Galápagos Penguins by decreasing food availability and reproduction rates.

2.) Foraging difficulties for Galápagos penguins have been magnified by competition with fisheries and fishery activities increase incidence of penguin bycatch.
3.) An increase in disease and invasive mammalian species have slowed the recovery of the penguin population and these effects are magnified by low genetic diversity.

Methods

Testing these hypotheses required search and analysis of previous literature on Galápagos penguins to find data about their population numbers, foraging behaviors, adaptations to the tropics, and genetic diversity. I also looked for information concerning the patterns of weather events in the Galápagos, especially ENSO events, fishery activities in the islands, penguin bycatch, and introduced species and disease vectors.

Hypothesis 1:

- Compile data on penguin population trends over several decades, mostly through semi-frequent, well documented penguin censuses
- Compile data on breeding success and juvenile population numbers
- Analyze and compare population trends of penguins with patterns of ENSO events and food availability (using primary production as a measure of food source)

Hypothesis 2:

- Collect data concerning the foraging behaviors and ranges of the Galápagos penguins as well as their main food sources
- Collect data on local fishery activity in the western islands of the Galápagos and records of penguin bycatch
- Analyze overlap of fishery and penguin foraging ranges, types of species targeted by fisheries and look for evidence of reduced penguin prey due to the presence of fishing in penguin habitats
Hypothesis 3:

- Collect data on parasites/disease present in the Galápagos penguin populations and the potential for serious disease outbreaks
- Collect data concerning the effect of mammalian species on penguin populations and analyze these organisms as potential disease vectors
- Collect data on the genetics of the Galápagos penguins especially data concerning potential immunological weaknesses
- Analyze some of the combined effects of climate change, reduced prey availability, and low genetic diversity pose great threats to the species

Results

1. *El Niño events negatively impact Galápagos Penguins by decreasing food availability and reproduction rates.*

![Figure 2: Counts of Galápagos penguins around Isabela and Fernandina Islands, with the circles showing average yearly sea surface temperature, taken at Punta Ayora, Santa Cruz, Galápagos. Strong El Niño years were 1982–83 and 1997–98.](Boersma et al. 2013)

The penguin population in the Galápagos has been monitored for some time. The diagram above shows their population trends over the past few decades plotted over ocean temperature trends. One can clearly see that drops in population number coincide with high temperature
anomalies. Several of these anomalies are actually El Niño events. The most significant of these events appear to be the 1982-1983 event and the 1997-1998 event during which the population suffered major losses. One can also notice that the general trend in the population is decreasing; large drop offs in population are generally punctuated by slight recoveries, but the numbers tend to cluster around a population size below the population sizes recorded pre-1983.

The species is well adapted to very particular conditions that are almost completely absent during ENSO events. The Galápagos penguin relies heavily on the normal pattern of ocean currents that provide both cool temperatures and nutrient-rich water via the Cromwell Current (Vargas/De Roy 2009). During El Niño events, normal current patterns are reversed which brings warmer waters and disrupts upwelling in the islands which leads to much less planktonic activity and ultimately a weakened food web (Durham 2018).

Low primary productivity leads to a significant decrease in energy availability for organisms of higher trophic levels. In response to a strained food supply, Galápagos penguins often make no attempt to mate, or if they do, they often fail (Boersma et al. 2013). The energy investment to mate and brood chicks is quite demanding and in El Niño conditions, penguins are much less likely to survive if they invest their energy or devote their food to young. The severity of these energy investments is likely the driving force behind the selection of opportunistic mating behavior. The figure below demonstrates the number of documented breeding successes against measured temperatures from 1971 to 1973. The figure shows that breeding success is correlated with cooler ocean temperatures and vice versa.
An isolated El Niño event can pose a major threat to the Galápagos penguin; a single event intense or prolonged enough could likely drive the species to extinction. An increase in frequency or intensity of ENSO events would create another heavy selection pressure that could prove to be an impassible barrier for the species. Researchers have noted that this trend appears to be occurring; Boersma noted that from 1978-1998, the warming of the Pacific has been associated with an increase in El Niño events and a drop off in La Niña events (Boersma 1998). Data from NOAA indeed shows that this trend appears to be occurring.
This trend could prove extremely dangerous to the rebound of this penguin species. Increases in El Niño events lead to an increase in mortality while a reduction in La Niña events allows for much less time for populations to cover (Boersma 1998). Climate change threatens most all species in the world, but the Galápagos penguin is an excellent example of how evolutionary adaptation can become major vulnerabilities in a world of changing conditions.

Through the literature, we see that population declines have historically been correlated with El Niño events and that general decline of the population over time seems to be correlated with an increase in intensity and frequency of ENSO events. The hypothesis that El Niño negatively impacts penguin population numbers is well supported in scientific literature.

2. *Foraging difficulties for Galápagos penguins have been magnified by competition with fisheries and fishery activities increase incidence of penguin bycatch.*
With regards to fisheries, marine birds face two main threats: overfishing and bycatch. Many marine birds, including the Galápagos penguin, forage in areas that overlap the hunting grounds of fisheries (Crawford et al. 2017). In areas of high human fishing activity, the birds will have to compete with industrial fishing in order to survive. Furthermore, the methods by which fisheries hunt can lead directly to the entrapment of birds in fishing equipment such as nets, lines, and hooks (bycatch). The presence of fisheries in the Galápagos raises concern for many marine species and the Galápagos penguin is no exception; fishery actions in penguin foraging grounds have the potential to reduce foraging success (Boersma 1998).

Another concern with fishery activity in islands is that overfishing could lead to the removal or at least severe reduction of spiny lobsters which behave as a keystone species in the Galápagos (Graham et al 2010). These lobsters play a pivotal role in maintaining the food web of the islands. Similar to sea otters in California, spiny lobsters feed on urchins and the maintenance of urchin populations allows for a sustainable population of primary producers in the ecosystem (Graham et al 2010). There is also evidence of over-exploitation of predatory fish which could lead to long term damage to the food web and marine environment itself (Graham et al 2010).
The figures above show the range of the Galápagos penguin (left) and the range of fisheries that have been fished in the past and that are currently fished (right). This graphic shows the range of sea cucumber fisheries over two different time periods. The majority of the penguin population is concentrated on the west coast of Isabela and on the island of Fernandina (Vargas/De Roy 2009). The sea cucumber fishery industry represents only one of the various industries that work in the island, yet it encompassed much of the same areas that penguins live, breed, and forage in. In addition to changes in food web stability, fishery presence in these areas can also change the densities of penguin prey in their foraging areas (Boersma 1998). As discussed in the intro of this paper, the Galápagos penguin has a very limited hunting range and tends to hunt in shallow waters close to their nests. As fisheries deplete these waters of various prey and species integral to the food web, the penguins could be faced with more challenges when hunting. For example, the exploitation of predatory fish would extend the ranges of smaller schooling fish on which penguins feed (Graham et al. 2010). With less predators, these fish could move into deeper or more pelagic waters, away from normal penguin hunting grounds making them less accessible to penguins and exacerbating the difficulty of finding prey. This effect could be worsened during El Niño years when penguins would be less willing to expend large amounts of energy to hunt whilst trying to conserve energy due to food shortages.

There is surprisingly little data on penguin bycatch in the Galápagos. There are few if any papers that focus solely on this issue as it relates to Galápagos penguins. However, Boersma et al. noted that in addition to the other effects of fishery presence in penguin ranges, gillnets pose a threat to them if they end up in their range as they’ve been known to kill the Galápagos penguin (Boersma et al. 2013). Close relatives of the Galápagos penguin such as Magellanic penguins in Argentina have been documented as being a frequent victim of bycatch in trawl fisheries.
This same study also makes note of the fact that it is often difficult to document the effects of gillnet fisheries on penguins as they are so widely used in South America and it is hard to monitor so many locations. Although illegal, some fisheries use gillnets in shallow waters off Isabela, and some penguins have been observed caught in fishing gear in the Bolivar channel (Crawford et al. 2017). These activities occur in the immediate habitat of the Galápagos penguin where their concentrations are highest. The bycatch in these areas is not well documented because use of gillnets is illegal in the area; it’s possible that bycatch is underreported and that it may pose a bigger threat than currently believed. In any case, fishing in shallow waters in the Bolivar Chanel could easily have negative effects on the population as explained earlier in this section.

There is sufficient support for the hypothesis that fishery activity has the potential to interfere with not only penguin foraging, but also the stability of the food web as a whole. Although there is not much support for the hypothesis that bycatch poses a major threat to these birds, further research is needed to better document the incidences and frequencies of bycatch as well as illegal fishing in protected areas.

3. *An increase in disease and invasive mammalian species have slowed the recovery of the penguin population and these effects are magnified by low genetic diversity.*

As human presence and activity in the Galápagos has increased, so too has the incidence of introduced species and other dangers to the native and endemic species of the islands. Recent studies have revealed the presence of various diseases and parasites in the penguin population (Levin et al. 2009). One of the most worrisome of these is the introduction of *Plasmodium spp.* which is known to cause avian malaria that often leads to high mortality rates in birds (Palmer et al. 2013). While *Plasmodium spp.* has been detected in the population, there were not individuals
that displayed symptoms a decade ago (Vargas/De Roy 2009). The protozoa is transferred through mosquitos and it is widely believed that it was brought to the islands through the mosquito Culex quinquefasciatus which was introduced to the archipelago in the 1980s (Vargas/De Roy 2009).

Although Plasmodium spp. has been documented in the population for quite some time, there have not been any mortalities recorded that are credited to the effects of avian malaria. It is theorized that the Galápagos penguin is not a suitable host for the protozoan (Palmer et al. 2013). This is hopeful, although it’s also possible that the penguins are able to survive in spite of the parasite during normal, favorable conditions but that the stresses of El Niño would provide enough traction for malaria to develop in the population.

If malaria were to arise in the population, computer and mathematical modeling shows a bleak picture of species persistence for the penguins in the next century (Meile et al. 2013).

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**Figure 7 – Meile et al. 2013.**

Fig. 1. Mean probability of persistence of the Galápagos Penguin after 100 years under (A) the scenario without relapses, (B) the scenario with relapses during strong El Niño events, and (C) the scenario with relapses during all El Niño events. Each graph shows the probability of persistence for each combination of parameter values (probability of infection and pathogenicity), starting at 5% and increasing in 5% intervals. Pathogenicity is the increased mortality due to infection. The baseline model used by Vargas et al. (2007) gave a probability of persistence of 70%. 

The figure above shows how the penguin population could be destroyed depending on the pathogenicity of *Plasmodium spp.* for the Galápagos penguin. The best-case scenario is shown in graph A, with the least pathogenicity while graph C shows the case where the disease is highly pathogenic.

One of the major concerns about the Galápagos penguin with respect to disease is the low genetic diversity among the species. In particular, the Galápagos penguin demonstrates extremely low MHC variation (Bollmer et al. 2007). This protein is integral to immune response in defense against disease. Low diversity in this protein could indicate that the species would have an inefficient immune response to any disease that could infect the population and it’s likely that no individual would be safe from the ravages of a disease. This homogeneity in the

<table>
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<tr>
<th>Species</th>
<th>n</th>
<th>No. of alleles</th>
<th>No. of variable sites</th>
<th>Average no differences (±SE)</th>
<th>π</th>
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<tr>
<td>Adélie (<em>Pygoscelis adeliae</em>)a</td>
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<td>20</td>
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<td>3</td>
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<td>Gentoo (<em>P. papua</em>)a</td>
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<td>8</td>
<td>23</td>
<td>10.8 ± 2.1</td>
<td>0.068</td>
</tr>
<tr>
<td>Little blue (<em>Eudyptula minor</em>)</td>
<td>4</td>
<td>4</td>
<td>21</td>
<td>12.7 ± 2.6</td>
<td>0.081</td>
</tr>
<tr>
<td>Humboldt (<em>Spheniscus humboldti</em>)b</td>
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<td>20</td>
<td>9.7 ± 2.1</td>
<td>0.062</td>
</tr>
<tr>
<td>Galápagos (<em>S. mendiculus</em>)</td>
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<td>3</td>
<td>2.0 ± 1.2</td>
<td>0.013</td>
</tr>
<tr>
<td>Magellanic (<em>S. magellanicus</em>)</td>
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<td>2</td>
<td>16</td>
<td>16.0 ± 3.9</td>
<td>0.102</td>
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<tr>
<td>King (<em>Aptenodytes patagonicus</em>)</td>
<td>2</td>
<td>3</td>
<td>19</td>
<td>12.7 ± 2.7</td>
<td>0.081</td>
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</tbody>
</table>

*Figure 8– Bollmer et al. 2007*
MHC protein could’ve resulted due to genetic drift, the founder effect, or the frequent bottlenecks that the species experiences during El Niño years. The above figure demonstrates the low MHC variability in Galápagos penguins in comparison to other penguins. The Galápagos penguin has significantly fewer alleles and among the population, there is little difference in allele combinations. This nearly homogenous genetic composition makes this species highly vulnerable to disease.

I found little evidence of mammalian predators causing a significant amount of damage to the penguin population. Feral dogs and cats have been observed preying on penguins but their removal from the most penguin-dense islands has not facilitated the rebound of the species (Rosenberg, Harcourt 1987). While these predators may have been hurting the populations, they certainly can’t be the only factor preventing the species from rebounding to pre-1983 population sizes. The biggest threat to penguins with regards to introduced species is the potential of mammalian or rodent species performing as disease vectors that could translate to the penguin population.

This hypothesis is not well supported but it does provide grounds for future research and clearly indicates that there are possible risks that, in the future, could prove extremely detrimental to the penguin population in the Galápagos.

**Conclusions**

My initial hypothesis is well supported. ENSO clearly has a negative and widespread effect on the Galápagos penguin population. The conditions of El Niño years lead to reduced prey availability, and thus less mating. My second hypothesis was somewhat supported– there is evidence to support the hypothesis that the activities of fisheries has the potential to disrupt
penguin foraging and their food web as a whole. However, there was not sufficient evidence to support the hypothesis that bycatch is a major barrier to population rebound in penguins, however it does leave room for future research into penguin bycatch in the Galápagos. My final hypothesis was not well supported as disease already in the penguin population does not appear to be having a major effect on their numbers. However, it does indicate that there are very real threats to the species that could arise in the near future and it merits further research into the topic.

**Conservation Implications**

Rather than a single factor being the single cause for the demise of the Galápagos penguin, it is more likely that a combination of many or all of the factors I’ve addressed will decimate the penguin population in the long run. For example, as climate change worsens, ocean temperatures warm, ENSO events intensify and become more frequent, more bottlenecks occur leading to even less genetic diversity leaving the population more exposed to disease or other dangers. Some of the most immediate effects on these penguins originate from the issues they face in light of anthropogenic climate change. A warmer climate is not conducive to the survival of this species. In order to increase their longevity, immediate action should be taken in an attempt to carbon emissions and other anthropogenic activities that contribute to climate change. Furthermore, efforts should be made to reduce fishing in penguin foraging ranges, especially following El Niño years. In order to reduce the risk of introducing further disease, it might also be beneficial to reduce human traffic to the islands, or at least to areas where there are large concentrations of Galápagos penguins.
Acknowledgments

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NOAA Southern Oscillation Index (SOI)

https://www.ncdc.noaa.gov/teleconnections/enso/indicators/soi/


http://www.iucnredlist.org/details/22697825/0


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