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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 3.4 region is the smallest and eastern-most of the Niño SST regions (15°S–5°N, 120°–170°W), developed to understand the effects of ENSO on the coast of Peru (Figure 1).
- This index shows the largest variances of the Niño SST indices (Figure 2).

Methods
- Peruvian fur seal vibrissae (whisker) samples were pulled from live animals by wildlife veterinarians every November (from years 2010 (n=229), 2011 (n=12), 2012 (n=11) and 2015 (n=12)) during pinniped health assessments (Figures 3 and 4).
- Vibrissae were analyzed for stable carbon (δ13C) and nitrogen (δ15N) 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 (δ13C) and nitrogen (δ15N) isotope ratios.
- Additional stable isotope values for prey items were compiled from literature (Espinoza et al., 2017).
- All samples were analyzed for δ13C and δ15N using a mass spectrometer at the Museum Support Center (MSC) Smithsonian Institution, Suitland, MD.

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

Figure 1. A 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. (adapted from Cárdenas-Alayza 2012)

Figure 2. Sea surface temperature (SST) anomaly time series for Hendrix et al. (2000) to present data (Honomichl 2017). Positive anomalies represent warm periods (El Niño) and negative anomalies (La Niña) periods as Niño.)

Figure 3. Example of vibrissa (whisker) extraction for Si on a sea lion.

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

Figure 5. Plot A and B represent 13C (blue) and 15N (red) in a pulled PFS vibrissa. The length of vibrissa 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 vibrissa δ13C values. Black dashed lines reveal time frame vibrissa enrichment. Red dashed lines show how periods of inverse relationship in 13C (blue) and 15N (red) coincide with strong El Niño and strong La Niña events.

Figure 7. Enriched (max) and depleted (min) vibrissa stable isotope values compared to potential coastal prey items. Vibrissae δ13C 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 13C and 15N depleted 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 Niño 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 13C and 15N 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 vibrissa for evaluation of the 2015/16 ENSO event, the strongest recorded since 1997/98.

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