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Peruvian Pinnipeds as Archivist of ENSO Effects off the Coast of Peru

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Background

- Peruvian fur seals (PFS) are a genetically isolated subspecies of South American fur seals, distributed between the southern coast of Peru and northern coast of Chile, with a major breeding colony located in Punta San Juan (PSJ), part of the RNSIIPG marine protected network (Figure 1).
- The South American coastal upwelling ecosystem extends from 4˚S to 40˚S.
- High 1˚ productivity results from strong upwelling currents.
- PFS show strong site fidelity to their rookeries and forage within the strong upwelling ecosystem year round.
- The Eastern Pacific Ocean is subject to strong environmental fluctuations in the form of the El Niño-Southern Oscillation (ENSO) events.

What is an ENSO event?

- ENSO is an alternating cycle of warm and cold phases evidenced by sea surface temperature (SST) in the tropical central and eastern Pacific Ocean.
- The precursor to the ocean temperature changes begins when the southeast trade winds weaken, thereby decreasing the upwelling strength of cold, nutrient-rich water.
- The warm SST phase is referred to as El Niño and the cooler SST phase is known as La Niña.
- ENSO events are classified through indices that rank the magnitude and duration of the SST anomalies.
- The Niño 1+2 region is the smallest and eastern-most of the Niño SST regions (0-10°S, 90°W-80°W), developed to understand the effects of ENSO on the coast of Peru (Figure 1).
- This index shows the largest variance of the Niño SST indices (Figure 2).

Figure 1. Map of Punta San Juan, and its location in Peru and South America. Red square shows the region of coastal waters of El Niño index 1+2 region. (Map adapted from Cárdenas-Alayza 2012.)

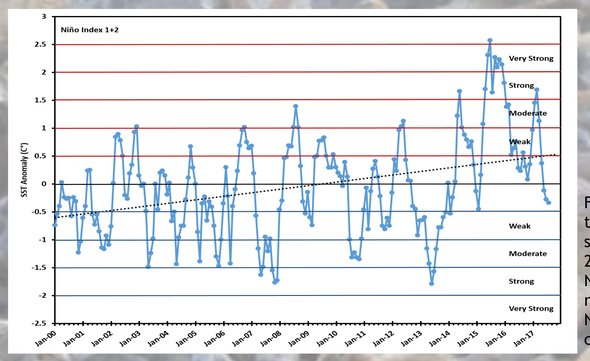

Figure 2. Sea surface temperature (SST) anomaly time series for Nino index 1+2 from 2000 to present date (Data: NOAA, 2017). Positive anomalies represent warm periods (El Niño) and negative anomalies cold periods (La Niña).

- During the mid-1900s PFS were nearly extirpated due to commercial hunting.
- PFS abundances increased after sealing ban, until 1997 when Peru suffered from the largest ENSO event on record.
- The 1997/98 ENSO event corresponded with an over 65% population decline, but definitive cause for the decline could not be isolated.
- The vulnerable PFS continue to show signs of declines, most likely in relation to periodic ENSO events in synergy with competition with fisheries.

What are $\delta^{13}C$ and $\delta^{15}N$?

- Consumer tissues contain a higher ratio of carbon and nitrogen isotopes (isotopically enriched) than prey tissue.
- Carbon isotope ratios ($\delta^{13}C$) are slightly enriched (0.5 – 1.1‰) per trophic level.
- Nitrogen isotope ratios ($\delta^{15}N$) change with trophic level in a predictable manner and are enriched ~3-5‰ per trophic level. All stable isotope (SI) values are reported) as:

$$\delta\ (‰) = [(R_{sample} * R_{standard})\text{-}1] * 1000$$

Figure 3. Example of vibrissae (whisker) extraction for SI on a sea lion.

Methodology

- Peruvian fur seal vibrissae (whisker) samples were pulled from live animals by wildlife veterinarians every November (from years 2010 (n=29), 2011 (n=12), 2012 (n=11) and 2015 (n=12)) during pinniped health assessments (Figures 3 and 4).
- Vibrissae were analyzed for stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios.
- The base of the vibrissae represents the newest growth.
- PFS prey items have been obtained from a local fishing market proximate to PSJ in Marcona, Ica, Peru.
- Potential prey species were analyzed for stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios.
- Additional stable isotope values for prey items were compiled from literature (Espinoza et al. 2017).
- All samples were analyzed for $\delta^{13}C$ and $\delta^{15}N$ using a mass spectrometer at the Museum Support Center (MSC) Smithsonian Institution, Suitland, MD.

Figure 4. Collection of tissue samples in Punta San Juan Reserve, Peru.

Results

- All PFS vibrissae demonstrate oscillating $\delta^{13}C$ and $\delta^{15}N$ patterns.
- Vibrissae demonstrate multi-year growth estimated growth rate is 0.09 mm/day (Kelleher 2016; Foley 2017) (Figure 5).
- Periodic inverse relationships occur along vibrissae of all PFS samples.
- Periods of inverse relationship in $\delta^{13}C$ and $\delta^{15}N$ coincide with strong El Niño and La Niña events. These events most often corresponded with either the most enriched (max) or the most depleted (min) $\delta^{13}C$ and/or $\delta^{15}N$, indicating changes in ocean production and potential dietary changes.
- $\delta^{15}N$ will correspond to individual dietary preferences. High $\delta^{15}N$ values (max) currently do not correspond to any acquired coastal prey items. Low $\delta^{15}N$ values (min) corresponds to species from order Perciformes (grunts, sea bass, mackerel) (Figure 7).

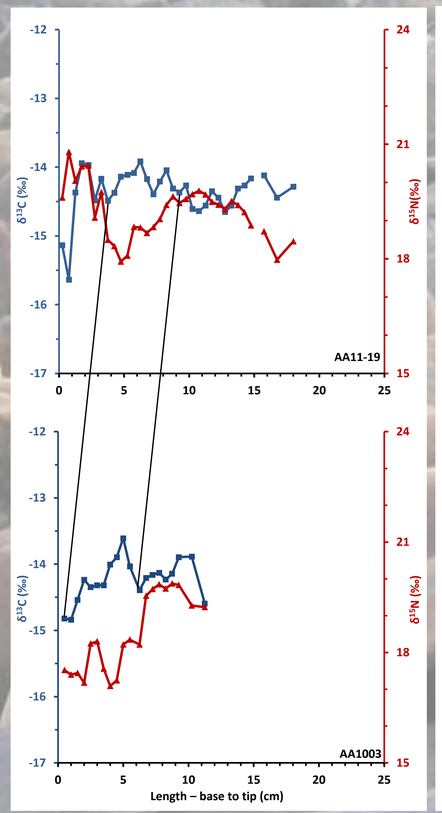

Figure 5. Plot A and B represents $\delta^{13}C$ (blue) and $\delta^{15}N$ (red) in a pulled PFS vibrissae. The length of vibrissae between the two black lines refers to approximately two years of strong La Niña SST anomalies.

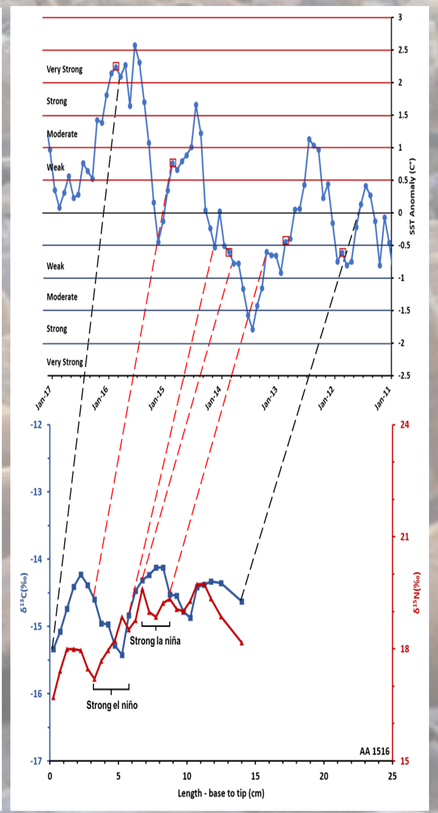

Figure 6. Plot A shows SST anomalies over time. Plot B shows vibrissae SI values. Black dashed lines reveal time frame vibrissae represents. Red dashed lines show how periods of inverse relationship in $\delta^{13}C$ (blue) and $\delta^{15}N$ (red) coincide with strong El Niño and strong La Niña events.

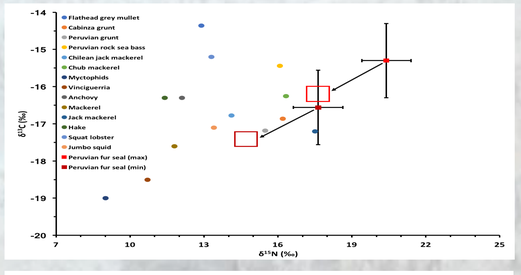

Figure 7. Enriched (max) and depleted (min) vibrissae stable isotope values compared to potential coastal prey items. Vibrissae $\delta^{13}C$ values were corrected for 1.5‰ keratin enrichment. Prey SI data for myctophids through jumbo squid were from Espinoza et al. 2017.

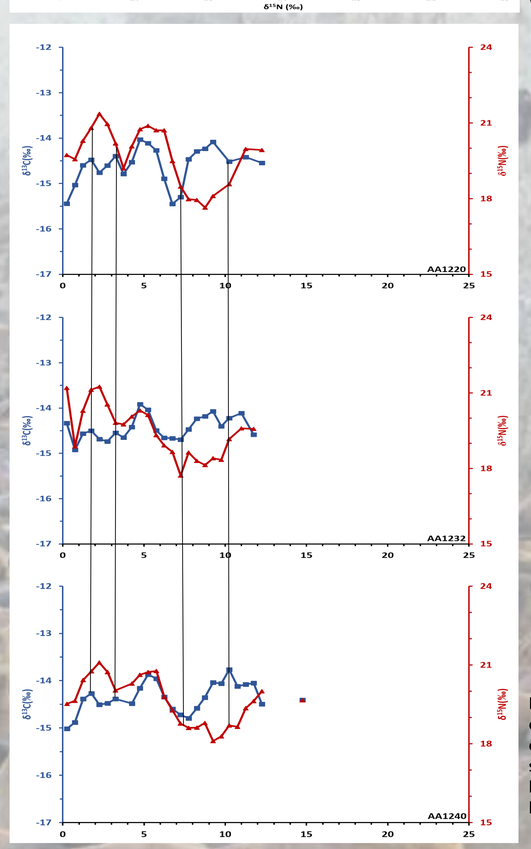

Figure 8. Three PFS vibrissae show consistent patterns in $\delta^{13}C$ and $\delta^{15}N$ expressed among all adult female fur seals in all years sampled. The solid black lines represent similarities between individuals.

Key Findings

- SST anomaly trend since 2000 from ENSO index Nino 1+2 increased over 1°C (Figure 2).
- All PFS vibrissae demonstrate covarying multi-year oscillations with periodic inverse relationships. Distinct annual isotopic patterns in the vibrissae were expressed by all sampled PFS (Figures 5 and 8).
- Periods of inverse relationship in $\delta^{13}C$ and $\delta^{15}N$ coincide with strong El Niño and strong La Niña events (Figure 6).
- Periods of inverse relationships appear to correspond to ENSO events which seem to alter potential prey items. These dietary changes offer the first clues to changes in foraging, and likely survival, strategies.

Future Research

- Develop an understanding of the local marine environment by creating a food web for the Punta San Juan marine protected area via collection of coastal flora and fauna. This will help determine potential alternate foraging strategies.
- Complete an on-going growth rate study of vibrissae to accurately establish timelines.
- Analyze tissues from dam-pup pairs to help determine adult female foraging patterns while pups are in utero. The high mortality rate in pups during ENSO events makes this information critical.
- Analyze the collected 2016 PFS vibrissae for evaluation of the 2015/16 ENSO event, the strongest recorded since 1997/98.

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