A Model of Adelie Penguin Colony Establishment

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Abstract

Adelie penguins are flightless aquatic birds that breed on gravel beaches along the Antarctic coastline. The ecosystem in Antarctica has a delicate balance due to the low number of species. Changing climatic conditions have led to variations in the ice cover, thus breeding sites of Adelie penguins are more dynamic now. New colony establishment is becoming more common as penguins emigrate from crowded colonies to the new breeding sites. It is important to understand colony formation as it will affect overall penguin population dynamics. A model was developed to further understand population patterns of an establishing colony and the number of immigrant penguins required. In order for a new colony to be self-sustaining, the immigrating penguins must produce enough chicks that survive to maturity to replace the adult penguins who perish. The various mortality and survival factors of adults and their young were integrated into a model on the Similie computer program. The model was able to predict that 44 was the minimum number of immigrating adult penguins required to establish a self-sustaining colony. However this number was determined to be highly dependent on fluctuations in mortality. As well, a pattern for population growth during a colony establishment period was found which included a 'lag time' and a 'recovery period.'

Description of Adelie penguins

Adelie penguins are aquatic, flightless birds that live and breed on the Antarctic coast. They have only black and white feathers and are the typical 'tuxedo' penguins commonly seen in cartoons. They have a black back, head and wings, and a white stomach (Davis 2003). This coloring is for camouflage from aquatic predators. They are well suited for extreme cold; they have a thick blubber layer, and feathers are found at the base of the beak and far down their feet to minimize heat loss (Davis 2003).

Adelie penguins obtain all of their nutrients from the ocean, eating krill and other small aquatic invertebrates. They are able to withstand long periods of fasting, although when they are feeding young they must feed and forage more often (Davis 2003). They require close proximity to the ocean, especially while breeding. The main aquatic predator of Adelie penguins is the leopard seal which preys on them while they are feeding (Oelke 1975). Adult penguins do not have any land predators, but skuas, large flying birds, regularly prey on their eggs and chicks and commonly nest close to penguin colonies (Oelke 1975).

Adelie penguins breed in large colonies on gravel beaches during the Antarctic summer. The use of colonies is for protections from predators (skuas) and from the elements. When the penguins are in a circular colony formation, those in the center have a higher degree of protection against the skuas (Penney 1968). Adelie's have high colony and nest site fidelity, returning to the exact same breeding location from previous years (Penney 1968). They also are natally philopatric, meaning they return to the site of their hatching on the year that they first breed (Ainley 2002). This enables their population to be quite predictable.

When the arrive at their breeding site, penguins will locate a mate and construct a nest out of gravel into which 2 eggs are laid, generally in late October (note that October in the Southern Hemisphere is the spring not the fall). The egg is incubated for a month and hatch in late

November. Chicks are watched closely for their first month, but as they grow larger both parents need to forage to feed the chick. The chicks form crèches, a cluster of chicks that huddle together for warmth and protection. Chicks fledge, leave on their own, when they are roughly 2-3 months old. Once a fledgling leaves the parents, they have no future contact or responsibility (Davis 2003). Young penguins will return to the colony in the spring every year, but they will not being breeding until they are 5 years old (Davis 2003).

Adelie penguins have a highly migratory lifestyle spending the summer along the coastline, while in the winter they migrate to the pack ice surrounding the continent (Davis 2003). This migratory lifestyle is necessary for the penguins, as they must always have close access to the ocean for food. The majority of research on Adelie penguins has involved their breeding season, relatively little is known about their winter movements. Breeding colonies are convenient to study due to 24-hour daylight in the Antarctic summer.

Phenomenon

The size of Adelie colonies can vary in size from several dozen to over a hundred thousand. The largest colony is found on Cape Adare on mainland Antarctica and has over 170 000 breeding pairs (Ainley 2002). In these large colonies, space and rocks (for building nests) are at a premium and much squabbling occurs over these precious resources. As climatic conditions are changing, scientists have noticed variations in the ice cover. Areas that previously were covered in permanent pack ice are melting in the spring, while other colony sites are becoming smaller (Micol 2001). Thus breeding sites are more dynamic now than before and new colony establishment is becoming more common. When a group of penguins cannot find a space to breed in an existing colony, they may immediately emigrate to a new beach; or they may not breed for a year and the next year attempt to find a new site. When establishing a

new colony, population dynamics will be quite different from those of an established colony.

The goal of this model is to further understand patterns in penguin colony establishment and predict a minimum number of immigrating adult penguins in order to begin a self-sustaining colony. In order for a new colony to be self-sustaining, the immigrating penguins must produce enough chicks that survive to maturity to replace the adult penguins who perish. There are many factors that are involved in the mortality and survival in penguin colonies, and these must be integrated so that predictions can be made.

Model Construction

The model was an age-structured analytical model that was run on the Similie program.

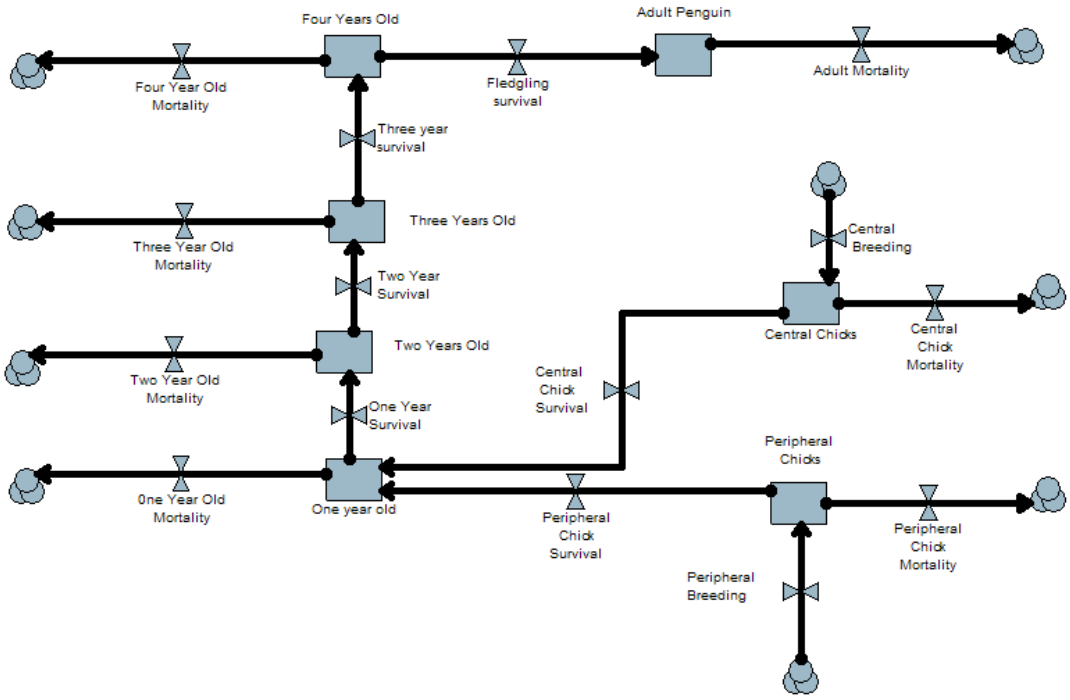


Fig 1. Similie model of Adelie Penguin Colony Establishment

Each age category had a compartment with two flows exiting, the mortality and the survival. The adult penguin compartment was the

value that was adjusted throughout the model as it's initial value represented the number of immigrating penguins. All other initial values were 0. Adult mortality was a combination of winter mortality, and mortality during the breeding season; the average adult mortality was found to be 13% (Davis 2003). The mortality rate and the survival rate always added up to one. For breeding, the average number of eggs per nesting pair was 1.85 (Penney 1968). However the nests were divided up into central nests and peripheral nests. This was to reflect the higher mortality in peripheral nests due to higher predation. As penguins nest in a regular pattern, an equation was developed to determine the number of central nests. (See Appendix 1).

Table 1. Mortality Factors for Various Penguin Age Groups (Davis 2003)

Mortality of Adults:
2.7% adults killed during breeding season
89.2% winter survival
Mortality of Young:
8.9% of eggs fail to hatch
12.9% of chick die due to starvation
6% of eggs in center of colony stolen by skuas
27.1% of eggs on periphery of colony stolen by skuas
10% of chicks in center predated by skuas
30% of chicks on periphery predated by skuas
75% winter survival for fledglings

There were four mortality factors to be considered for chicks: the failure of eggs to hatch, starvation, egg predation, and chick predation. As well, once the fledge, they must survive the harsh Antarctic winters. Peripheral chick mortality was 68.8% while central chick mortality was 49.7%. For fledglings from 1-4 years old the mortality was 25% per year (Davis 2003).

The Similie computer program was used to integrate the various mortality and survival factors in order to predict the outcome of certain immigrating populations of penguins.

Assumptions

There are multiple assumptions built into this model. First of all it is assumed that the nest diameter is 0.79 m (Penney 1968), and that colonies are circular, on flat ground and have a regular pattern. This assumption is valid for smaller colonies (less than 100 nests). On flat ground, the penguins have extremely regular nest patterns. In larger colonies, there is a limited amount of flat ground and penguins nest on more irregular surfaces such as hillsides and rock formations, this leads to variations in nest size. This is an important assumption to make for this model as the nest size is used to determine the number of central and peripheral chicks. As a colony expands, this assumption will become less and less valid. However, as this model only deals with colony establishment, it is acceptable. As well, when colonies expand, generally smaller sub-colonies form within the larger colony (Oelke 1975). This is to provide easier access to the water. If all the nests are crowded together, it would be extremely difficult for birds in the center to reach the beach through the dense mass of birds, none of whom appreciate other penguins walking close to their nest. However, this model assumes that this is not a problem, that the colony is circular, with no sub colonies and that birds in the center do not have an increased mortality from their difficulty in reaching the beach. In a smaller colony this is a valid assumption.

This model also assumes that the penguins begin to breed at age 5. This is an average value, some Adelie penguins begin to breed as early as 3 years old while others breed at age 6 or 7 (Ainley 1980). However, it is easier in this model to assume that the age of first breeding is 5 years old as this is the age that the majority of them begin to breed. It is also assumed that there is an equal number of male and female birds present so that there is no bird 'left out' without a mate.

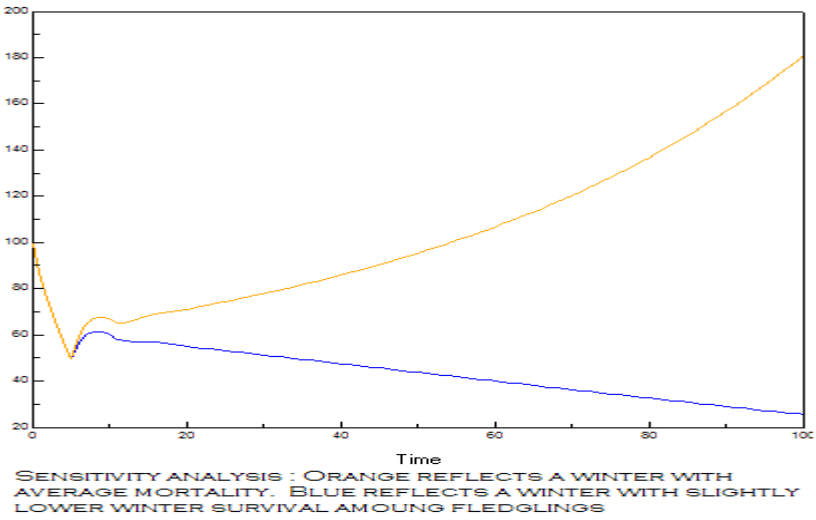
It is assumed that the mortality factors are constant. All of the values here are averages determined by research. Although they are

accurate, they may not reflect the dynamic conditions in Antarctica. An especially harsh or mild winter may have dramatic effects on the mortality of these penguins and so affect colony establishment. However, this is impossible to integrate into the model as yearly mortality values will fluctuate and are not predictable, so average values must be used.

The main difference between survival of chicks in the peripheral and central nests is the predation by skuas. This assumes that skuas are breeding near the colony. It is possible that in the early years of a colony, skuas may not have found this location yet and so may not be breeding there. This would affect the chick mortality. However, as skuas are capable of flight, they will locate the colony eventually. There is no current data as to how soon after a penguin colony is established that skuas begin to breed there, so it was assumed that skuas began nesting in close proximity as soon as the penguins immigrated. Another species interaction assumption made was that there were no other species of penguins mating near or within the colony. It is not uncommon in penguin colonies to have several species, especially Adelie, Chinstrap, Emperor and Gentoo penguins in the same colony.

The last assumption made was that the only immigrating birds to the colony were the ones that came in year 1. There were no new adult birds added to the colony that were not the product of the initial population. In different colonies, this may not be true, and would depend heavily on the proximity of the colony to other colonies.

Techniques to Test the Model



SENSITIVITY ANALYSIS : ORANGE REFLECTS A WINTER WITH AVERAGE MORTALITY. BLUE REFLECTS A WINTER WITH SLIGHTLY LOWER WINTER SURVIVAL AMOUNG FLEDGLINGS

Fig 2

A sensitivity analysis was done to test how the model would be affected by a slight change in mortality values. This is an important test to do as the values used in the model were only averages and in reality would fluctuate significantly over the years. The mortality values were increased for chicks to reflect an especially harsh winter or higher predation and the model was run using the same number of immigrating penguins (100). This test showed that the model and its predictions were actually quite sensitive to changes in mortality. While this is disappointing, it is actually quite an accurate reflection of how penguin populations are affected by nature. A slightly harsher winter can have a huge effect on the population and may be devastating to an establishing colony. Thus any numerical predictions should be viewed as averages not constants.

Insights

The model predicts a minimum number of 44 immigrating adult penguins to establish a colony on a new breeding location. Fig 3. shows

how this was determined. The immigrating penguin population variable was put into the model from 100 penguins to 10, and it was determine that between 40 – 50 immigrants, the results shift from self-sustaining to declining. Populations from 40 – 50 were then graphed and it was found that with 44 immigrants, the penguins will be able to establish a self-sustaining colony.

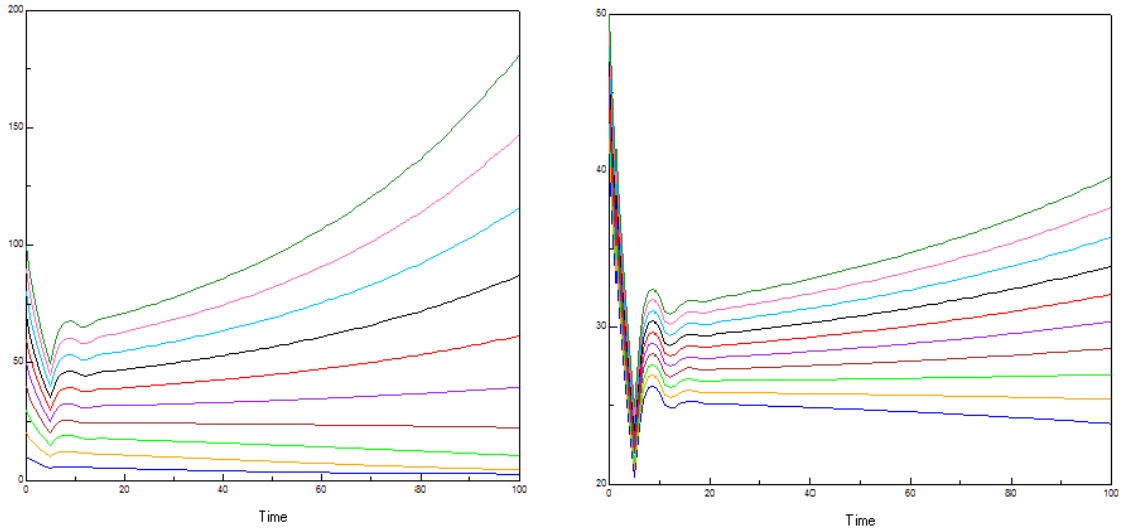


Fig 3. Determination of minimum number of penguins required to establish a colony.

However, the sensitivity analysis reveals that this number will be quite dependant on fluctuations in mortality values and is likely an average value not a constant. Thus the prediction should be interpreted that on average, a self-sustaining colony will have been started with greater than 44 immigrating adult penguins.

The more valuable prediction from the model is the shape of the curve. It remained constant when mortality values were changed. It leads to insights as to how the population will grow (or shrink) during the first few years of a new colony and predicts that all colonies will follow a similar pattern.

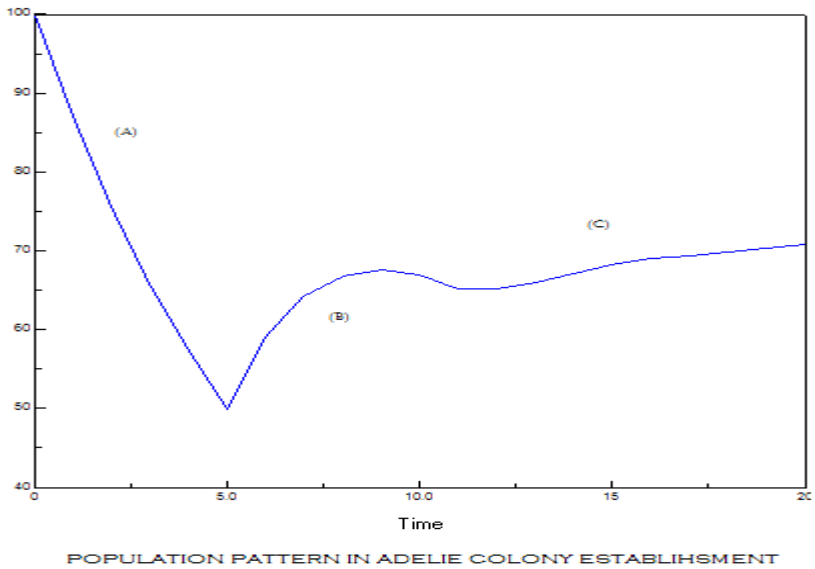


Fig 4.

Part (A) of Fig 4. is the first five years, without new adult immigrants, the adult population declines sharply. This is because while adults are dying no new adults are being added. There is a five year "lag time" as the chicks that were born when the colony first established mature to adulthood. This will be a crucial time for the colony as there must be enough adults to sustain the colony. If too many die then the mortality of young will increase (due to increased predation) and likely the colony will fail or the penguins will immigrate to else where.

Part (B) of the graph is from years 5-10. This shows an increase in adult population as the chicks born in the first 5 years are become breeding adults. However, because the adult population was declined so sharply during those first 5 years, the number of chicks decreases as well. Thus the number of adults added in year 10 is substantially less than in year 5. So the graph levels off, and in some cases the population may actually decrease again as the number of chicks added is not enough to replace the number of adults dying.

In part (C) of the graph the population stabilizes and will steadily increase or decrease. However, this stage in real population may be less

predictable than the first two parts of the graph because it depends on the mortality staying constant which will likely not be the case in nature.

Conclusion

This model was able to predict the yearly changes in penguin population and predict patterns in colony establishment. Although it can not perfectly reflect the infinite variable that penguins will encounter, it does give some insight into how penguins, in such a harsh environment and with such harsh conditions, are able to survive. Colonies are essential to the survival of Adelie penguins but establishing a new colony is difficult. Thus as climates continue to change, and tourism is having a becoming more popular, colony patterns will continue to shift, and this will affect penguin population. There is a very limited amount of research that has been done on new colony formation. Further research should be done into how this increase in new colony formation will affect overall penguin population and breeding success.

References

Ainley, D., De Master, D. 1980. Survival and Mortality in a Population of Adelie Penguins. *Ecology*. 61(3):522-530.

Ainley, D. 2002. *The Adelie Penguin*. New York: Columbia University Press.

Davis, L., Renner, M., 2003. *Penguins*. London: A&C Black Publishers.

Micol, T., Jouventin, P. 2001. Long-term Population Trends in Seven Antarctic seabirds at Pointe Geologie (Terre Adelie): Human Impact compared with Environmental Change. *Polar Biology* 24: 175-185

Oelke, H., 1975. Breeding Behavior and Success in a Colony of Adelie penguins *Pygoscelis adeliae* at Cape Crozier Antarctica. *The Biology of Penguins.* Stonehouse, B., Ed. Baltimore: University Park Press.

Penney, Richard L. 1968 Territorial and Social Behavior in the Adelie Penguin. *Antarctic Bird Studies*. Austin, Oliver. Ed. Washington D.C.: American Geophysical Union.

Similie computer program