Hare and Mantua updated: Four decades of climate-biology covariation in the northeast Pacific

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Climate-biology covariation in the NE Pacific
Climate-biology covariation in the NE Pacific

Are there basin-scale biological effects of global warming?

Variable sea ice cover
Seasonal hypoxia

Mean global temperature (HadCRUT3)

Temperature wrt 1961-1990 (°C)

Climate-biology covariation in the NE Pacific

Is the Pacific Decadal Oscillation still biologically important?

1988-89 shift
Winter Victoria score

Climate-biology covariation in the NE Pacific

Has the Victoria pattern become biologically important?

Victoria Pattern

1988-89 shift
Updated climate & biology time series from Hare and Mantua (2000)

Questions

1) Which climate indices regulate NE Pacific biology?
   - Test hypothesis of anthropogenic climate effect

2) What are recent changes in ecosystem services?
   - Test for shifts in updated time series
66 Biological time series 1965-2007

- **S** salmon catch, lagged to ocean entry year
- **G** groundfish recruitment, lagged to cohort year
- **P** small pelagic catch/recruitment, lagged to cohort year
- **I** invertebrate abundance/growth
- **B** seabird reproductive success
- Division based on regional PC1 loadings
- Allows for hypotheses of region-specific climate control
PC1 – 34% of variance
PC2 – 11% of variance

Alaska

PC1 – 34% of variance
PC2 – 11% of variance

West Coast

PC1 – 34% of variance
PC2 – 11% of variance
1. Climate forcing

**Elucidating climate forcing**

**Approach**

Response variables: Alaska & West Coast biology PC1 & PC2

Explanatory variables:

- Alaska:
  - Global temp. (HadCRUT3)
  - Winter PDO
  - Annual Arctic Oscillation
  - Annual Multivariate ENSO Index

- West Coast:
  - Global temp. (HadCRUT3)
  - Winter PDO
  - Winter Victoria Pattern
  - Annual Multivariate ENSO Index

Smoothed – 3 yr running mean

**Winter PDO**

- Annual values
- 3-yr running mean

Graph showing PDO score from 1965 to 2005.
1. Climate forcing

**Elucidating climate forcing**

**Approach**

Competing Generalized Additive Models for each biology PC

Models chosen by rewarding parsimony and predictive ability

Parameter smoothness limited ($k = 3$) to avoid over-fitting model
1. Climate forcing

Alaska biology PC1

PC1 ~ s(PDO) + s(AO) + s(global temp)

Model $R^2 = 0.87$
Residuals AR1 = 0.10
1. Climate forcing

**Alaska biology PC2**

PC2 ~ s(global temp) + s(PDO) + s(AO) + s(ENSO lag1)

![Graphs showing the effect of various climate forcings on PC2](image)
1. Climate forcing

West coast biology PC1

PC1 ~ s(global temp) + s(Victoria)

Model $R^2 = 0.82$
Residuals $AR1 = 0.29$
1. Climate forcing

**West coast biology PC2**

1965-1988: PC2 ~ s(PDO) + s(ENSO lag0)
1989-2007: PC2 ~ s(global temp)

**Pre-1988/89**
Model $R^2 = 0.65$
Residuals AR1 = 0.17

**Post-1988/89**
Model $R^2 = 0.54$
Residuals AR1 = -0.22
1. Climate forcing

But...

• Autocorrelation may inflate df (residuals autocorrelated at AR1 = -0.22 – 0.44)

• Chance of spurious results when fitting linear global warming trend to community variability (e.g., due to anadromous habitat loss, exploitation)
1. Climate forcing

The next step (if climate correlation results are robust): hypothesizing effects on individual populations

• 1976/77 PDO regime shift had general “winners” (e.g., Alaska groundfish & salmon) and “losers” (e.g., Alaska crustaceans)

• Correlations between individual time series and PC score in this study can be used to generate hypotheses of global warming “winners” and “losers”

• Provides a conceptual framework for developing mechanistic understanding of global warming effects on individual populations
1. Climate forcing

Hypothesizing global warming effects on individual populations

Gulf of Alaska
Arrowtooth flounder

Eastern Bering Sea
Chinook salmon

Global temperature anomaly (° C)
2. Recent shifts

Recent change in ecosystem services

STARS-defined states
α = 0.05, adjusted for autocorrelation
Length of proposed ‘regimes’ = 10 yr

Error bars ± 2 SD (multiple imputation to estimate missing values)
2. Recent shifts

Recent change in ecosystem services

West coast biology PC1

West coast biology PC2

PC Score

PC Score


STARS-defined states

$\alpha = 0.05$, adjusted for autocorrelation

Length of proposed ‘regimes’ = 10 yr

Error bars ± 2 SD (multiple imputation to estimate missing values)
Implications

**Question 1: Elucidating climate forcing**

1) Preliminary results, need to consider possibility of spurious results / autocorrelation influence

2) Victoria Pattern correlates with upper trophic level status (West Coast PC1) - extend understanding of North Pacific Gyre Oscillation to upper trophic levels?

3) Global warming correlates with NE Pacific ecosystem variability

1) Correlations between individual time series & PC scores suggest hypotheses for understanding population-level global warming effects
Question 2: Testing for recent shifts

1) Recent shifts in Alaska PC1 & PC2 appear transient

2) STARS indicates possibility of incipient shifts in West Coast PC1 & PC2
For help in accessing data sets, we thank: Jennifer Boldt, Jen Bowen, Greg Buck, Melissa Carter, Paul Crone, Sherri Dressel, Michael Folkes, Dana Hanselman, Amy Hays, Jim Ianelli, Jim Ingraham, Bruce Kauffman, David Mackas, Steve Moffitt, Paul Spencer, Bill Sydeman, Grant Thompson, Dan Urban, John Wallace and Muyin Wang.

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3. Predicting future change

Implications for predicting future biological change
3. Predicting future change

Understanding of past climate-biology covariation
How good is prediction based on the past? A 20-year test

3. Predicting future change

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**Alaska PC1 and PC2**

**West Coast PC1 and PC2**

- **Data**
- **Model prediction**

![Graphs showing principal component scores for Alaska and West Coast over time](image-url)
3. Predicting future change

Predictions based on first 20 years of data

- **Alaska PC1**
- **West Coast PC1**
- **Alaska PC2**
- **West Coast PC2**
3. Predicting future change

Possible sources of “ecological surprise”

• Incomplete set of possible system configurations observed

• Internal ecosystem mechanisms (e.g., trophic control, competition, temperature-fitness relationships) not static in time
3. Predicting future change

Sources of ‘ecological surprise’

Modeling the past based on current observations also problematic
3. Predicting future change

**Sources of ‘ecological surprise’**

Modeling the past based on current observations also problematic
Implications

Goal 3: Making inferences about predictive capability

1) No confidence in which climate-biology models have predictive ability over short time scales

2) Need to account for novel system configurations and changing mechanistic relationships when predicting future biological state
Sources of ‘ecological surprise’

Understanding based on incomplete set of possible system configurations

3. Predicting future change

Climate autocorrelation

PDO & Alaska biology

First-order autocorrelation coefficient (AR1)

PDO
Victoria Pattern

Alaska biology PC1

PDO (3-yr running mean)

1965-1988

1965-1976
1977-1988
3. Predicting future change

Sources of ‘ecological surprise’

Understanding based on incomplete set of possible system configurations
Sources of ‘ecological surprise’

No ‘balance of nature’ in ecosystem mechanics

Different factors regulate population in each state

20th Century climate forcing of NE Pacific ecosystems – mostly the PDO

Example from Hare and Mantua 2000
Annual PDO score

The 21st Century...

PDO

Biology PC1

Biology PC2

Standard anomaly

The 21st Century...

- PDO
- Biology PC1
- Biology PC2
The 21st Century...

- Victoria
- Biology PC1
- Biology PC2

Winter Victoria score

Standard anomaly
The 21st Century...

Hare and Mantua 2000 - PCA of 69 biological time series, 1965-1997

Mean global temperature (HadCRUT3)

Biology PC1

Biology PC2

Temperature wrt 1961-1990 (°C)

Standard anomaly

3. Predicting future change

Sources of ‘ecological surprise’

Non-additive climate-biology relationships
Elucidating climate forcing

**Approach**

Test hypothesis that anthropogenic climate change regulates biology

Explanatory variable = global average land and sea temperature

- Better measure of anthropogenic forcing than global or N. Pacific SST

- Climate index should be >> scale than ecosystem of interest (Hallett et al. 2004. Nature)

- Less likely to be correlated with PDO, Victoria Pattern than N. Pacific SST
Elucidating climate forcing

**Approach**

Competing Generalized Additive Models for each biology PC

- Best model constructed with PDO / Victoria / AO / global temp.
- Attempted to improve model with Multivariate ENSO Index lag 0-2
- Models chosen by minimizing Generalized Cross Validation score, similar to AIC
3. Predicting future change

Predictions based on first 20 years of data

Prediction ability over time

Root mean squared error (scaled to observed data)

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<thead>
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<tbody>
<tr>
<td><strong>Observed</strong></td>
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<tr>
<td><strong>Predicted:</strong></td>
<td>1-10 years in future</td>
<td>11-20 years in future</td>
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- **Predicted:**
  - 1965-1984: Observed data
  - 1985-1994: Predicted: 1-10 years in future
  - 1995-2004: Predicted: 11-20 years in future
3. Predicting future change

Sources of ‘ecological surprise’

Understanding based on incomplete set of possible system configurations
Elucidating climate forcing

**Approach**

Response variables: Alaska & West Coast biology PC1 & PC2

Explanatory variables:

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- Seabird reproductive success

Dominated by early-life history processes

Strongly affected by non-climate mechanisms

Exploitation & over-exploitation

Should provide short-lag response to climate forcing
1. Climate forcing

Caveat!
Potential for spurious global warming effects

![Graph showing AK total fisheries catch and global temp anomaly (3-yr mean)]