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# POPULATION TRENDS OF THE GALÁPAGOS PENGUIN: IMPACTS OF EL NIÑO AND LA NIÑA[1]

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*Abstract.* The Galápagos Penguin (*Spheniscus mendiculus*) population probably has always been small and largely restricted to the islands of Fernandina and Isabela. Counts suggest the current population of Galápagos Penguins is likely between 4,250 and 8,500, half of what it was in the early 1970s. Population size has varied and declined probably because of substantial changes in oceanic conditions. Body condition as evidenced by weight is enhanced during cold surface water conditions, La Niña, and deteriorates when surface waters are warmed, El Niño, and under the most severe conditions, penguins starve. Analysis of a long-term data set from counts of the population suggests that the population has fluctuated, dropping precipitously after the 1982–1983 El Niño and has since then been recovering very slowly. This parallels the overall warming in the Pacific during the last 20 years associated with the more frequent El Niño and less frequent La Niña events. These trends suggest that long-term global climate warming is likely to threaten the Galápagos Penguin population particularly because the population is small and its distribution restricted. New threats from climatic warming and increasing human perturbations such as fishing, inadvertent discharge of petroleum products, and transport of potential predators and pathogens to islands increase the risk of extinction.

*Key words: El Niño, El Niño Southern Oscillation, Galápagos, Galápagos Penguins, global climate change, La Niña, population trends,* Spheniscus mendiculus.

## INTRODUCTION

The Galápagos Penguin is the most northerly species of penguin and the only one that lives along the equator. Its survival in this low latitude environment is dependent upon upwelling of cool nutrient rich oceanic water that supports small schooling fish (Boersma 1974a, 1974b, 1977). The breeding areas of the Galápagos Penguin are confined largely to areas where the Cromwell current upwells around Fernandina and Isabela Islands (Fig. 1; Boersma 1977, 1978).

The strength of upwelling as indicated by surface water temperatures is closely associated with seabird feeding aggregations and breeding of Galápagos Penguins (Boersma 1977, 1978). Previously, I found El Niño Southern Oscillation (ENSO) events had a strong negative influence on the behavior, breeding, and reproductive success of Galápagos Penguins. This led me to predict that a change in the frequency of warm or cold water events, such as those associated with ENSO, over a long period should affect the demography of the Galápagos Penguin (Boersma 1977, 1978).

Although much is known about the climate changes of the Eastern Pacific, there are few long-term data sets on breeding seabirds in the region. The Galápagos Penguin population has been counted several times since the 1970s (Rosenberg and Harcourt 1987, Valle et al. 1987, Mills and Vargas 1997). A change in the frequency of El Niños, warm water events, and La Niñas, cold water events, over the last twenty years can be used as a natural experiment to determine how climatic variation affects the abundance and distribution of Galápagos Penguins. This paper summarizes population trends of the Galápagos Penguin for more than 25 years and examines the long term patterns of climate and climate change on the population.

## METHODS

In 1970 and 1971 an assistant and I counted penguins from a boat driven within 0.25–0.5 km of the coastline of Isabela and Fernandina Island (Fig. 1). During each census we counted all penguins seen on shore or in the water and distinguished adults from juveniles by plumage. The number of penguins counted during the census, the area where they were sighted, and reproductive success of the population from following marked individuals and their nest sites in 1970,

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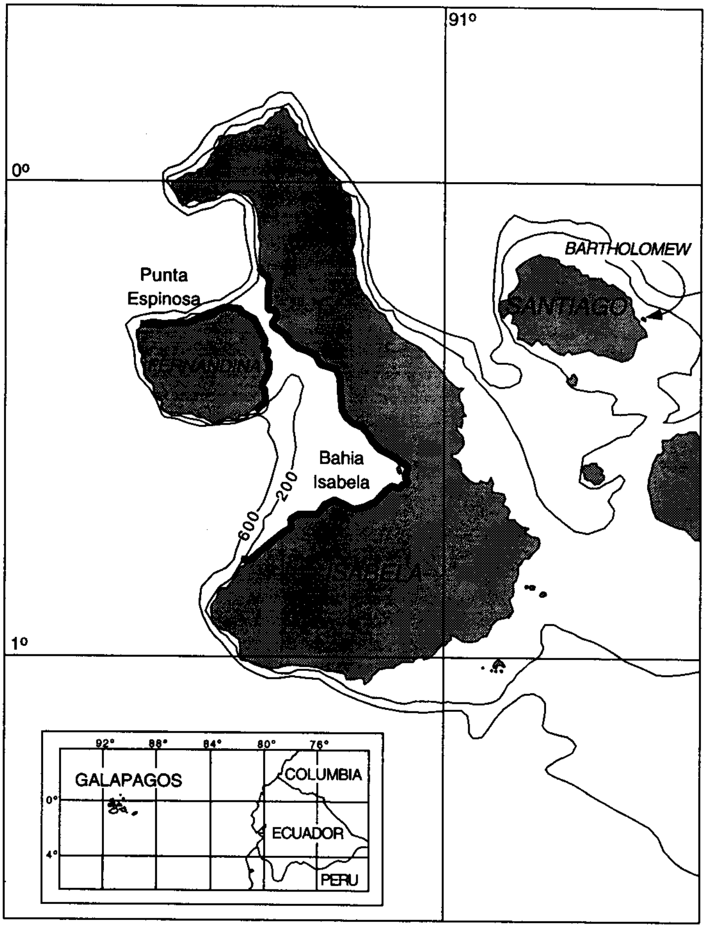


FIGURE 1. The Galápagos Islands showing the main breeding areas of the Galápagos Penguin, highlighted in black, around the two most western islands, Fernandina and Isabela, in the Galápagos Archipelago. The distribution of Galápagos Penguins is largely restricted to the 200 fathom contour line with the highest abundance where the shelf is widest in Bahia Isabela.

1971, and 1972 are reported in Boersma (1974b, 1977, 1978).

In addition, I visited breeding areas of the penguins in July 1978, July 1988, and March 1991, and assessed reproductive success. In areas where penguins appeared to be breeding I searched for nest sites from 15 July to 11 September 1970, 15 July to 7 September 1971, 9 January to 1 March 1972, 22 June to 2 October 1972, 18–25 August 1978, 18–22 July 1988, and 26–28 March 1991 to determine whether eggs or chicks were present. When penguins were breeding or standing on land I captured and weighed them using a spring balance graduated in 25 g increments. From 1970 through 1972, I banded penguins and determined sex from bill size using a vernier caliper (Boersma 1974b), performed necropsies on three adults, and took surface water temperatures with a hand held thermometer placed over the side of a boat about 50 m from shore. In 1978, I took surface water temperatures several times each day around Fernandina and Isabela.

The Charles Darwin Station and the Ecuadorian National Park Service conducted subsequent censuses of the population using small fishing boats and a dinghy following the methods of Boersma (1974b, 1977), except that they used three people and a boatman instead of two people to search for birds (Rosenberg et al. 1990). Most of these subsequent surveys were done in August and September when penguins are usually breeding. Census data from Harcourt (1980b), Valle (1986), Valle and Coulter (1987), Rosenberg and Harcourt (1987), Vargas (1996), Mills and Vargas (1997), and Merlen and Vargas (pers. comm.) were used to analyze population trends in Galápagos Penguins from 1970 to 1997. Values listed are means ± SE except where noted.

## RESULTS

### REPRODUCTION AND BODY CONDITION

Surface water temperature was a good predictor of reproduction. During the months when penguins were breeding in 1970 through 1972, surface water temperature ranged from 17°C to 27°C with a mean (± SD) of 22 ± 1°C. Penguins were significantly more likely to breed when surface temperatures were ≤ 22°C than when temperatures were warmer ($t_{30}$ = 5.9, $P$ < 0.001). All nests failed and courtship ceased when mean (± SD) surface water temperature rose to 25 ± 2°C.

During the breeding period in 1970 (June to September), many chicks fledged, although I did not quantify reproductive success. I found fewer nests and chicks in 1970 than in 1971 and therefore concluded 1970 was less successful. In 1971, during a La Niña event, reproduction was very successful with 80 chicks fledging from 62 nests. In 1972, during an El Niño period, all but 1 of 92 nests failed in the first breeding period (December 1971 to March 1972). In the next breeding period, August to October 1972, all 108 nests found failed.

Adult body mass was compared in 1971 and 1972 during the early breeding season in July. During the 1971 La Niña when penguins were breeding and surface water temperatures were just under 21°C, most penguins had chicks and mean female weight was 2.10 ± 0.03 kg ($n$ = 64). During the 1972 El Niño when surface water temperatures were near 25°C and no penguins were breeding, female body weight was significantly less ($\bar{x}$ = 1.79 ± 0.07 kg, $n$ = 9, $t_{10}$ = 4.62, $P$ < 0.001, Fig. 2). Likewise, males were significantly heavier during the 1971 La Niña ($\bar{x}$ = 2.43 ± 0.02, $n$ = 85) than during the 1972 El Niño ($\bar{x}$ = 2.22 ± 0.07, $n$ = 12, $t_{13}$ = 2.82, $P$ < 0.01, Fig. 2).

I weighed 53 penguins during a La Niña (July–September 1971) when penguins had large chicks. I expected the penguins to weigh less

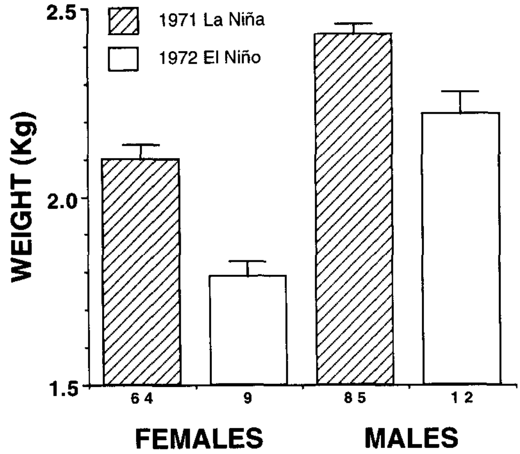


FIGURE 2. Weight of adult male and female Galápagos Penguins in July 1971, La Niña, and July 1972, El Niño, showing that both sexes were heavier in 1971 than in 1972. Error bars indicate SD and sample size is below the x-axis.

while raising large chicks than at the beginning of the breeding season because of the increased food needed to rear chicks. I weighed these same 53 penguins the following year during courtship when I expected them to be in good body condition and consequently heavier than during chick rearing, but this was during an El Niño period. The mean weight of these penguins during a La Niña was 2.34 ± 0.03 kg ($n$ = 53) compared to only 1.99 ± 0.04 kg ($n$ = 53) during the El Niño. Even though these penguins were older and at the beginning of the reproductive cycle they weighed significantly less during the El Niño than during the La Niña period when they were rearing chicks (paired $t_{52}$ = 10.51, $P$ < 0.001).

Reproduction was poor in 1978, although this year was neither an El Niño or La Niña year. I checked 88 nest sites and only 5 were active, 3 had two young ready to fledge. The weight of two adults males that were in nests with chicks were 1.86 kg and 2.08 kg, August 20, 1978. Both weighed less than three males with chicks during the La Niña event in August 1971 ($\bar{x}$ = 2.27 ± 0.09, $n$ = 3) but were comparable to four males weighed during the August 1972 El Niño event ($\bar{x}$ = 2.18 ± 0.10). Although few birds were breeding, there was some braying and other courtship activities and water temperatures around Fernandina and Isabela were between 17°C and 19°C.

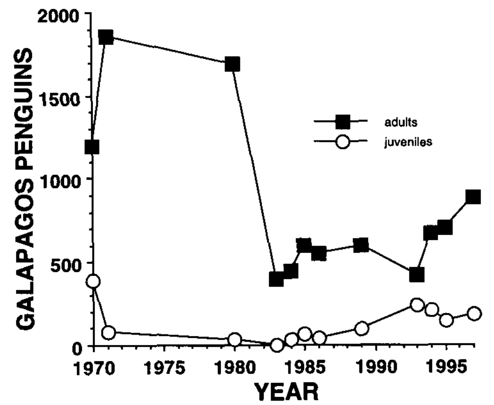


FIGURE 3. The number of juvenile (open circles) and adult (black squares) Galápagos Penguins sighted around Fernandina and Isabela Islands on surveys between 1970 to 1997 (H. Vargas, unpubl. data).

Reproduction also was poor in 1988. On 20 July 1988, after a La Niña event, I saw a number of juveniles suggesting reproduction had been successful. I checked approximately 60 nests on the small islands in Bahia Isabela and I found one active nest with two recently laid eggs. In March 1991, when surface water temperature was 26.9°C and an El Niño event was developing, I found no active nests among the 20 sites I checked and saw only six juveniles.

## POPULATION TRENDS

In 1970, I censused approximately 60% of the coast where penguins occur and observed 1,589 penguins. In 1971, I censused approximately 83% of the coast with penguins and counted 1,888 penguins (Fig. 3). There was no significant difference between 1970 and 1971 in the number of penguins counted in the 10 segments of the coastline of Fernandina and Isabela Island that I distinguished by landmarks (Wilcoxon matched-pairs sign-rank test, $T = -0.65$, $P = 0.51$). Seven of the areas had more penguins in 1971 than in 1970, and two segments had several hundred fewer penguins in 1971 than in 1970. Because the counts were similar in 1970 and 1971 in the areas surveyed, I used the 1970 penguin counts of areas not surveyed in 1971 to estimate what the direct count of the population in 1971 would have been if I had censused all areas: an additional 230 penguins would have been counted. Therefore, a complete direct count in 1971 would have been more than 2,000 adult penguins. I saw more juveniles in 1970 (387 juveniles, primarily in Bahia Isabela) than in 1971 (78 juveniles primarily in Bahia Isabela).

Direct counts of the Galápagos Penguin population show the population size has varied (Fig. 3). The population dropped to about one-fourth its 1970 size following the 1982–1983 El Niño, and by the late 1990s showed evidence of a slow recovery (Fig. 3). Nonetheless, the 1990 adult population was about half of what it was in 1970 and 1971 (Fig. 3).

More than twice the number of juveniles were counted in 1970 as in any other year and this was after a La Niña period. I found no dead penguins in 1970 or 1971 when surface water temperatures were cool. In 1972, I found three dead adults. Each was under the average weight, weighing less than 1.8 kg, had an empty stomach, and little to no fat, suggesting they had died from starvation, probably as a result of the El Niño. The population likely declined after the 1972 El Niño event, however to what extent is not known because the next census was not until 1980 when slightly more than 1,700 adults were counted (Harcourt 1980a, 1980b). The adult population declined by about 15% from 1970 to 1980 (Fig. 3).

The severe 1982–1983 ENSO caused the penguin population to fall (Valle 1985) an estimated 77% (Rosenberg and Harcourt 1987), most likely due to the death of adult birds (Merlen 1984, 1985). Based upon survey counts, the population was approximately 20% of what it was in 1970 and 1971. Reproduction apparently was poor throughout the 1980s as evidenced by the small number of juveniles counted (Fig. 3).

During the counts in 1970 and 1971 when La Niña was well developed, approximately 60% of the penguins sighted were seen at sea where they are most difficult to detect. In 1995, when upwelling was probably relatively poor (as indicated by Southern Oscillation Index, SOI, Fig. 4), and penguins would be expected to have trouble finding food, 82% of the penguins counted were seen at sea (Vargas 1996). The adult population does appear to be slowly recovering as more juveniles are being counted (Fig. 3). Nonetheless, the population appears to be about half of what it was in the early 1970s.

## DISTRIBUTION

Penguins were found nearly exclusively around Isabela and Fernandina Islands (Boersma 1977). Penguins are more common and breed along the

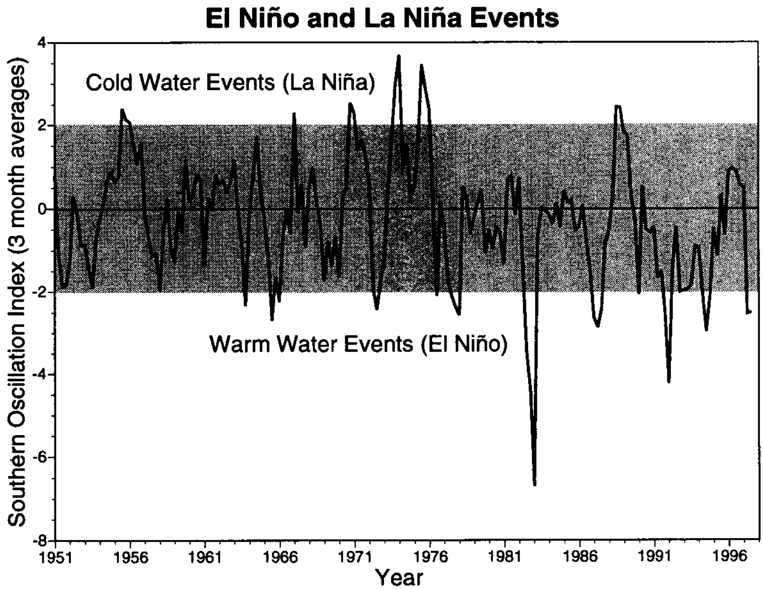


FIGURE 4. The Southern Oscillation Index (SOI) with three-month averages using data from National Centers for Environmental Prediction, National Oceanographic and Atmospheric Administration. The warm water surface temperatures of El Niño are indicated by strong negative SOI values, and unusually cool surface water temperatures by a positive SOI value. The shaded area indicates a less than two standard deviation departure from the 1950 to 1980 base period. Positive peaks outside the shaded area are considered La Niña events and negative peaks outside the shaded area are considered El Niño events.

coast of these islands where the continental shelf is relatively wide and water depth is less than 200 m (Fig. 1). The only other places in the archipelago where a few penguins are regularly seen is around Bartolomé, Floreana, and Rábida Islands, areas where the shelf is wide and schooling fish are common.

The relative abundance of penguins in eight different sectors of Isabela and Fernandina Islands (see Boersma 1977) remained similar from 1971 to 1995 (Wilcoxon matched-pairs signed-ranks, 1971 vs. 1995, $T = -2.10$, $n = 8$, $P = 0.04$). In our surveys, Bahia Isabela had the largest number of penguins and this is where the shelf is widest (Fig. 1).

## DISCUSSION

### REPRODUCTION AND BODY CONDITION

For Galápagos Penguins, reproduction and body condition appear to be tightly linked to oceanic conditions. This pattern probably holds for many seabirds. Viet et al. (1997) showed that a decline in shearwaters was negatively correlated with increasing temperatures within the California Current and suggested the mechanisms were reduced advection and upwelling of nutrients. A time lag between changes in physical and biological processes is expected between large-scale climate changes and bird population dynamics. Over the last 42 years, surface water temperature increased by 0.8°C which Viet et al. suggest may have led to a 70% decline in zooplankton over the last 20 years, and a 90% decline in shearwater abundance over the last 8 years. Boersma and Parrish (1998) found decadal changes in growth rates of Fork-tailed Storm-Petrels (*Oceanodroma furcata*) in the North Pacific and suggested that the variation is a response to environmental change.

Around Fernandina and Isabela Islands in the Galápagos, the time lag for changes in surface water temperature to be reflected in seabird body condition and reproduction appear to be small and can happen in a matter of days (Boersma 1978). The major difference in weight of the same breeding adults during La Niña in 1971 and El Niño in 1972 underscore the sensitivity of Galápagos Penguins to oceanic conditions. During the La Niña conditions of 1971, penguins were significantly heavier and most pairs reared young. In contrast, all nests failed during the El Niño event of 1972. During an El Niño event and at the beginning of their breeding season in September 1972, when birds should have been in good body condition, penguins weighed 15% less than they had in the previous year during a La Niña period.

POPULATION TRENDS

The effects of oceanic conditions appear to be reflected in the counts of Galápagos Penguins which show variation but a strong decline. There were three El Niño events in the 1970s (1972, 1976, 1977) and four La Niña events (1970, 1971, 1973, 1975) (Ropelewski and Jones 1987). The El Niño events in the 1970s were not as strong as those in the 1980s and 1990s, and the La Niña events since the 1970s have been weak (Fig. 4). From 1970 to 1996, Ropelewski and Jones (1987) and Ropelewski (pers. comm.) found 11 warm water events (1972, 1976, 1977, 1982, 1983, 1986, 1987, 1991, 1992, 1994, and 1997) and seven cool water events (1970, 1971, 1973, 1975, 1984, 1988, and 1996) when the Southern Oscillation Index (SOI) remained in the lower or upper 25% of the distribution, respectively, for five months or longer.

The census count of juvenile Galápagos Penguins appears sensitive to reproductive success and phenology. The 1970 census took place in September, after most chicks had fledged and this was when the largest number of juveniles in any survey were counted. In contrast, the census in 1971 took place in August, before most chicks had fledged and although reproduction was very successful, few juveniles were seen.

The population declined precipitously after the 1982–1983 ENSO event. This ENSO event was the most severe recorded in the tropical Pacific Ocean, and resulted in large changes in fish and bird populations (Barber and Chavez 1983, Cane 1983, Schreiber and Schreiber 1984). It is particularly significant that only 29 juvenile Galápagos Penguins were seen during two censuses in 1984 (Valle and Coulter 1987), suggesting that the warm water affected reproduction, juvenile survival, and recruitment for many months after the 1982–1983 ENSO event. In 1986, sea temperatures in the Galápagos were still above 24°C (Rosenberg and Harcourt 1987). This probably is the upper temperature limit at which food is sufficient for the Galápagos Penguin to breed (Boersma 1977, 1978). Through the 1980s the number of breeding penguins and their reproductive success was low as evidenced by the small number of juveniles seen and the lack of breeding activity found (Fig. 3; G. Merlen, pers. comm., Boersma, pers. observ.). There were no La Niña events from 1977 until 1988 (Fig. 4). Of the 20 cold episodes between 1881 and 1988, only the 1988 episode had surface temperature averages above normal (Halpert and Ropelewski 1992). This may be why I found only one active nest in 1988, although I saw juveniles indicating the birds had reproduced successfully. In 1989 following the 1988 La Niña event, Merlin (pers. comm.) sighted 97 juveniles, the largest number of juveniles seen since the early 1970s but still far fewer than the several hundred seen in the 1970s. Nonetheless, the increase in juveniles in the population in 1989 suggests that La Niñas may be important for reproduction and recruitment of juveniles into the breeding population. Adult counts have increased slowly since the mid-1980s (Fig. 3). Bell and Halpert (1995) report that 1991–1993 was one of the longest periods of a continuous warm water episode on record for the Pacific ocean. From 1990 through 1995, the SOI was low, indicating warm water conditions (Fig. 4). Although the population seems to be in slow recovery, it may be sometime before it returns to 1970s numbers. The long-term population decline is probably due to changes in availability of schooling fish which are influenced by trends in warmer surface water temperatures.

The lack of population recovery is apparent from the data of juvenile sightings. In the 1970s nearly 30% of the penguins sighted were juveniles. The largest number of juveniles seen was following the 1970 La Niña event and the number of juveniles counted in 1971 would have been much higher if the count had occurred after, instead of before, fledgling. Nonetheless, 78 juveniles were seen, still more than were seen in counts done in 1980, 1983, 1984, 1985, and 1986 when there were no La Niñas (Fig 4). In the 1980s less than 10% of the individuals seen were juveniles. In 1993–1995, about 20% of the penguins counted were juveniles.

The upward trend in the number of adult Galápagos Penguins counted indicates the population may be slowly recovering from the severe adult mortality during the 1983 ENSO event and the several decades of poor reproduction and poor recruitment that followed (Fig 3). In September 1997, 883 penguins were counted (H.

Vargas, pers. comm.). This increase in the population followed the 1996 La Niña episode.

## DISTRIBUTION AND ABUNDANCE

There was no difference in the distribution pattern of penguins over the last 25 years, suggesting that the general locations of upwelling in the islands have not changed. However, the amount of food available to penguins as indicated by changes in SOI (Fig. 4) has been highly variable. Moreover, direct counts are likely to be higher during La Niña events when penguins spend more time on land where they are easier to see as opposed to El Niño episodes when penguins are likely to be in the water where they are more difficult to see. Consequently, direct counts are likely to overestimate changes in the population size.

Using my 1977 estimate of 10 to 20% of the population as counted on a survey, the 850 penguins seen in 1994 and 1995 suggest the current population is 4,250 to 8,500 Galápagos Penguins, although it could be as low as 1,700. In 1995, approximately 700 penguins were counted that were adults or of unknown age, indicating that the adult population has doubled since its low in the mid-1980s, but it is still less than half of what it was in the early 1970s.

## THE POPULATION'S FUTURE

A reduction in the frequency of La Niña events during the last two decades may have kept the penguin population from recovery. If females are more likely to die under the most severe El Niños because they are in poorer condition than males (Fig. 2), then El Niño events may have a disproportionate negative impact on females that could result in a biased sex ratio making population recovery slower. The severe 1982–1983 ENSO that killed adults coupled with the reduced frequency of La Niña events is the likely determinate of the penguin's current small population size.

Climate changes can have dramatic and negative impact on seabirds, causing reproductive failure and massive population declines (Boersma 1978, Schreiber and Schreiber 1984, Tovar and Cabrera 1985). There is evidence that seabird population dynamics are influenced by large-scale climatic changes (Aebischer et al. 1990).

The global tropics in the Pacific are well studied and are most directly affected by one of the largest sources of environmental variability in the climate system, ENSO (Allan et al. 1996). Above-normal surface water temperatures accompany low phases of the Southern Oscillation index (El Niños), and below-normal surface water temperatures (La Niñas) accompany the high phase (Halpert and Ropelewski 1992, Allan et al. 1996). Since the late 1970s, surface water temperatures in the Pacific basin have been warmer than the historical average (Tibbetts 1996). In addition, there have been fewer La Niña events, when surface water temperatures cool and upwelling is stronger, and more El Niño events, when surface water temperatures warm and upwelling is weaker (Trenberth 1990, Trenberth and Hurrell 1994, Graham 1995). By some measures the recent warm water event, lasting from 1990 to June 1995, was the longest on record since 1882 (Trenberth and Hoar 1996). Monastersky (1996) suggests the warming of the Pacific such as from the mid 1970s to the mid-1990s has occurred only once every 1,500 to 2,000 years.

The natural experiment of sea surface-temperature warming indicates that the Galápagos Penguin will be affected by long-term changes in climate. Adults are vulnerable in the strongest ENSO events such as the one in 1982–1983. A series of these events with increased long-term global warming and fewer and weaker La Niña episodes coupled with human perturbations have the potential to cause the extinction of the Galápagos Penguin.

Whereas climatic warming may affect the Galápagos Penguin negatively by reducing the frequency and length of La Niña events, a more immediate threat may be direct human perturbations to this species. Economic and political interests in the islands are accelerating, leading to intense conflicts (Snell 1996). Transport among the islands is likely to increase pollution and potentially introduce rats or cats to Fernandina Island, which is currently without introduced predators. Fishing brings penguins and fishing gear in close proximity and can injure and kill penguins. If a bait fishery starts around Isabela or Fernandina Islands, it likely would have a negative effect on penguins by reducing penguin foraging success.

Small physical changes in surface water temperature have profound effects on the reproduction, survival, and consequently population size of Galápagos Penguins, suggesting that directional changes in surface water temperatures are likely to result in major alterations in seabird communities. A strong feedback mechanism between body condition and oceanic productivity may explain the unusual breeding biology of the Galápagos Penguin (molting before breeding), their distribution (restricted to upwelling areas), and their population dynamics (variation associated with El Niño and La Niña). Although the Galápagos Penguin seems to be resilient, it may have a difficult time surviving under global warming conditions. Moreover, the impacts of global warming on seabird communities in the Pacific Ocean as compared to the Atlantic will likely be larger, reflecting the Pacific Basin's greater responsiveness to climatic variation.

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