Stable Isotope Analysis of Adélie Penguin Bone Collagen: Assessing Ancient and Modern Foraging Grounds in the Ross Sea, Antarctica

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Introduction

Background
There are 3.79 million breeding pairs of Adélie Penguins (Pygoscelis adeliae) in Antarctica [1]. Their diet consists mostly of fish and krill. Adélie penguins return to beaches with ice-free terrain from October–February to breed. The parents take turns foraging to feed 1-2 chicks and cannot travel more than 120 km from breeding grounds to forage as this is energetically costly [2]. Colonies such as Cape Adare and Cape Hallett have little ice cover allowing direct access to the open ocean. For most colonies in the Ross Sea (Fig. 1) this is not the case. During high ice cover Adélie penguins rely on openings in the sea ice called polynyas as their only access to food. There are 3 polynyas in Ross Sea, Antarctica, McMurdo Sound Polynya (MSP), Ross Sea Polynya (RSP), and the Terra Nova Bay Polynya (TNBP; Fig. 1).

Colonies are abandoned due to sea ice blocking beach access, excess snow accumulation over nesting sites, or changes in availability of nearby food resources to feed to their chicks. New openings of ice-free terrain can establish a new colony. Due to lack of information on foraging behavior and tracking throughout history, researchers have not been able to determine causes for past abandonments of many of these colonies. Linking dietary shifts to past and current location of colonies could provide more evidence on the reliance colonies have on current polynyas, reasons for change in migratory patterns, and how future climate trends affect present colonies.

Stable Isotopes
The isotopic composition of penguin tissues reflects the surrounding primary productivity (δ13C), food availability (δ15N), and inshore/offshore foraging (δ34S). Due to low turnover the stable isotope composition of penguin chick bone reflects parental foraging behavior during the first 4 – 7 weeks of its life. Because polynyas have their own unique ecosystem the isotopic composition of penguin chick bones should reflect that of the polynya in which parents forage.

Objectives
The isotopic signatures of polynyas can be used to determine where colonies from hundreds to thousands of years ago foraged and potentially explain why some of those colonies were abandoned such as Cape Ross, Marble Point, Cape Hallett, Campo Icarus, North Adélie Cove, and Cape Barne.

Hypotheses
H1: Existing polynyas in the north, central and southern Ross Sea will each have distinct δ13C, δ15N, δ34S isotopic signatures.

H2: Multiple isotope analyses (δ13C, δ15N, δ34S) of bone collagen from penguin chicks will reflect different parental foraging grounds (polynyas) in the Ross Sea based on colony locations.

H3: Isotopic signatures of polynyas can be tracked over the past 5000 years in the Ross Sea using bone collagen from ancient penguin chick bones and prey remains.

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References

Methods
Study Area and Sample Collection
A total of 155 samples were collected between the austral summers of 2000–2001 and 2019–2020. Adélie penguin chick remains were collected from the surface or by excavation of ornithogenic soils from 27 sites within 14 breeding locations across the Ross Sea, Antarctica (Figs. 2-4). Additional isotope data from 16 bone collagen samples were taken from [3]. For observational analysis, mean calibrated radiocarbon dates from previous research were used for bone samples from corresponding sites and levels to determine if changes in time were influencing stable isotopic values from a given location.

Bone Collagen Extraction
Approximately 0.5–1.0 g of cortical bone was cut into bone chunks, or small pieces weighing less than 15 mg. Bone chunks were demineralized in 0.5M EDTA to extract bone collagen. Bone chunks were treated in 0.1M NaOH and a 2:1 chloroform:methanol solution to remove humic acids and lipids.

Stable Isotope Analyses
Stable carbon and nitrogen isotope analyses were conducted at the University of North Carolina Wilmington Isotope Ratio Mass Spectrometry facility using a Costech 4010 Elemental Analyzer interfaced with a Thermo Delta V Plus Stable Isotope Ratio Mass Spectrometer. For sulfur isotope analysis, 50 samples were analyzed by the University of California Davis Mass Spectrometry facility.

Results & Discussion

Statistical Analyses

Results from the k-means cluster analysis and one-way ANOVA (Figs. 5-7) assigned locations to polynyas. Adélie penguins at Edmonson Point, Campo Icarus, North Adélie Cove, Adélie Cove, and Cape Hallett foraged in the TNBP. Adélie penguins from Beaufort Island, Cape Ross, and Marble Point foraged in the MSP, while those at Cape Barne, Bird, and Crozner, and Franklin Island foraged in the RSP. However, some samples from the same locations were assigned to two or more clusters rather than one. There was a significant positive correlation between all 171 δ 13C and δ 15N values (r = 0.615, P<0.001). There was a strong positive correlation between δ 13C δ 15N, δ 13C δ 34S, and δ 15N δ 34S with samples from <2000 calendar years before present (r = 0.6761947 P= 0.00148; r=0.662555 P=0.02007; r=0.5194245 P= 0.02266). This correlation reflects how offshore foraging is related to higher areas of primary productivity and higher trophic level prey. It is difficult to interpret correlations due to the small sample size of samples from this time periods due to these three variables changing annually from sea-ice cover.

Future research should include bone samples from a wider range of time periods to determine how differences in time compared to geographical factors are affecting isotopic signatures of the three polynyas.