Satellite Driven Studies of Climate-mediated Changes in Antarctic Food Webs

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Matthew Oliver, Megan Cimino, Andrew Irwin, William Fraser, Josh Kohut, Oscar Schofield, Mark Moline, et al.
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Larger starting prey supports large predators with fewer trophic steps.

Changes in lower trophic levels could be transferred to upper trophic levels.

Azam et al., 1983
West Antarctic Peninsula is Rapidly Warming
Recent Changes in Phytoplankton Communities Associated with Rapid Regional Climate Change Along the Western Antarctic Peninsula

The changes in phytoplankton are at least regional (West Antarctic Peninsula)

Fig. 2. Variation of phytoplankton biomass, composition, and cell size distribution over the WAP region. (A) Average of pixel-by-pixel absolute difference ($t_i - t_o$) in satellite-derived chlorophyll a concentration [$d\text{Chl}_a^{(\text{present-past})} = \text{Chl}_a(t_i) - \text{Chl}_a(t_o)$] between the mean January observations for 1978 to 1986 ($t_o$) and mean January observations for 1998 to 2006 ($t_i$). Positive (negative) $d\text{Chl}_a$ corresponds to an increase (decrease) of Chl$_a$ with respect to the 1970s. Negative (by a factor of -2, northern subregion, lower histogram) and positive (by a factor of ~1.5, southern subregion, upper histogram) trends in Chl$_a$ are evident in the satellite data. $N_{\text{bin}}/N_{\text{mode}}$ is the relative frequency of observations per bin, normalized by the mode. Gray pixels indicate areas without data or without valid geophysical retrieval due to cloud and sea ice contamination; black pixels indicate land. (B) Histograms of contribution of diatoms (fucoxanthin marker) and phytoplankton communities dominated by large ($>20\ \mu\text{m}$) versus small ($<20\ \mu\text{m}$) cell diameter to total in situ chlorophyll a concentration ($\text{Chl}_a^{\text{in situ}}$). Phytoplankton cell size spectra were computed from satellite imagery (1998 to 2006) (16), and phytoplankton pigments were measured over the northern and southern WAP subregions and during 1993 to 2006 Palmer-LTER cruises. Number of samples used to construct each histogram shown in parentheses.
Changing Phytoplankton Community Composition in the WAP

Alteration of the food web along the Antarctic Peninsula in response to a regional warming trend

MARK A. MOLINE*, HÉRVE CLAUSTRE†, THOMAS K. FRAZER‡, OSCAR SCHOFIELD§ and MARIA VERNET¶

Prey Items are changing with changing ice in the WAP.

**Figure 22.** Ratio of mean abundances of salps to Antarctic krill (N > 1000 m⁻³) as a function of the regional sea-ice index (open circles) and mean air temperature for the Antarctic Peninsula (closed circles). Drawn from Table 1 in Loeb et al. (1997).
Penguins are following suit with the change

NASA funded review of the system.
Short Food Webs Increase Chance of Prediction
Hypothesis: Environment Predicts Populations of Penguins

\[ \Delta Penguin = \beta \cdot \Delta Environment + \epsilon \]

The error term encapsulates small scale or cyclical environmental variation, and any top-down component. This is a bottom-up approach.
Look for places with big climate perturbations

West Antarctic Peninsula is Loosing Ice During the Summer Months (Winter too)
Look for places with big climate perturbations

West Antarctic Peninsula is Warming up during Summer Months
Look for places with big climate perturbations

Chlorophyll isn’t as clear of a signal on big scales
Problem

We have penguin location information, but not many population counts

\[
P(+\text{Penguin} \mid \text{Environment}) = \frac{P(\text{Environment} \mid +\text{Penguin})P(+\text{Penguin})}{P(\text{Environment})}
\]

Change the terms of the hypothesis

The probability of finding a specific penguin species dependent on the environment

Sets up a nice natural experiment between the WAP and the Continent

So Far, we have decent estimates of

\[
P(+\text{Penguin})
\]

\[
P(\text{Environment})
\]
$$P(+\text{Penguin} \mid \text{Environment}) = \frac{P(\text{Environment} \mid +\text{Penguin}) P(+\text{Penguin})}{P(\text{Environment})}$$

**Satellite Driven Niche Space of Chick Rearing Habitat (CRH)**

- Sea ice (%)
- Sea surface temperature (°C)
- Chl (mg chl·m$^{-3}$)
- Bathymetry (m)
Satellite Driven Niche Space of Chick Rearing Habitat (CRH)

\[ P(+\text{Penguin} \mid \text{Environment}) \]

1978-1984
Quantify the distribution and the **30 year trend** of CRH Niche Space

**So What?**

- **Adelie Penguin**
- **Gentoo Penguin**
- **Chinstrap Penguin**
Problem

$$\Delta Penguin = \beta \cdot \Delta Environment + \varepsilon$$

We have a lot of location information for penguins, not but sparse records for penguin counts.

$$CRH = P(+Penguin \mid Environment)$$

We can collapse the environment to an expected time series of penguin probabilities (CRH)

$$\Delta Penguin \approx \beta \cdot CRH + \varepsilon$$

We can treat Penguin as a factor, and determine if CRH is the same across each factor (ANOVA)
Problem

Hypothesis: Environment Predicts Populations of Penguins

\[ \Delta Penguin \approx \beta \cdot CRH + \varepsilon \]

The error term encapsulates small scale cyclical environmental variation, and any top-down component.
The Plan

- Satellite Tags
- Mission Planning
- ARGOS Position
- Deployment
- Assessment
Near-Real Time Mapping of Penguin Foraging Locations
Letting Penguins Lead: Dynamic Modeling of Penguin Locations Guides Autonomous Robotic Sampling

BY MATTHEW J. OLIVER, MARK A. MOLINE, IAN ROBBINS, WILLIAM FRASER, DONNA PATTERSON, AND OSCAR SCHOFIELD
Where did the Adélie penguins go?
Results from 2011 Field Season

Krill

Diurnal

Semi-Diurnal
Adélie Penguin Foraging Location Predicted by Tidal Regime Switching

Matthew J. Oliver¹*, Andrew Irwin², Mark A. Moline¹, William Fraser³, Donna Patterson³, Oscar Schofield⁴, Josh Kohut⁴
The Hypothesis
Penguin Foraging Location is Driven by Tide Regime

\[ \text{Foraging} = \beta \cdot \text{tide regime} + (1 \mid \text{trip}) + \varepsilon \]

Tide Regime $\sim$ Krill Density

Tidal Currents are strong enough to concentrate Krill

Courtesy: Travis Miles
Spatial Evidence of Tidal Influence
Future Work
Bring Down HF RADAR
Revisiting Original Model

\[ \Delta Penguin = \beta \cdot \Delta \text{Environment} + \epsilon \]

The error term encapsulates small scale or cyclical environmental variation, and any top-down component. This is a bottom-up approach.

\[ \Delta Penguin = \beta \cdot \Delta \text{Environment} + \eta \cdot \text{Tides} + \epsilon \]

- Implicit Climate Signal
- Implicit Resource Concentrating Signal
- Non-Climate Signal

So What?
Let’s speculate

Tidal Concentrating?

Warming Climate?

Length Scale (concentration) of prey

Trophic level
Future work

Does mesoscale variability provide refuge from a changing climate?

$$\Delta Penguin = \beta \cdot \Delta BigScale + \eta \cdot LocalScale + \epsilon$$

Implicit Climate Signal

Mesoscale Variability

Working with
Josh Kohut (Rutgers)
Bill Fraser (Polar Oceans)
Peter Winsor (U of Alaska)
Kim Bernard (OSU)
Megan Cimino (UD)

See Poster!