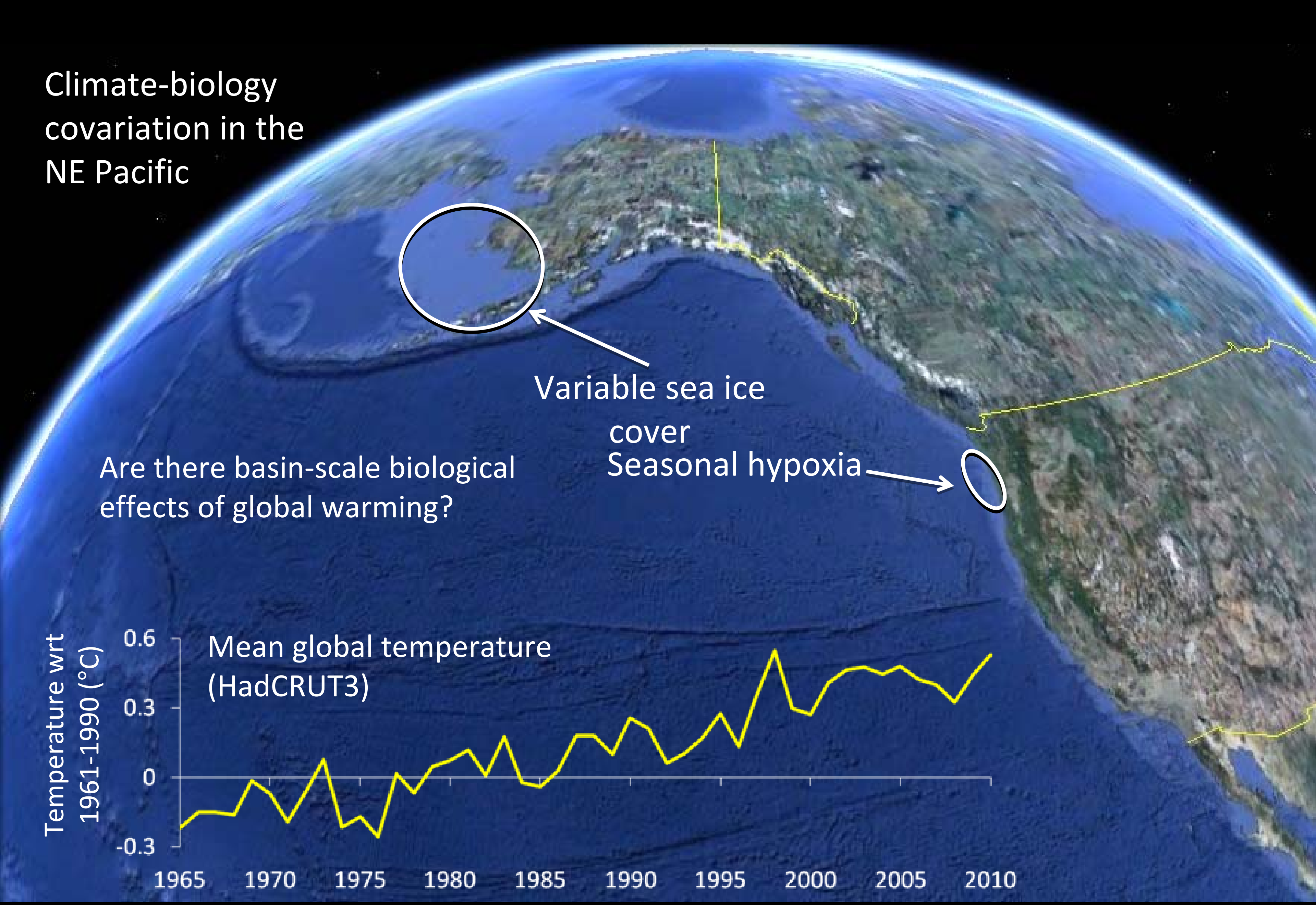
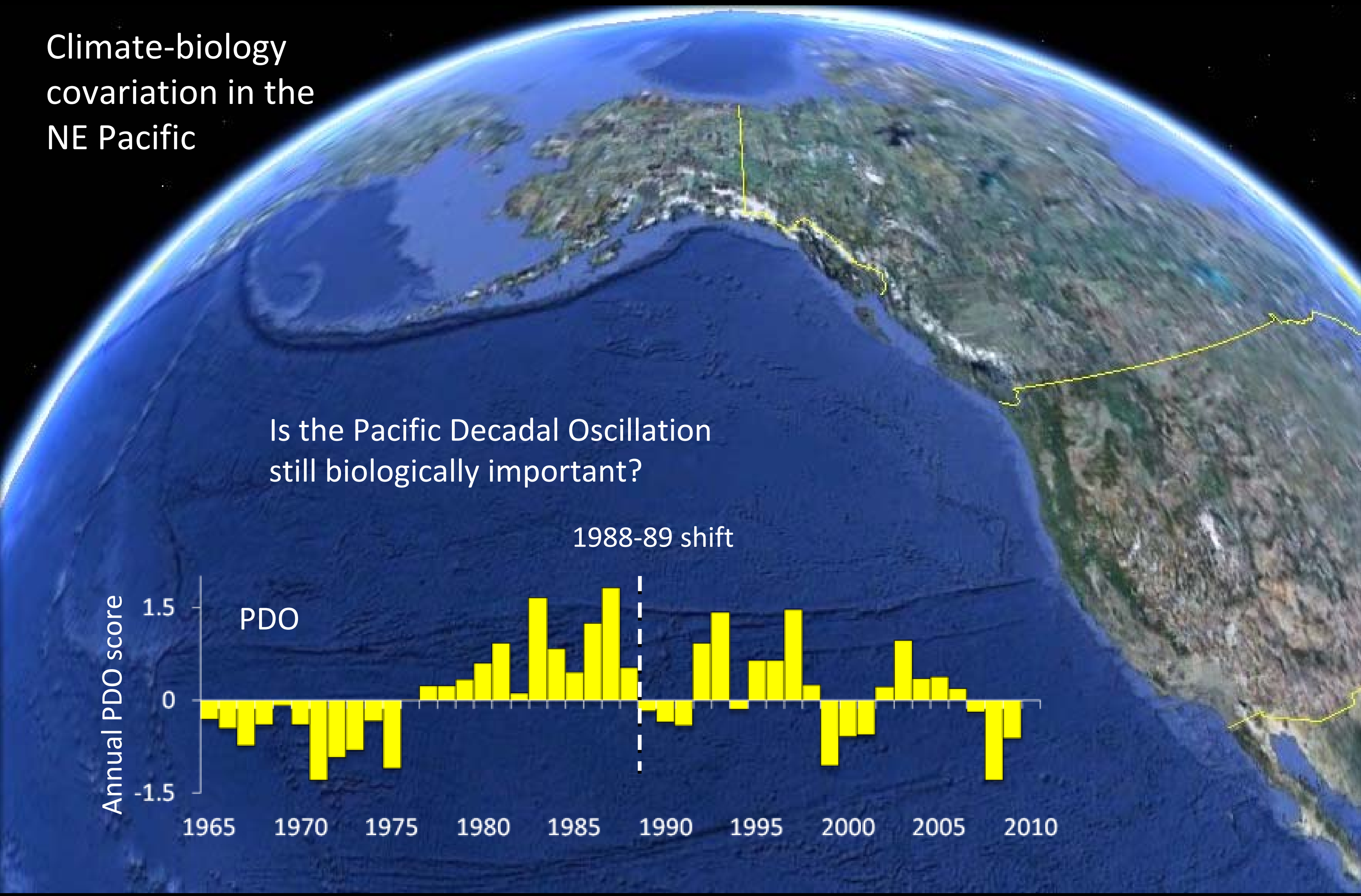
Hare and Mantua updated: Four decades of climate-biology covariation in the northeast Pacific

Mike Litzow
Blue World Research, Anchorage, AK, USA
University of Tasmania, Hobart, TAS, Australia

Franz Mueter
School of Fisheries and Ocean Sciences
University of Alaska Fairbanks, Juneau, AK, USA

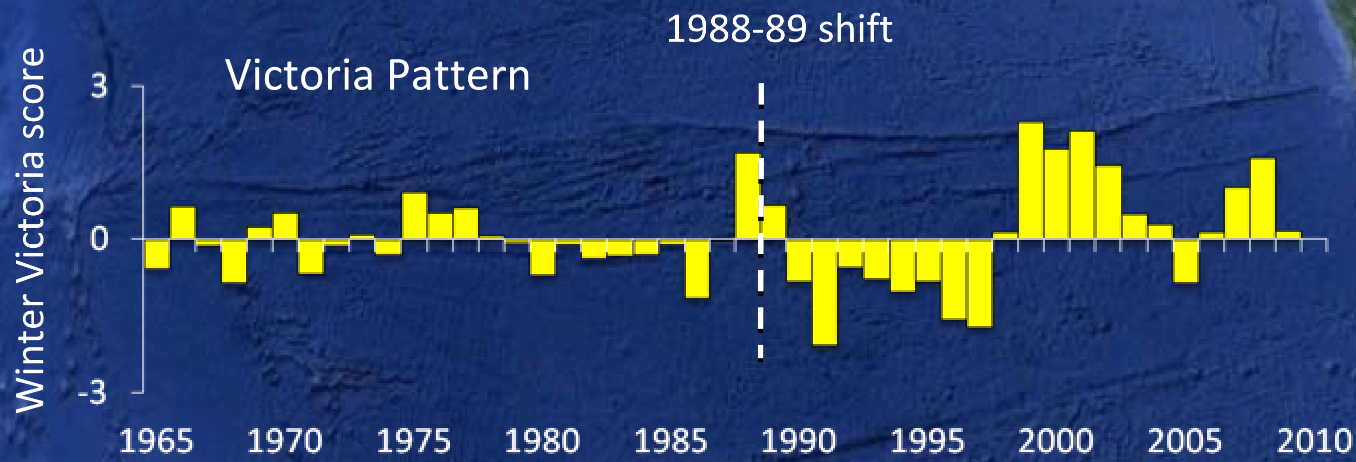
Climate-biology covariation in the NE Pacific


Climate-biology covariation in the NE Pacific
Variable sea ice cover
Seasonal hypoxia
Are there basin-scale biological effects of global warming?
Mean global temperature (HadCRUT3)
Temperature wrt 1961-1990 (°C)
0.6
0.3
0
-0.3
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010


Climate-biology covariation in the NE Pacific
Is the Pacific Decadal Oscillation still biologically important?
1988-89 shift
PDO
Annual PDO score
1.5
0
-1.5
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

Climate-biology covariation in the NE Pacific

Has the Victoria pattern become biologically important?



Updated climate & biology time series from Hare and Mantua (2000)

Pergamon

Progress in Oceanography 47 (2000) 103–145

Progress in Oceanography

www.elsevier.com/locate/pocean

Empirical evidence for North Pacific regime shifts in 1977 and 1989

Steven R. Hare [a,*], Nathan J. Mantua [b]

[a] International Pacific Halibut Commission, P.O. Box 95009, Seattle, WA 98145-2009, USA

[b] Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Box 354235, Seattle, WA 98195-4235, USA

Abstract

It is now widely accepted that a climatic regime shift transpired in the North Pacific Ocean in the winter of 1976–77. This regime shift has had far reaching consequences for the large marine ecosystems of the North Pacific. Despite the strength and scope of the changes initiated by the shift, it was 10–15 years before it was fully recognized. Subsequent research has suggested that this event was not unique in the historical record but merely the latest in a succession of climatic regime shifts. In this study, we assembled 100 environmental time series, 31 climatic and 69 biological, to determine if there is evidence for common regime signals in the 1965–1997 period of record. Our analysis reproduces previously documented features of the 1977 regime shift, and identifies a further shift in 1989 in some components of the North Pacific ecosystem. The 1989 changes were neither as pervasive as the 1977 changes nor did they signal a simple return to pre-1977 conditions. A notable feature of the 1989 regime shift is the relative clarity that is found in biological records, which contrasts with the relative lack of clear changes expressed by indices of Pacific climate. Thus, the large marine ecosystems of the North Pacific and Bering Sea appear to filter climate variability strongly, and respond nonlinearly to environmental forcing. We conclude that monitoring North Pacific and Bering Sea ecosystems may allow for an earlier identification of regime shifts than is possible from monitoring climate data alone. © 2000 Published by Elsevier Science Ltd.

Contents

1. Introduction 104

* Corresponding author. Tel.: +1 (206) 634-1838; fax: +1 (206) 632-2983.
E-mail address: hare@iphc.washington.edu (S.R. Hare).

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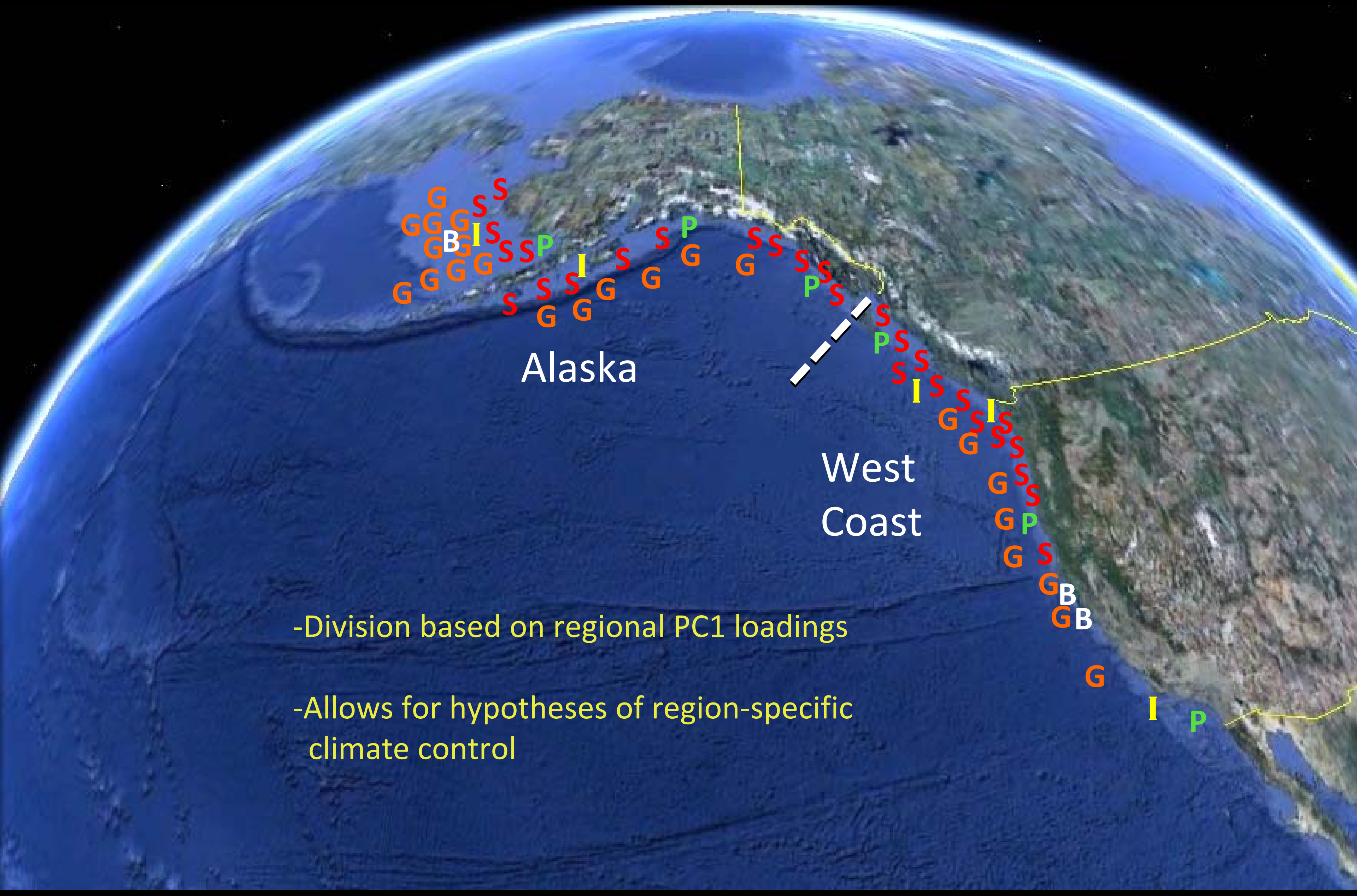
PII: S0079-6611(00)00033-1

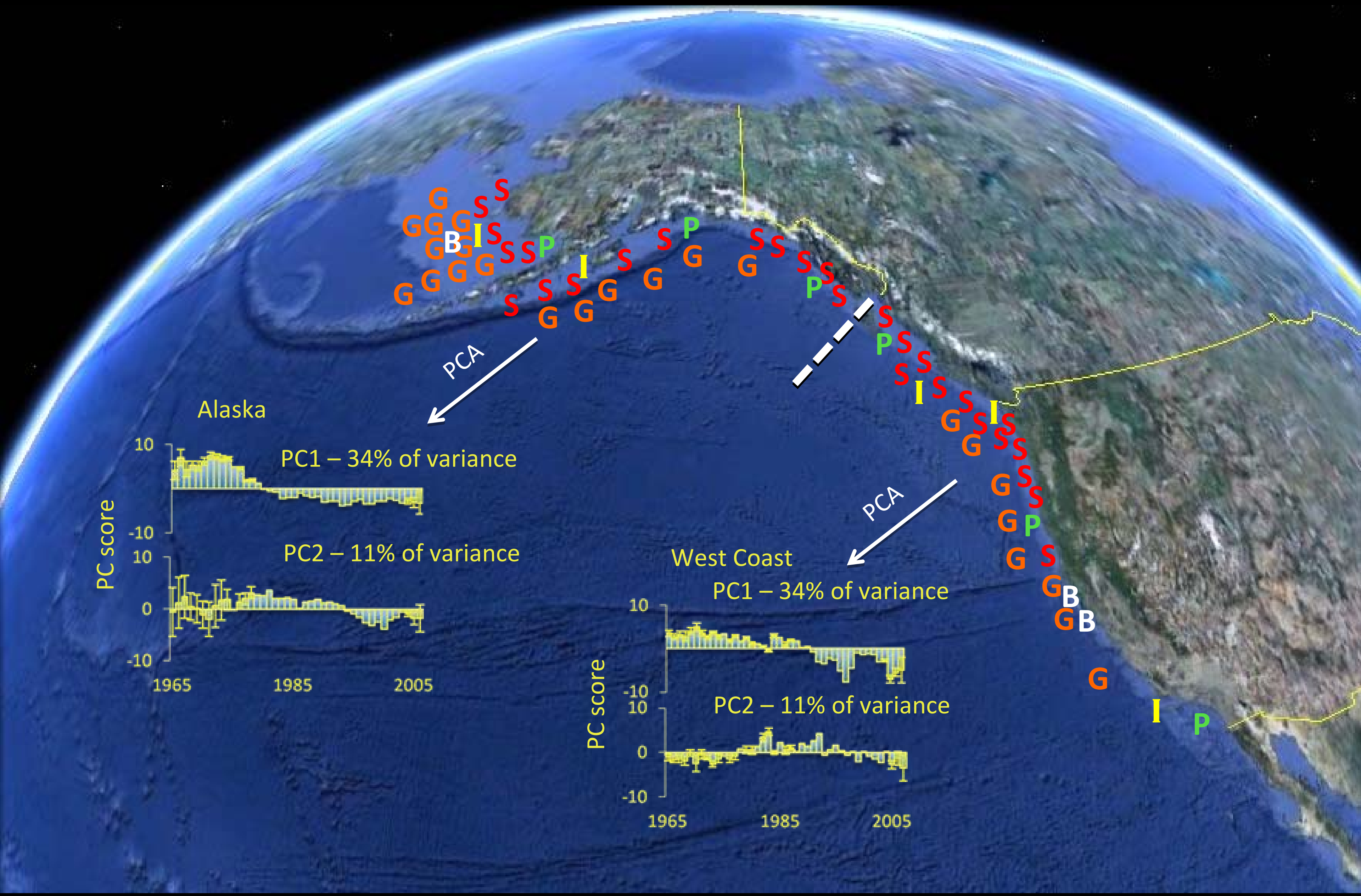
Questions

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


Alaska
West Coast
-Division based on regional PC1 loadings
-Allows for hypotheses of region-specific climate control



PCA
Alaska
PC1 – 34% of variance
PC2 – 11% of variance
PC score
10
-10
10
0
-10
1965
1985
2005
PCA
West Coast
PC1 – 34% of variance
PC2 – 11% of variance
PC score
10
-10
10
0
-10
1965
1985
2005

1. Climate forcing

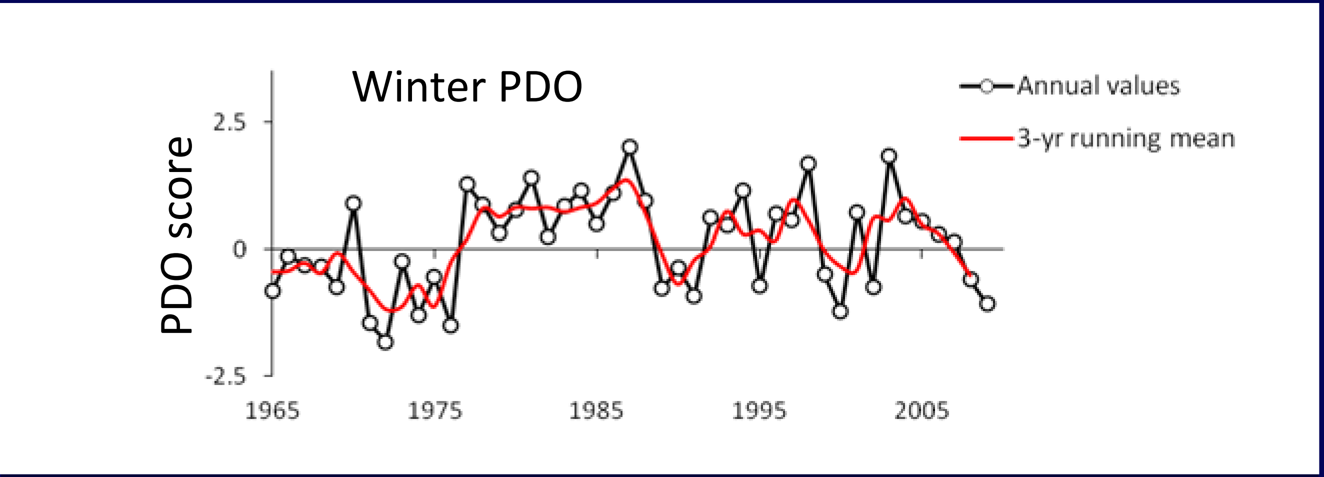
Elucidating climate forcing

Approach

Response variables: Alaska & West Coast biology PC1 & PC2

Explanatory variables:

	Alaska	West Coast
	Global temp. (HadCRUT3)	**Global temp. (HadCRUT3)**
Smoothed – 3 yr running mean →	**Winter PDO**	**Winter PDO**
	Annual Arctic Oscillation	**Winter Victoria Pattern**
	Annual Multivariate ENSO Index	Annual Multivariate ENSO Index



Elucidating climate forcing

Approach

Competing Generalized Additive Models for each biology PC

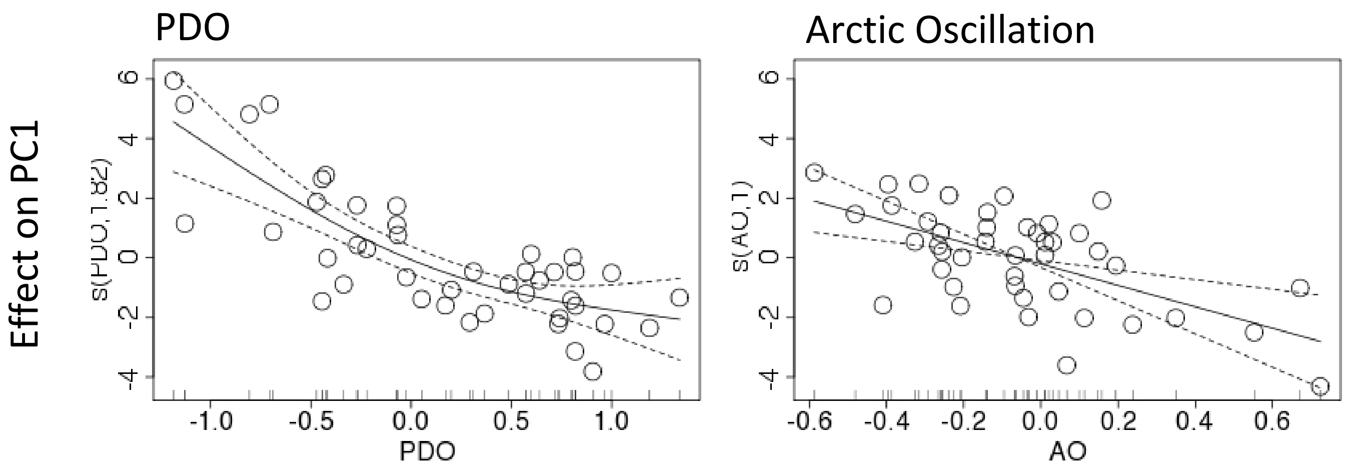
Models chosen by rewarding parsimony and predictive ability

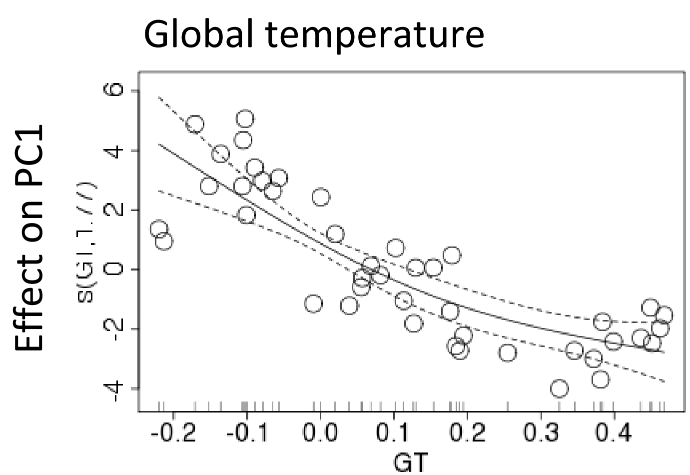
Parameter smoothness limited (k = 3) to avoid over-fitting model

1. Climate forcing

Alaska biology PC1

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





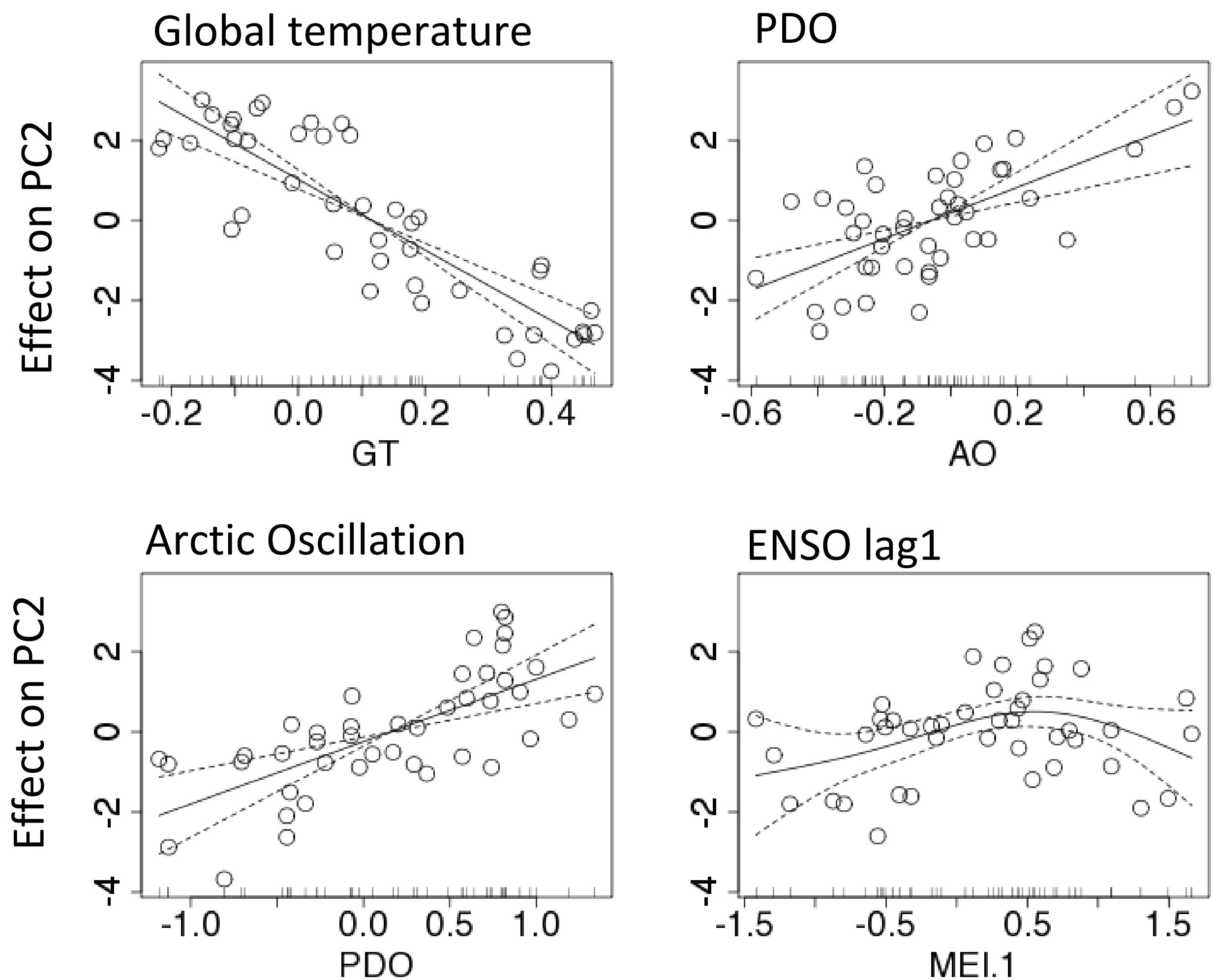
Model R^2 = 0.87

Residuals AR1 = 0.10

1. Climate forcing

Alaska biology PC2

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



Model
$R^2 = 0.63$

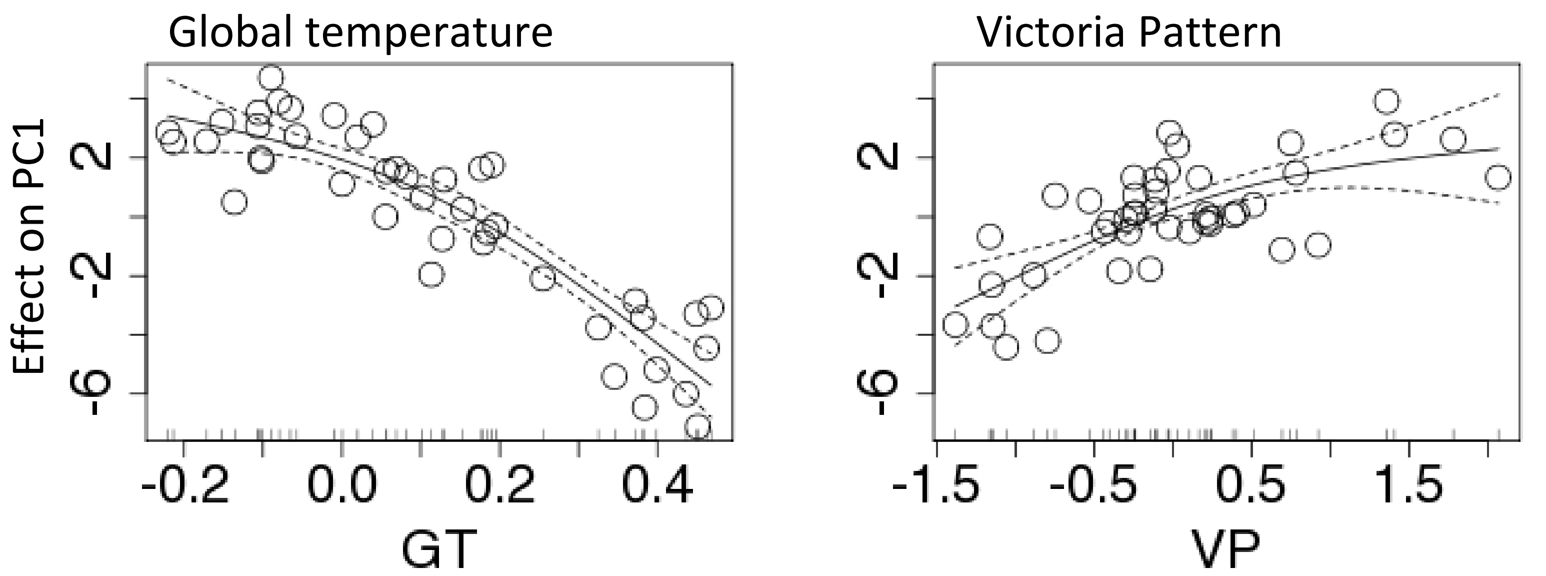
Residuals AR1 = 0.44

1. Climate forcing

West coast biology PC1

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

Model $R^2 = 0.82$
Residuals AR1 = 0.29



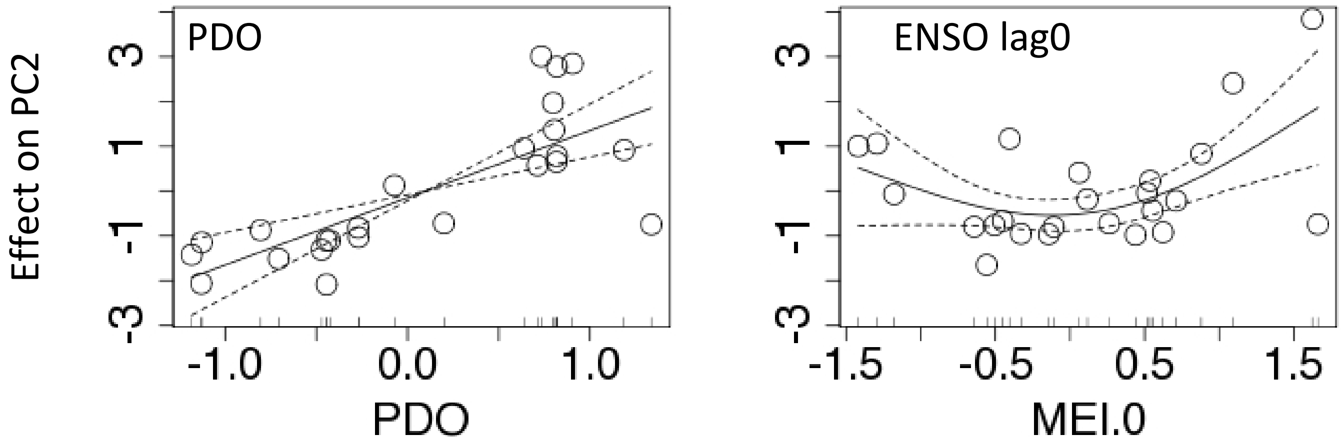
1. Climate forcing

West coast biology PC2

1965-1988: PC2 ~ s(PDO) + s(ENSO lag0)

1989-2007: PC2 ~ s(global temp)

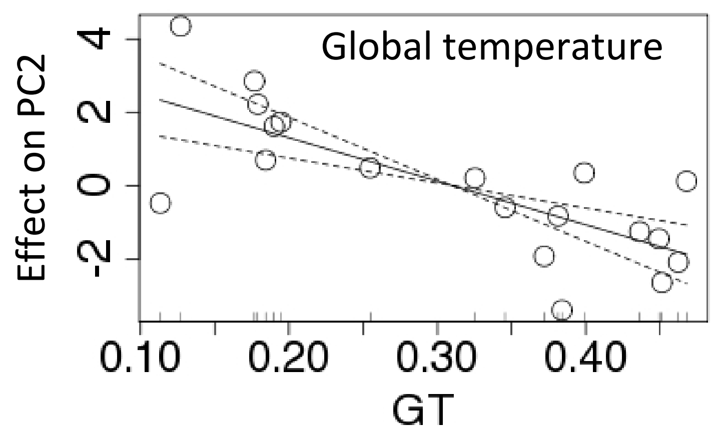
Pre-1988/89 Model $R^2 = 0.65$ Residuals AR1 = 0.17



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

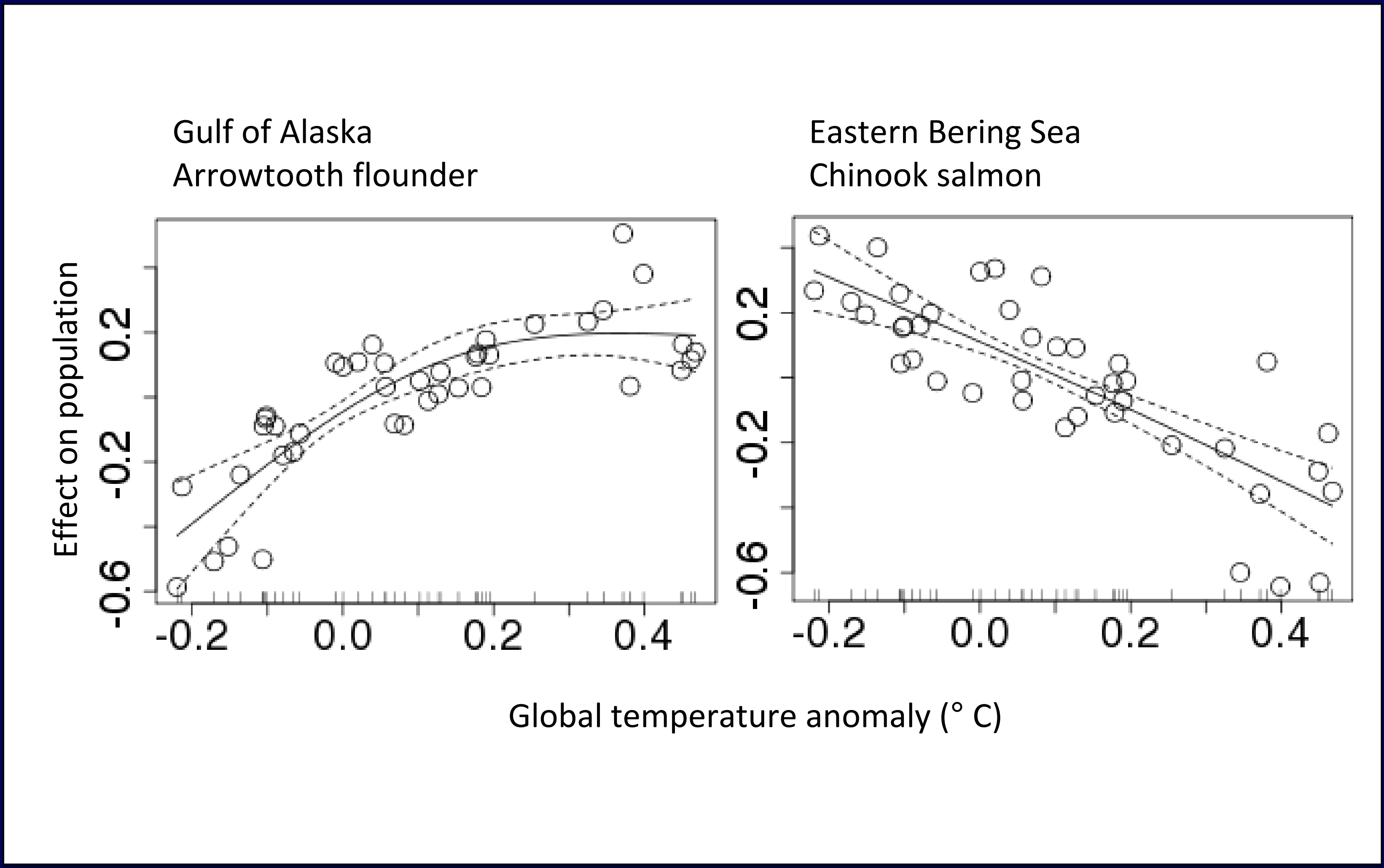
•1976/77 PDO regime shift had general “winners” (e.g., Alaska groundfish & salmon) and “losers” (e.g., Alaska crustaceans)

•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

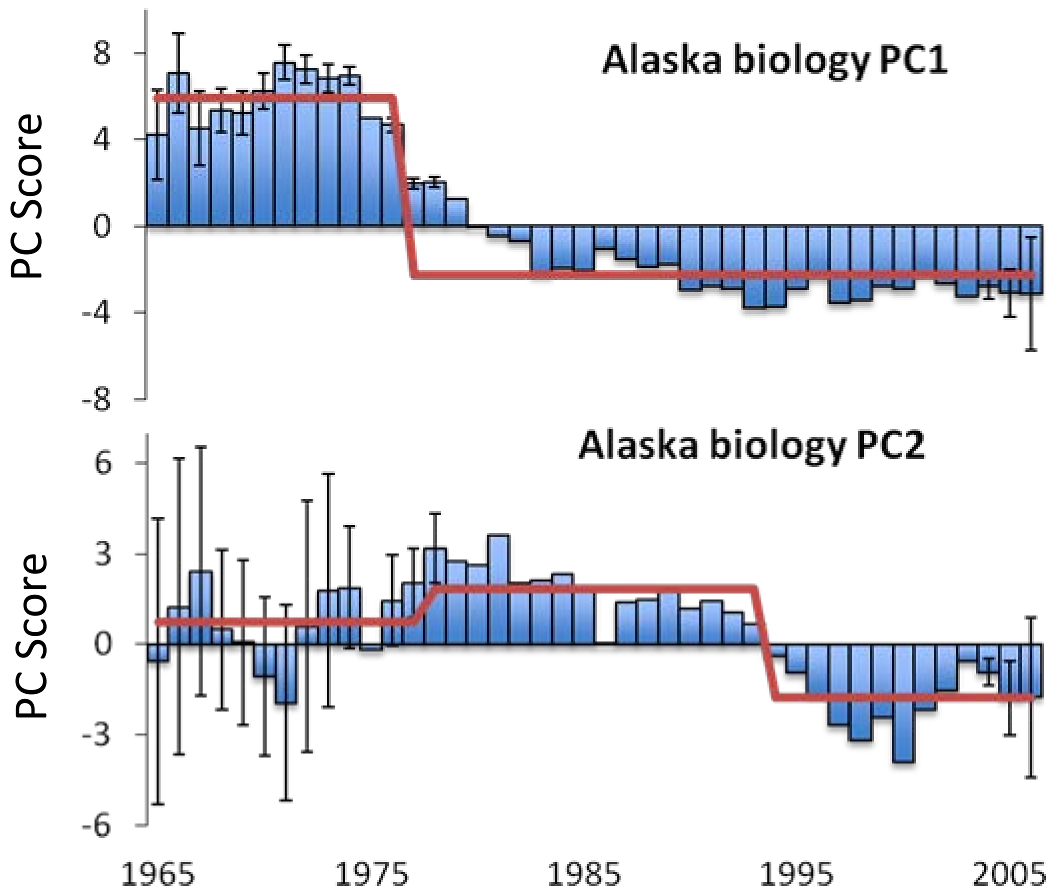
1. Climate forcing

Hypothesizing global warming effects on individual populations



2. Recent shifts

Recent change in ecosystem services



STARS-defined states

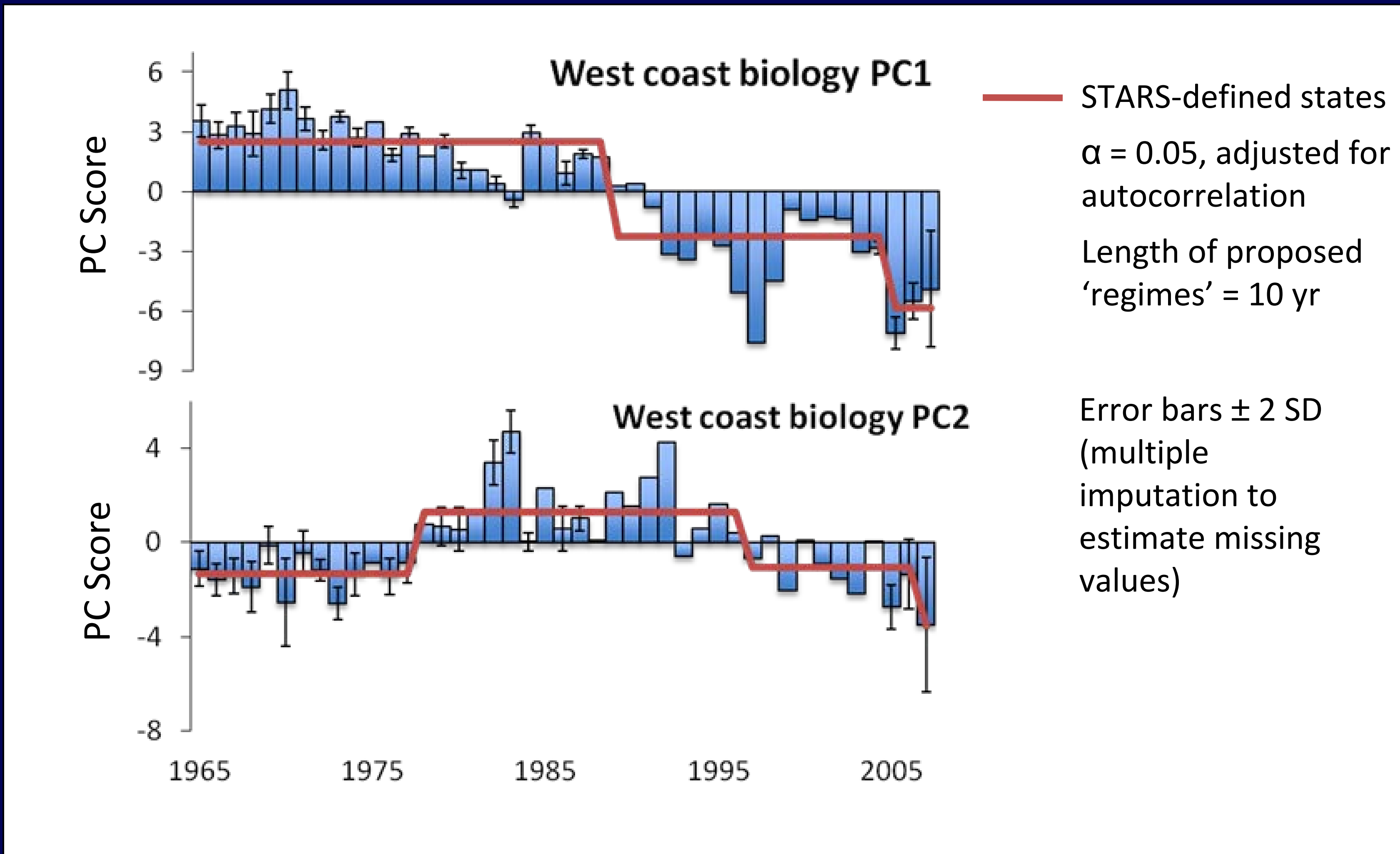
α = 0.05, adjusted for autocorrelation

Length of proposed 'regimes' = 10 yr

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

2. Recent shifts

Recent change in ecosystem services



Implications

<u>Question 1: Elucidating climate forcing</u>

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

Implications

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

Acknowledgements

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.

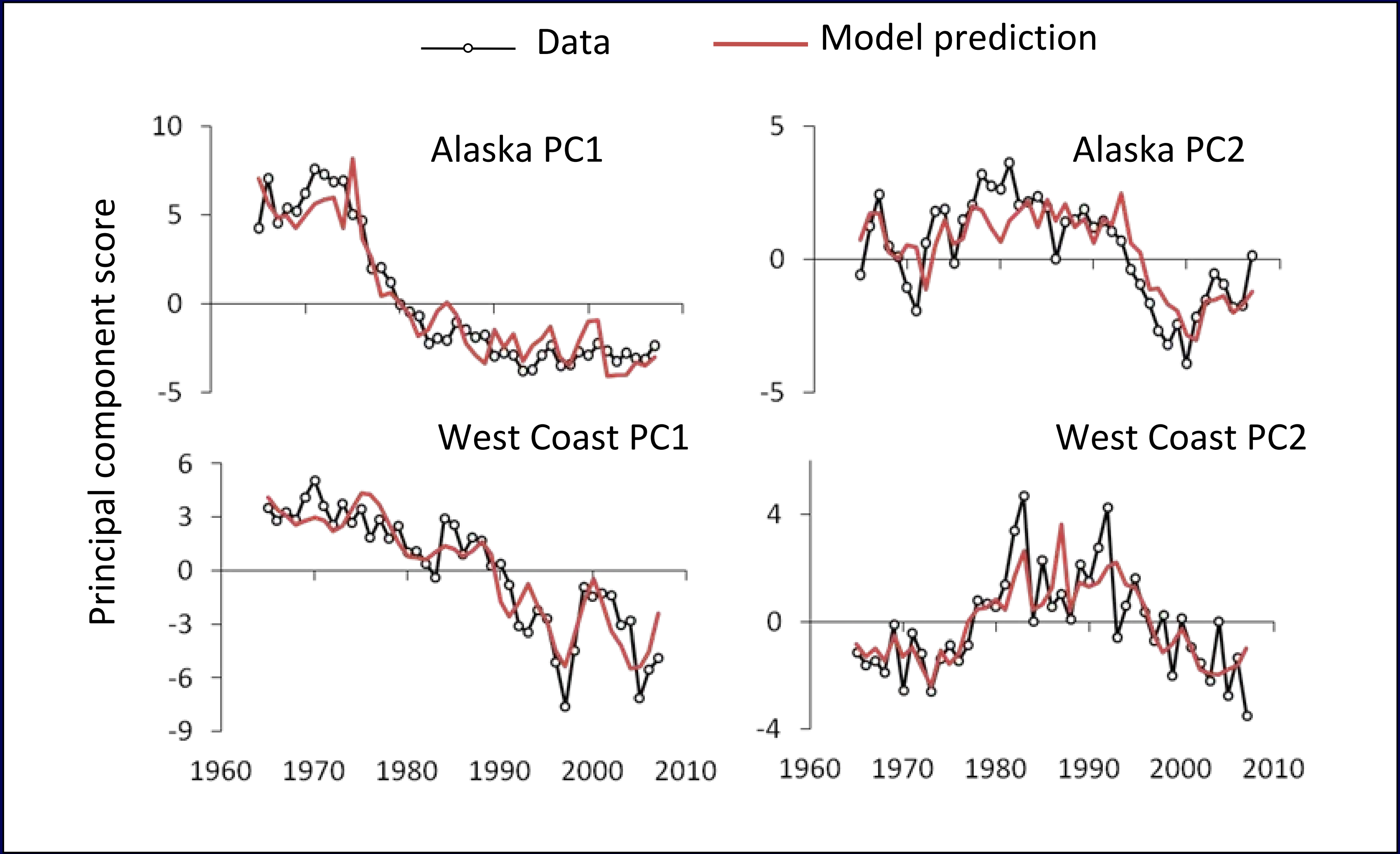
Financial support provided by the North Pacific Research Board (project # 1024), with additional support from the University of Tasmania and the University of Alaska, Fairbanks.

3. Predicting future change

Implications for predicting future biological change

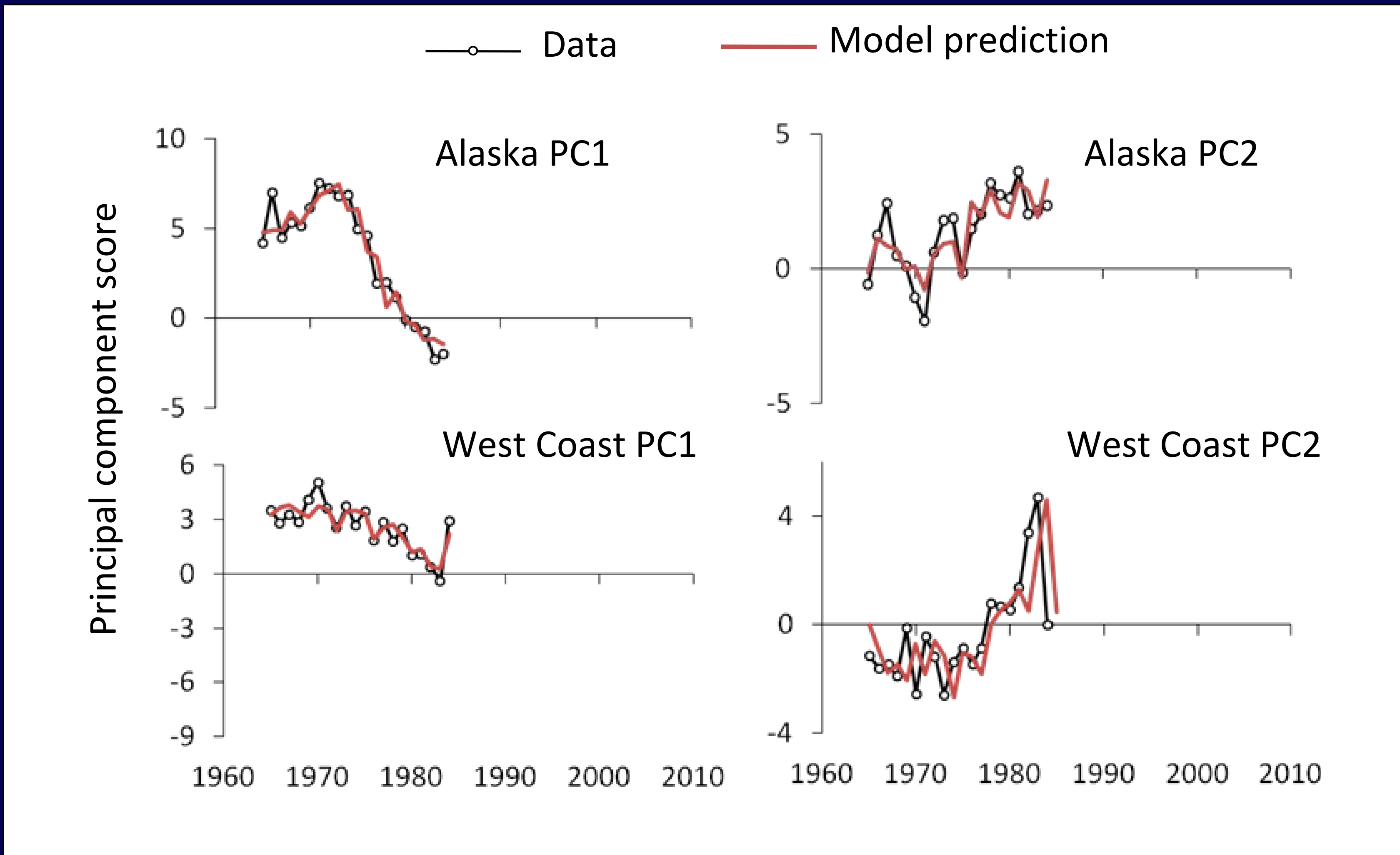
3. Predicting future change

Understanding of past climate-biology covariation



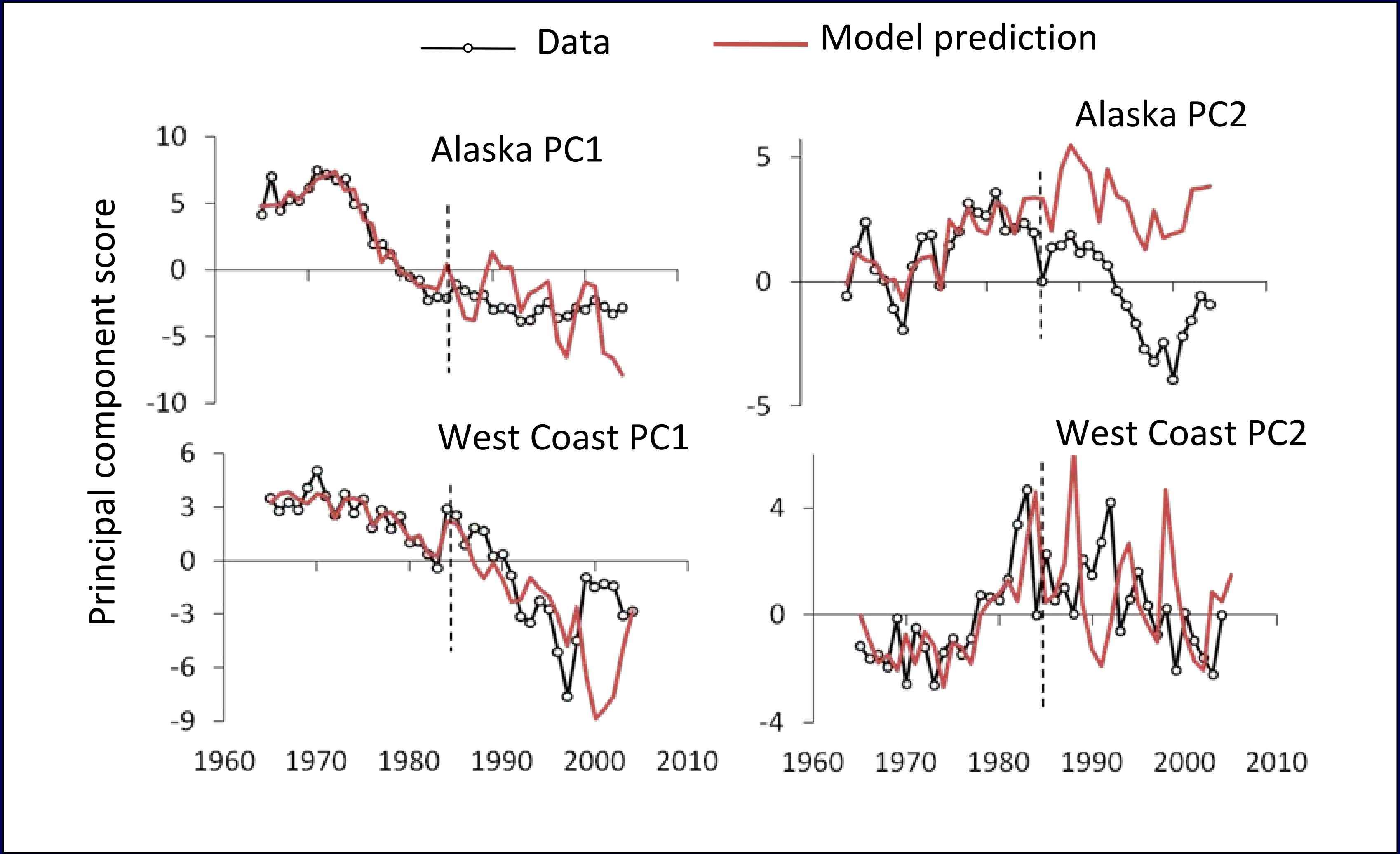
3. Predicting future change

How good is prediction based on the past? A 20-year test



3. Predicting future change

Predictions based on first 20 years of data



3. Predicting future change

Possible sources of "ecological surprise"

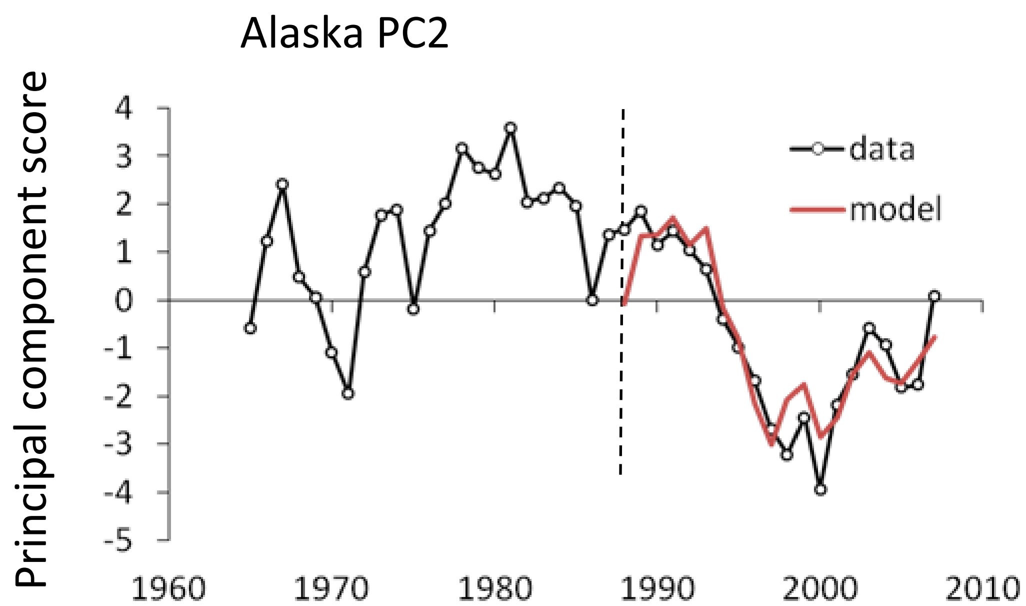
- Incomplete set of possible system configurations observed

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

3. Predicting future change

Sources of ‘ecological surprise’

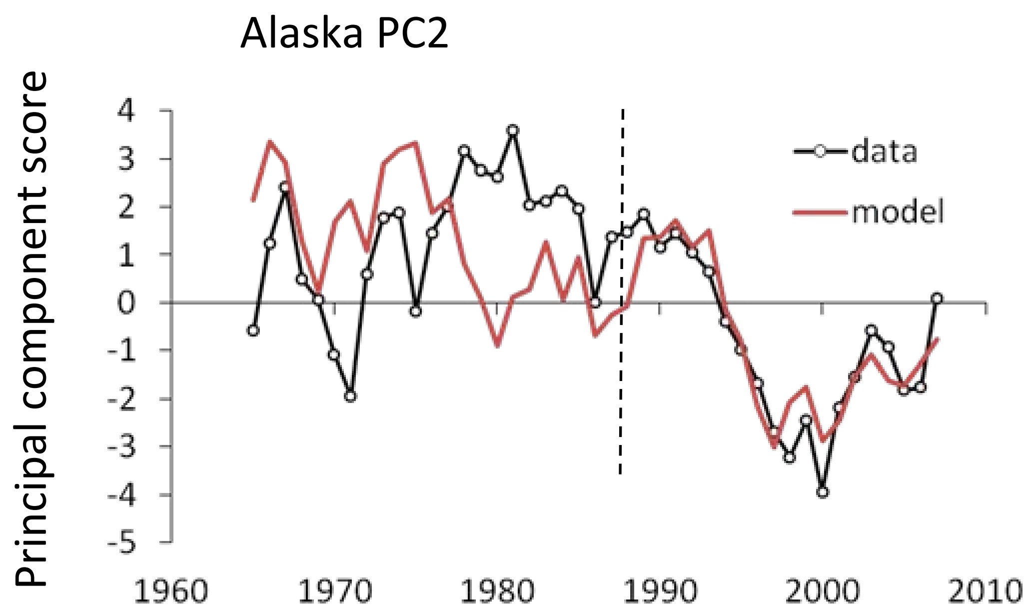
Modeling the past based on current observations also problematic



3. Predicting future change

Sources of 'ecological surprise'

Modeling the past based on current observations also problematic



Implications

<u>Goal 3: Making inferences about predictive capability</u>

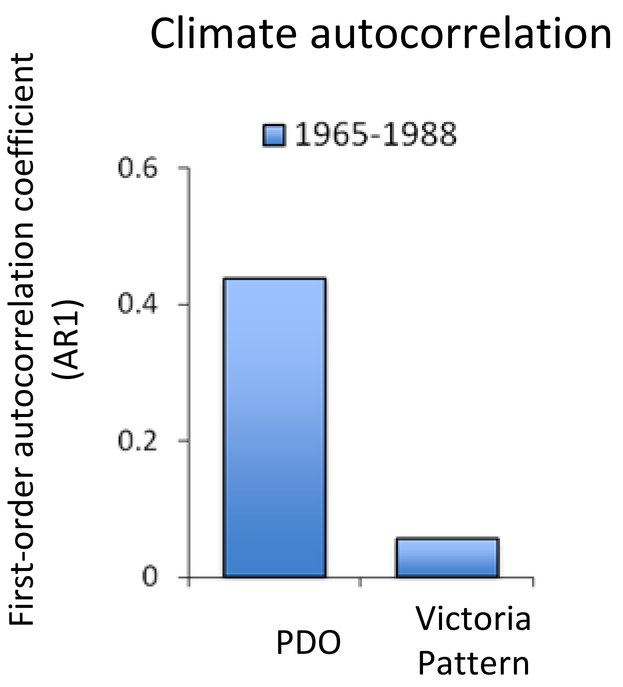
1) No confidence in which climate-biology models have predictive ability over short time scales

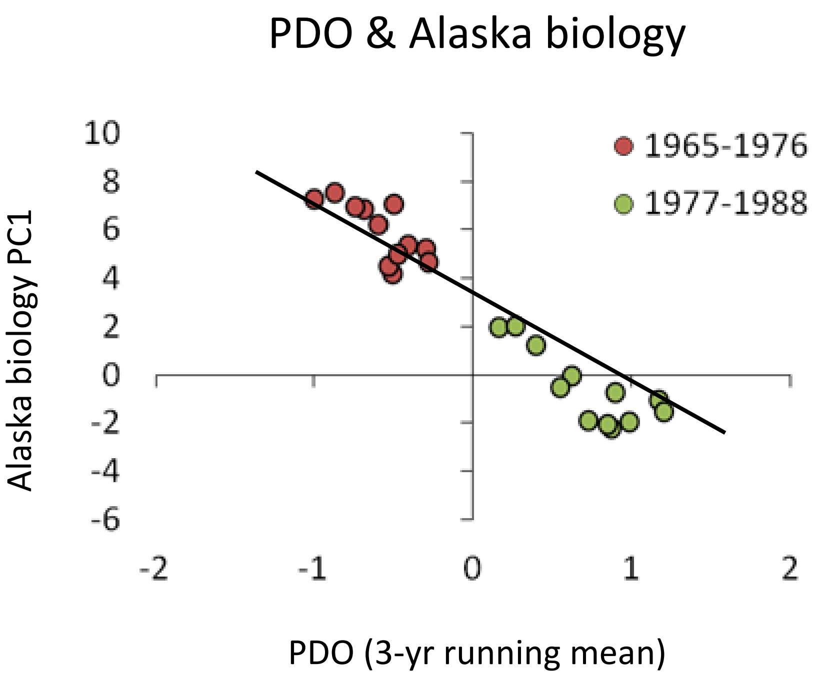
2) Need to account for novel system configurations and changing mechanistic relationships when predicting future biological state

3. Predicting future change

Sources of ‘ecological surprise’

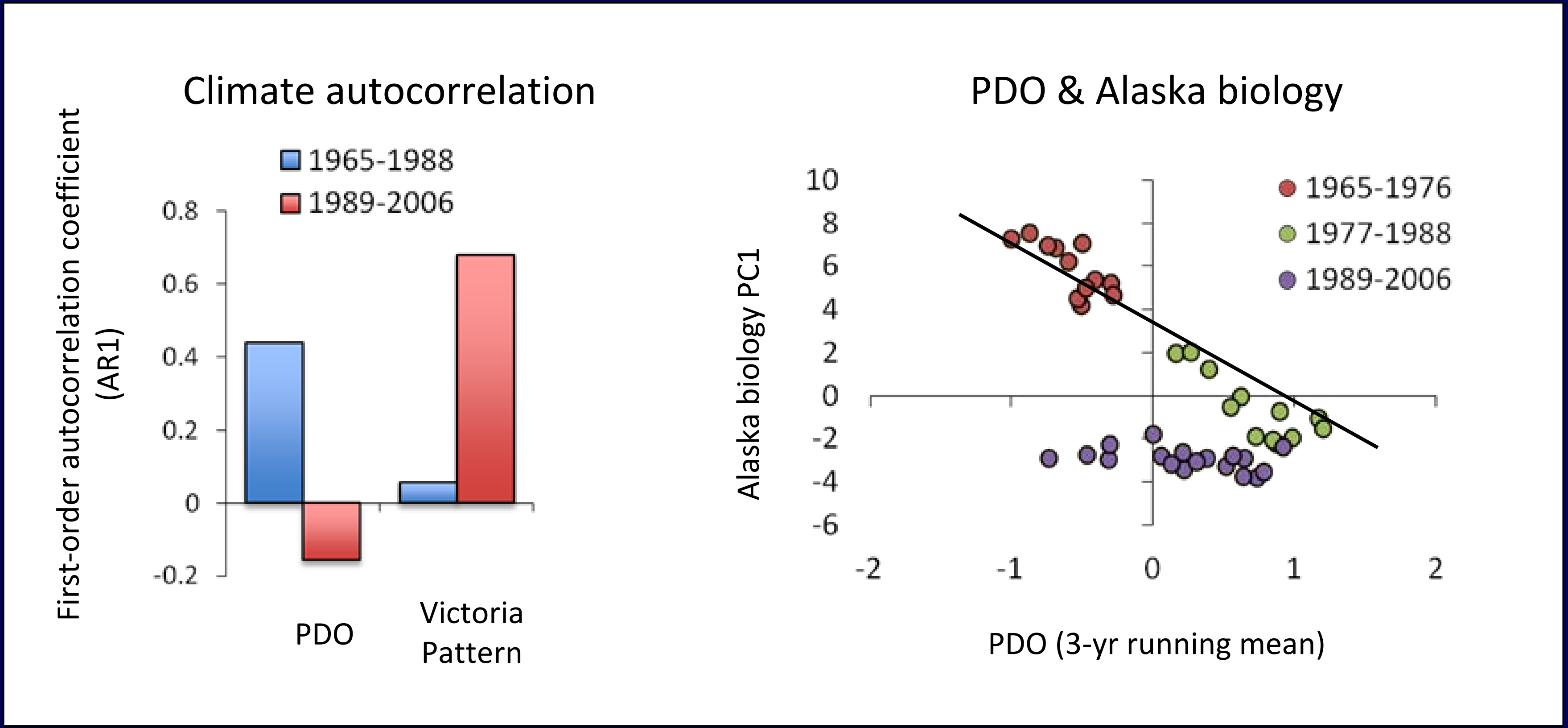
Understanding based on incomplete set of possible system configurations





Sources of 'ecological surprise'

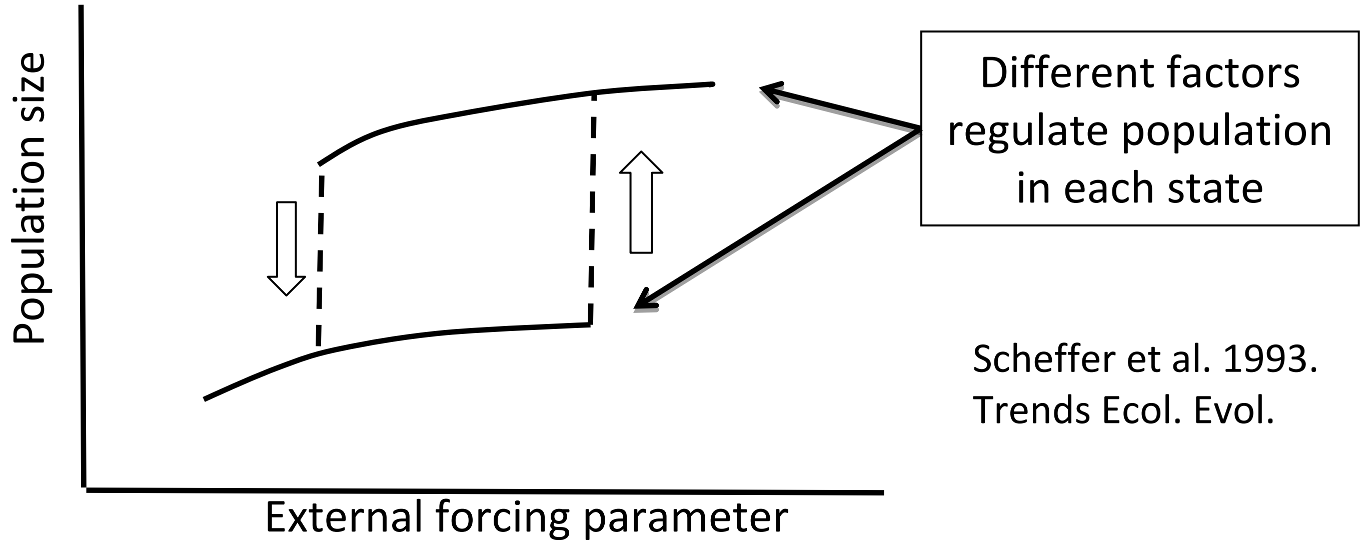
Understanding based on incomplete set of possible system configurations



3. Predicting future change

Sources of ‘ecological surprise’

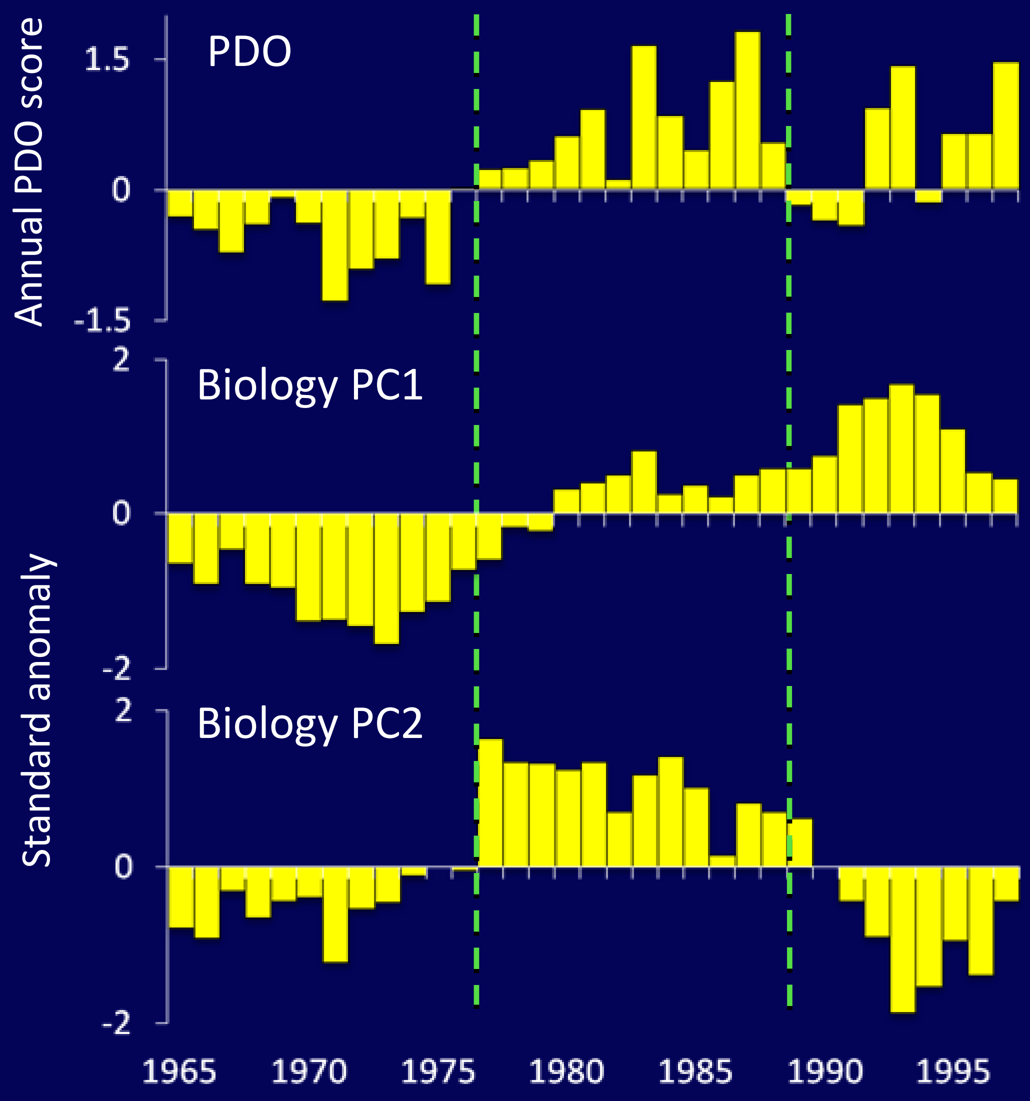
No ‘balance of nature’ in ecosystem mechanics



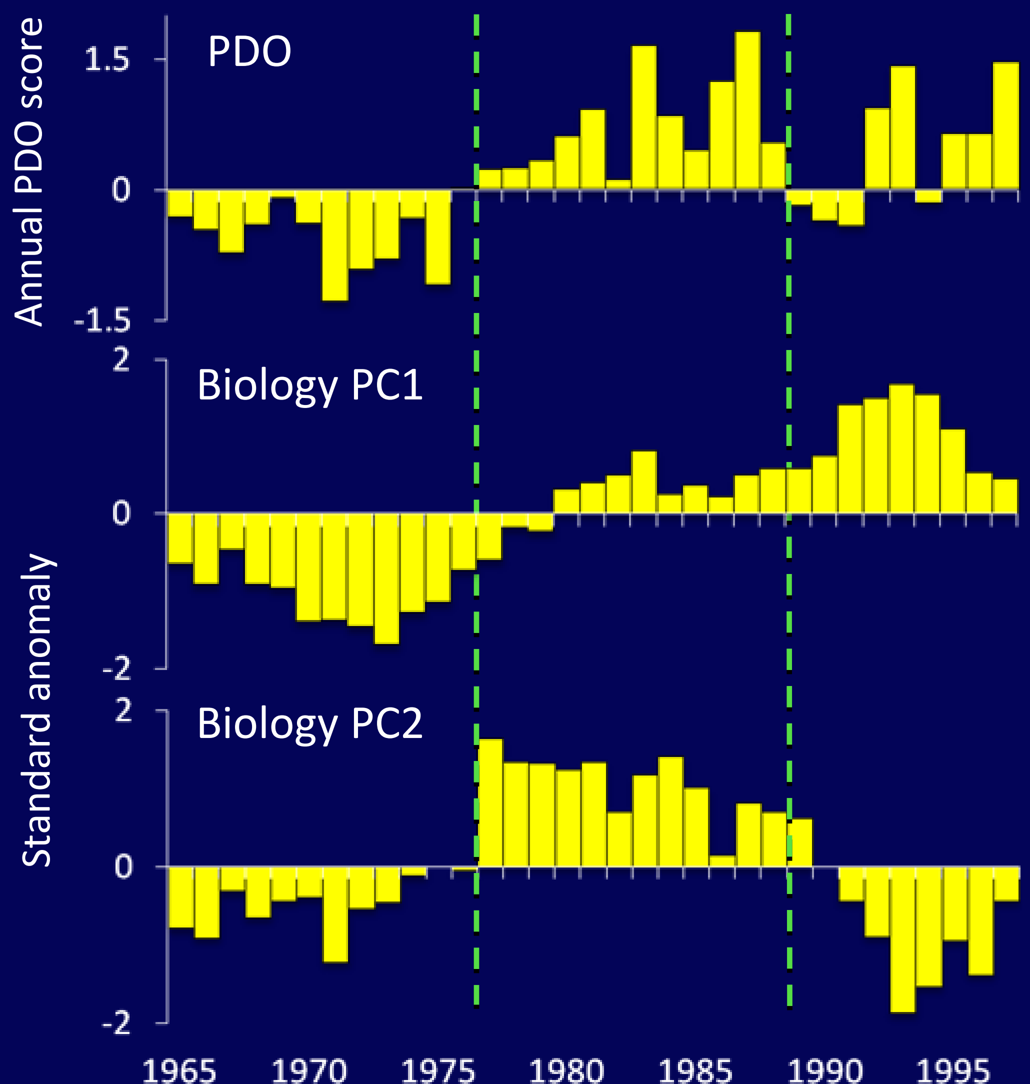
Scheffer et al. 1993. Trends Ecol. Evol.

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

Example from Hare and Mantua 2000



The 21st Century…



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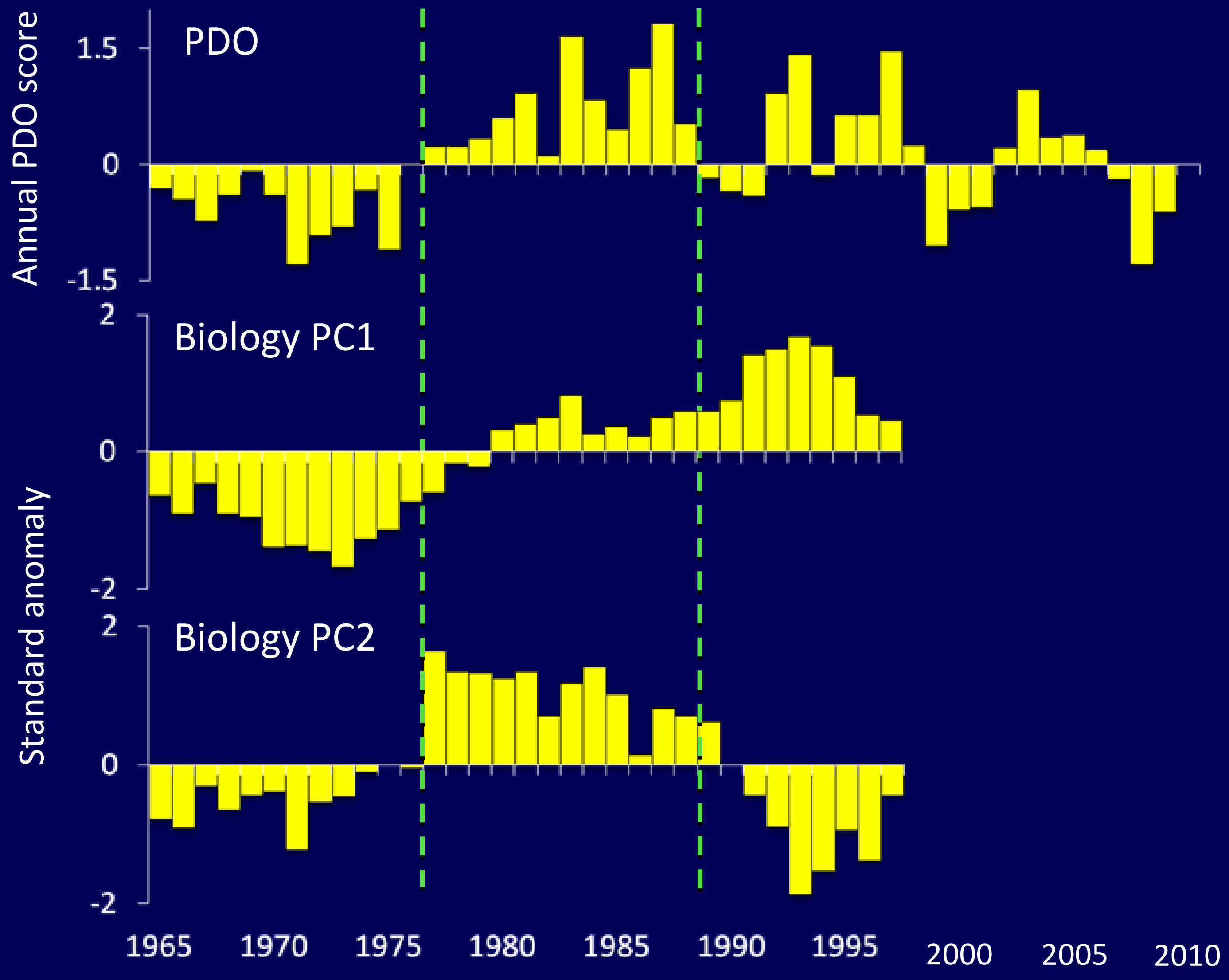

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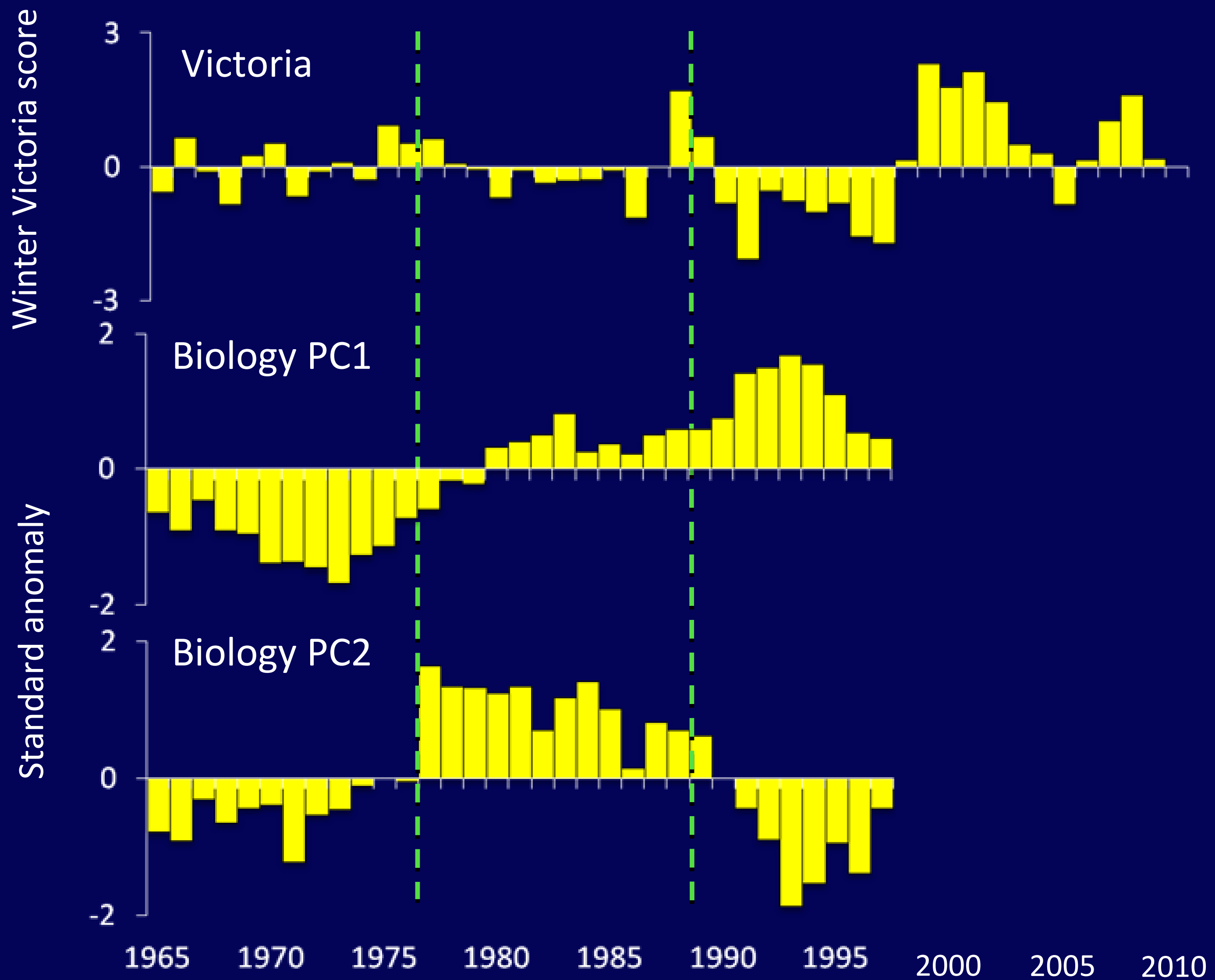
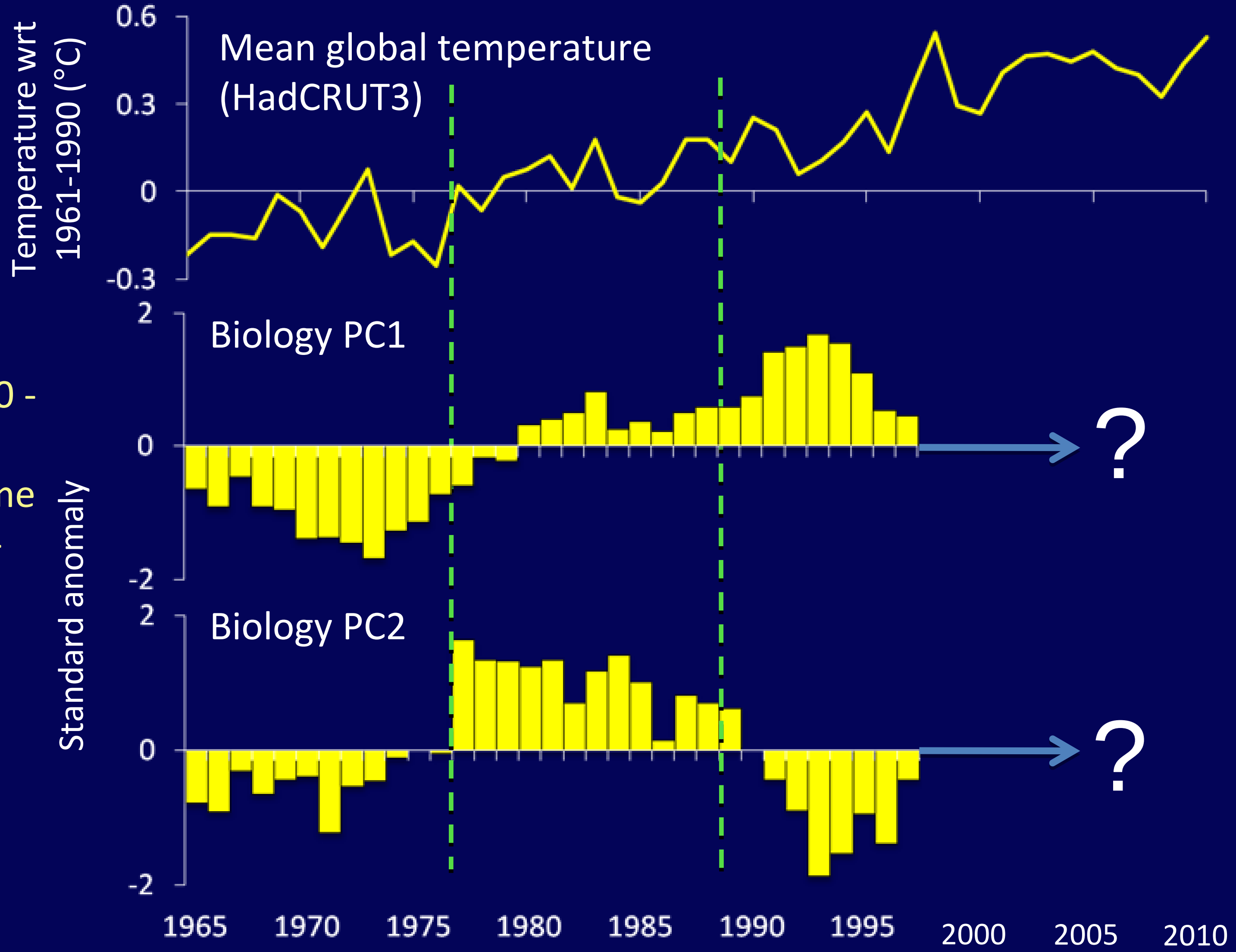


The 21st Century...

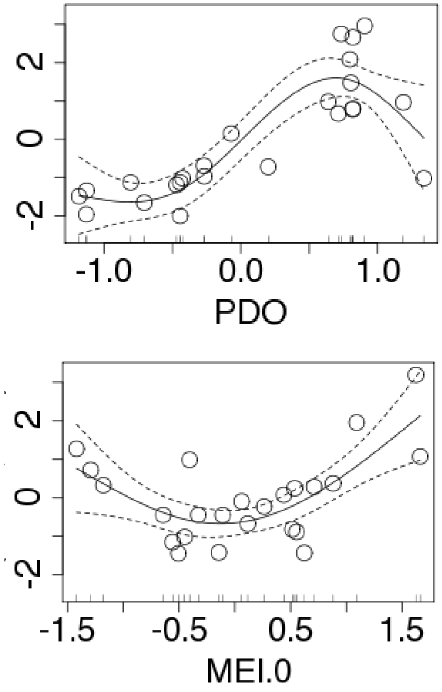
Hare and Mantua 2000 - PCA of 69 biological time series, 1965-1997

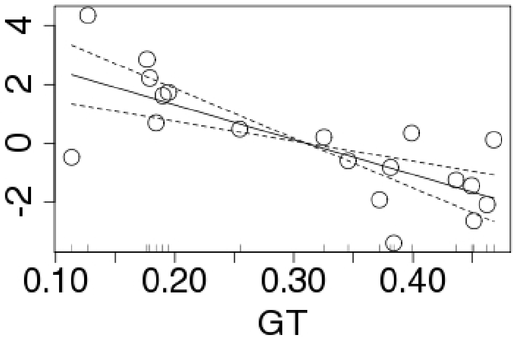


3. Predicting future change

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

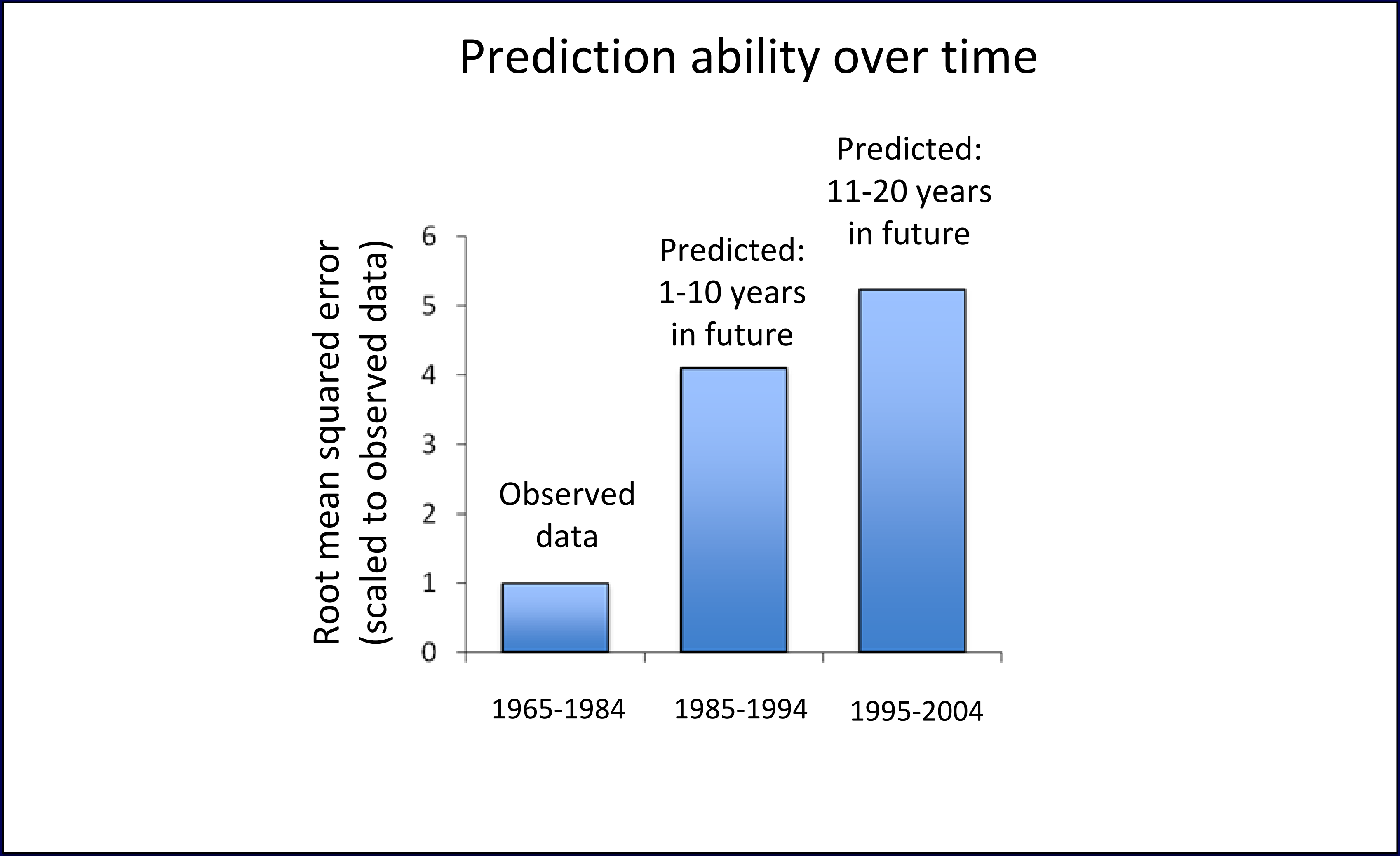
Competing Generalized Additive Models for each biology PC

-Best model constructedwith 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

Predictions based on first 20 years of data



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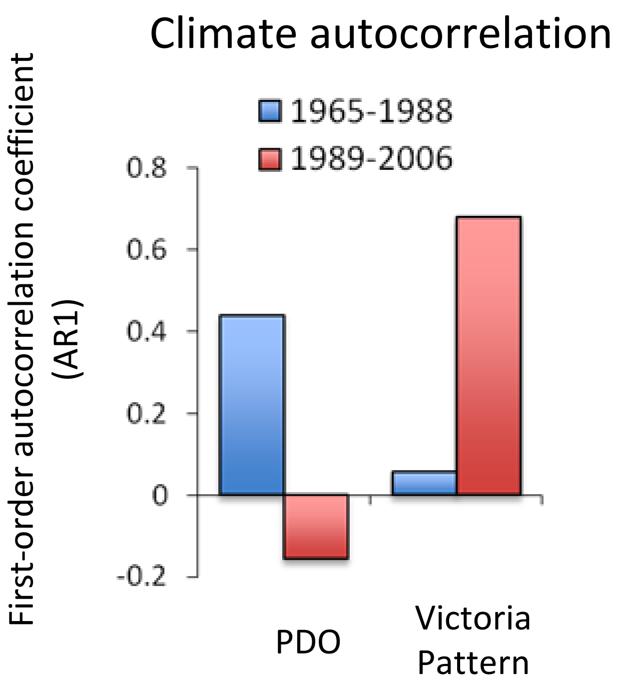
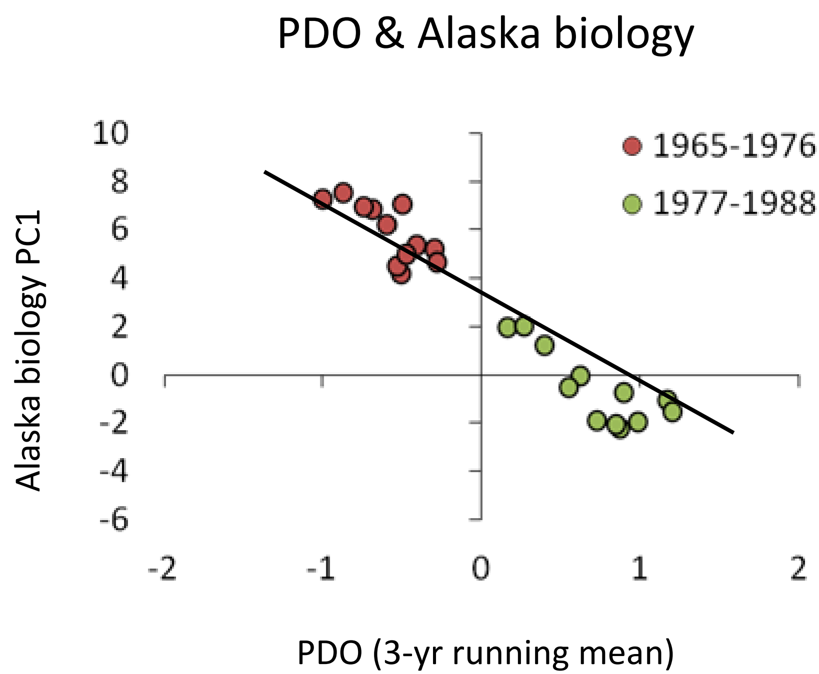




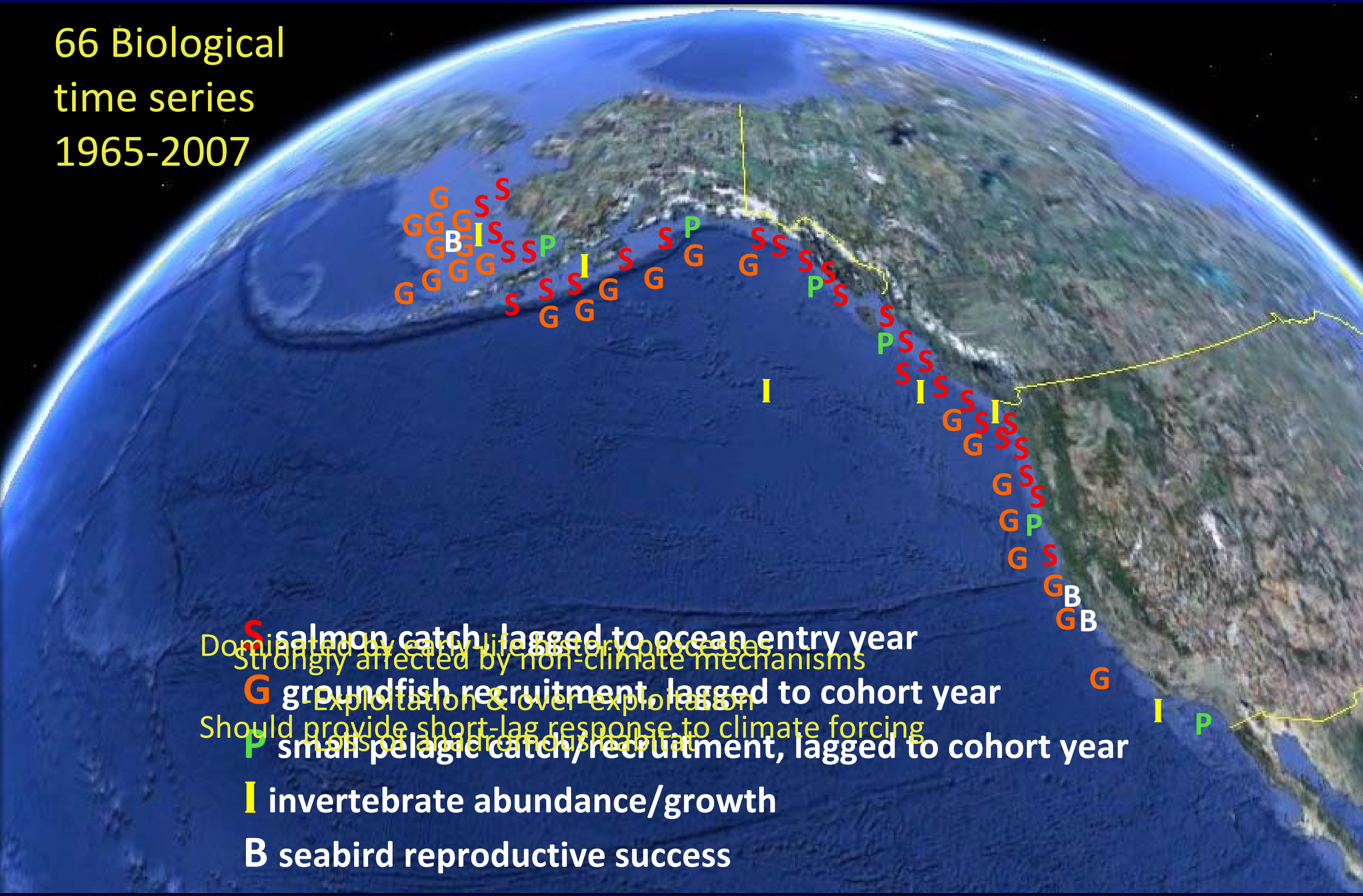
Elucidating climate forcing

Approach

Response variables: Alaska & West Coast biology PC1 & PC2

Explanatory variables:

Alaska	West Coast
Global temp. (HadCRUT3)	Global temp. (HadCRUT3)
Winter PDO	Winter PDO
Annual Arctic Oscillation	Winter Victoria Pattern
Annual Multivariate ENSO Index	Annual Multivariate ENSO Index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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
Dominated by early-life history processes
Strongly affected by non-climate mechanisms
-Exploitation & over-exploitation
Should provide short-lag response to climate forcing
-Loss of anadromous habitat

1. Climate forcing

Caveat!

Potential for spurious global warming effects