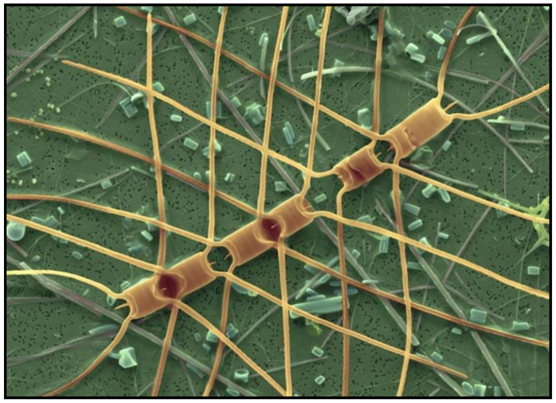
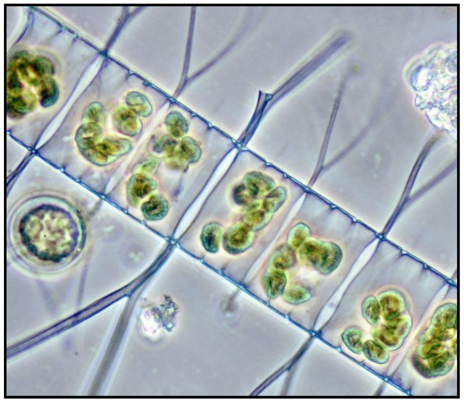
Climate Change and Trophic Mismatches between Plankton Blooms and Fish Phenology





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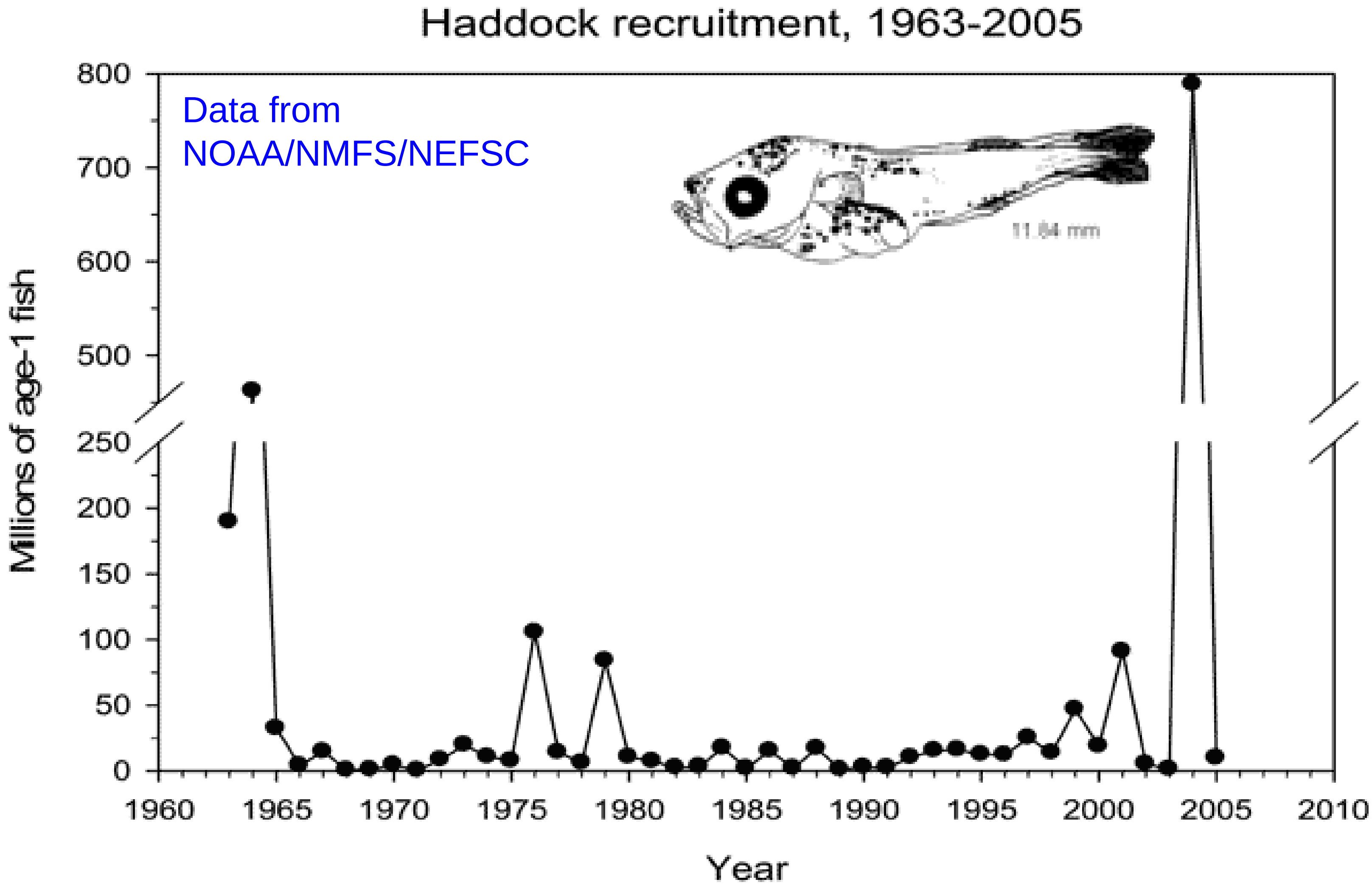
Jorge L. Sarmiento (Princeton)

July 28, 2016

Phenology is the study of biological, seasonal cycles and how they are affected by climate and weather.

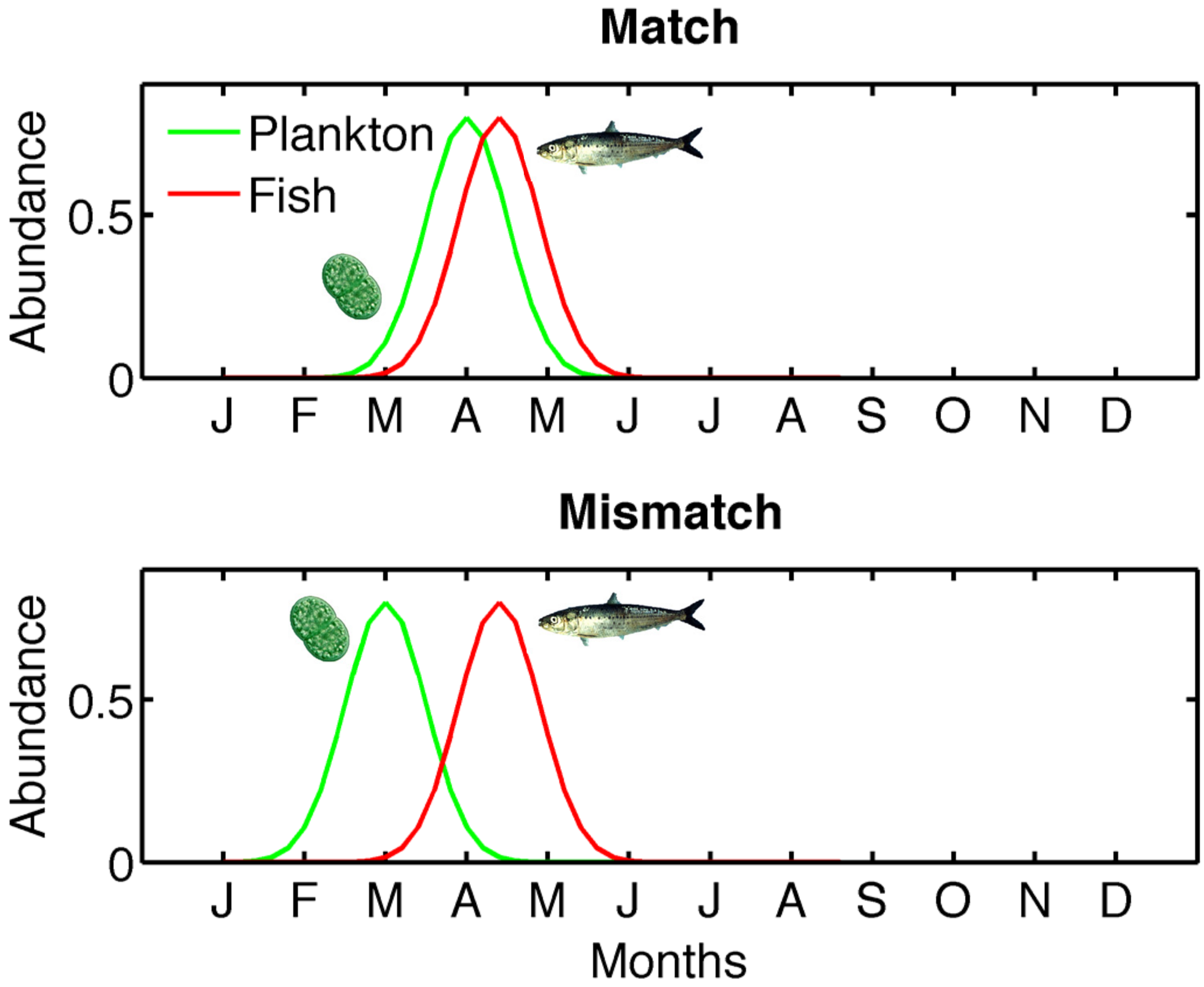
Why Is Phenology of Interest to Fisheries Oceanographers?



- Biggest influence on recruitment variability are oceanic conditions encountered by fish eggs and larvae

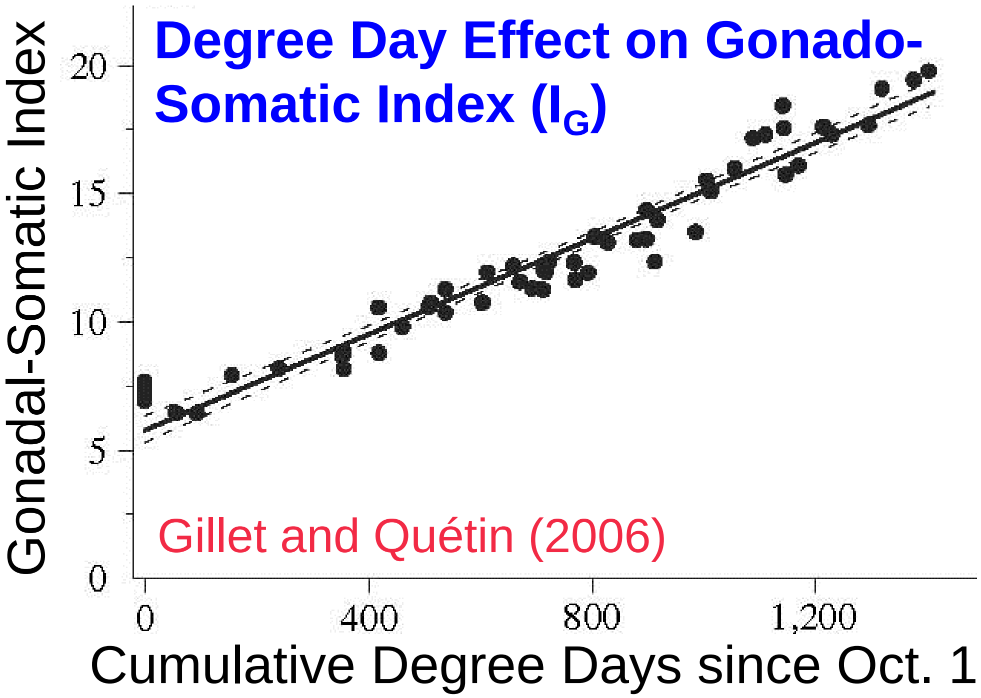
Match-Mismatch Hypothesis

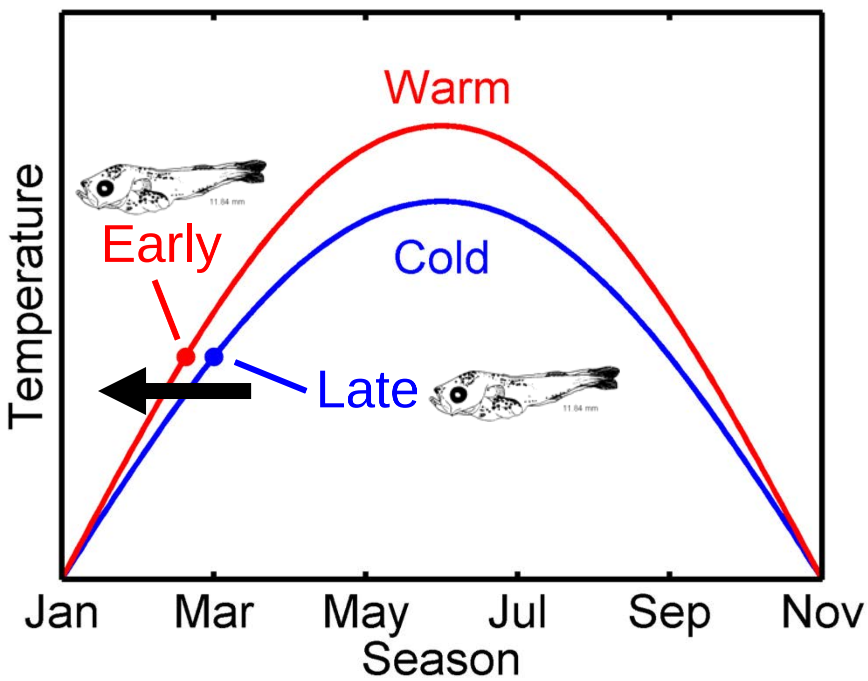
- Developed by Cushing (1974)
- Mismatches lead to poor larval survival, growth & recruitment



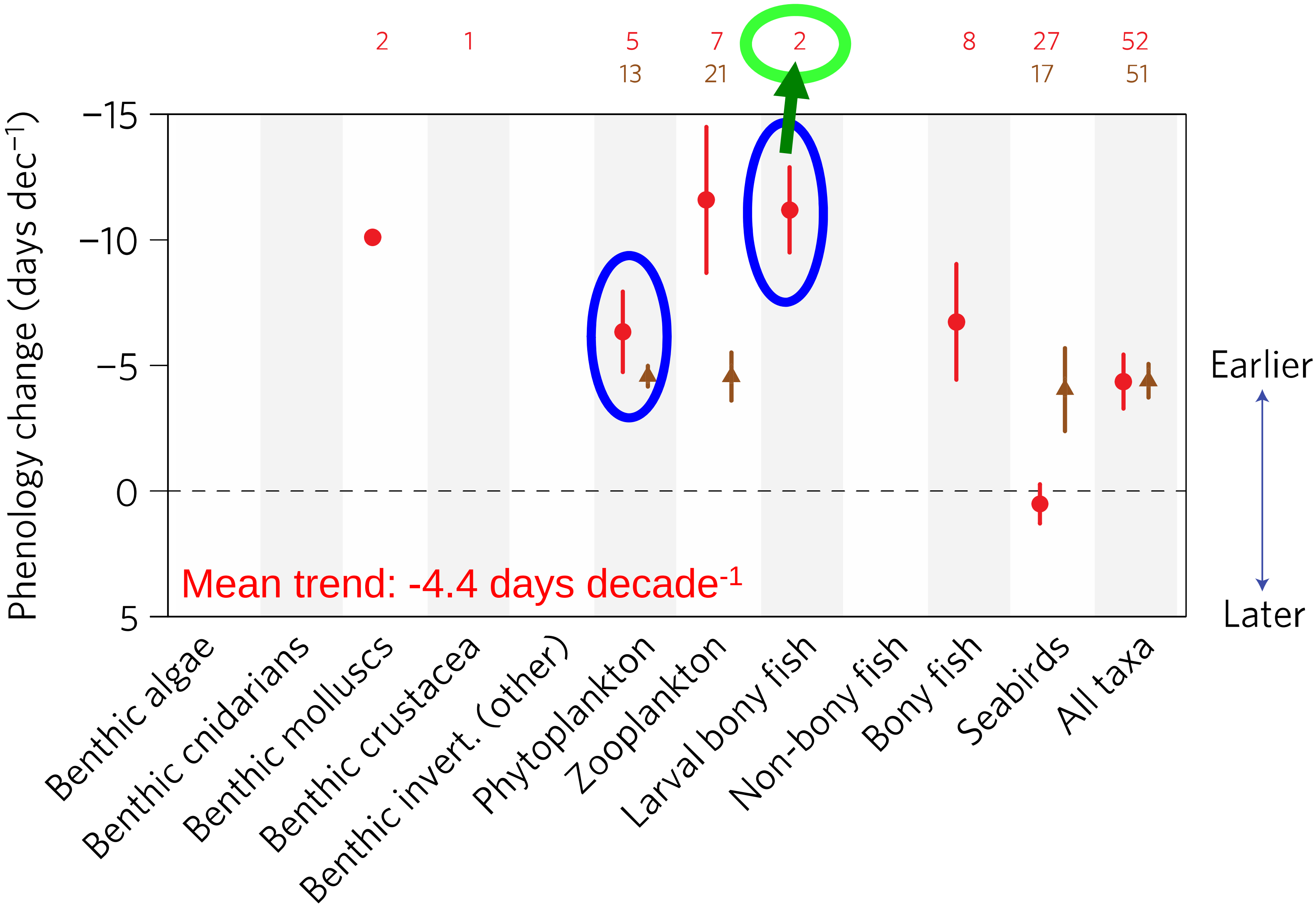
Why Can’t Fish Consistently Reproduce during Plankton Blooms?

What Is the Primary Control on Spawning Time?



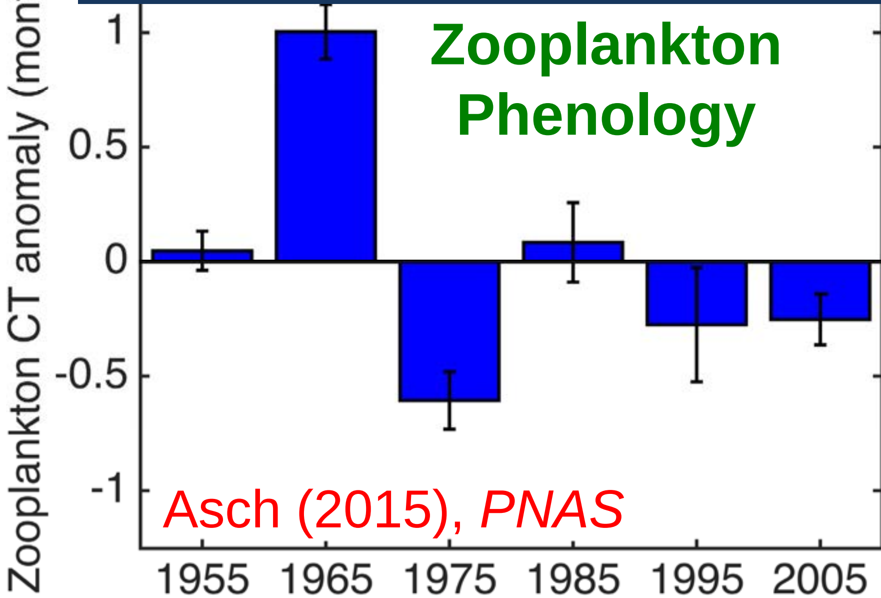


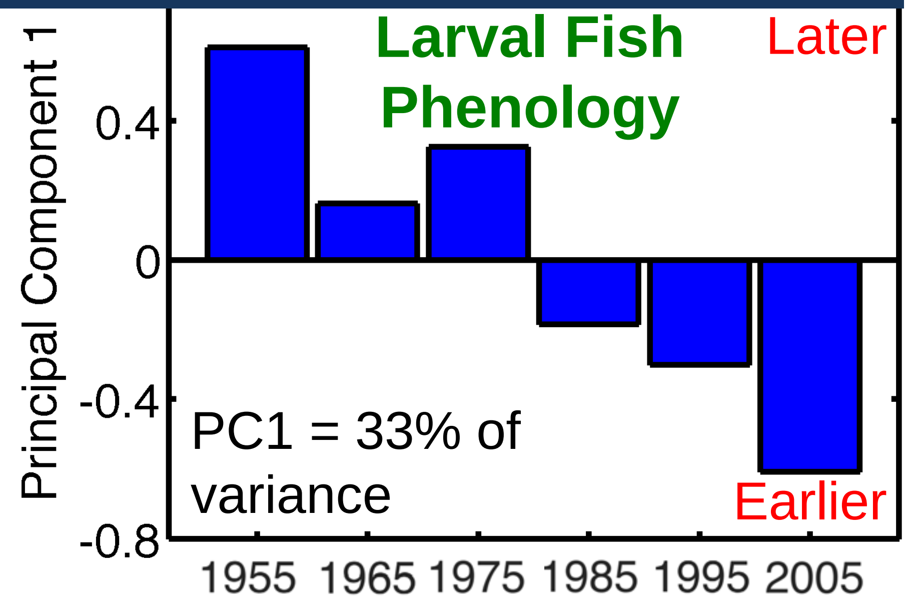
Phenology Trends Related to Climate Change



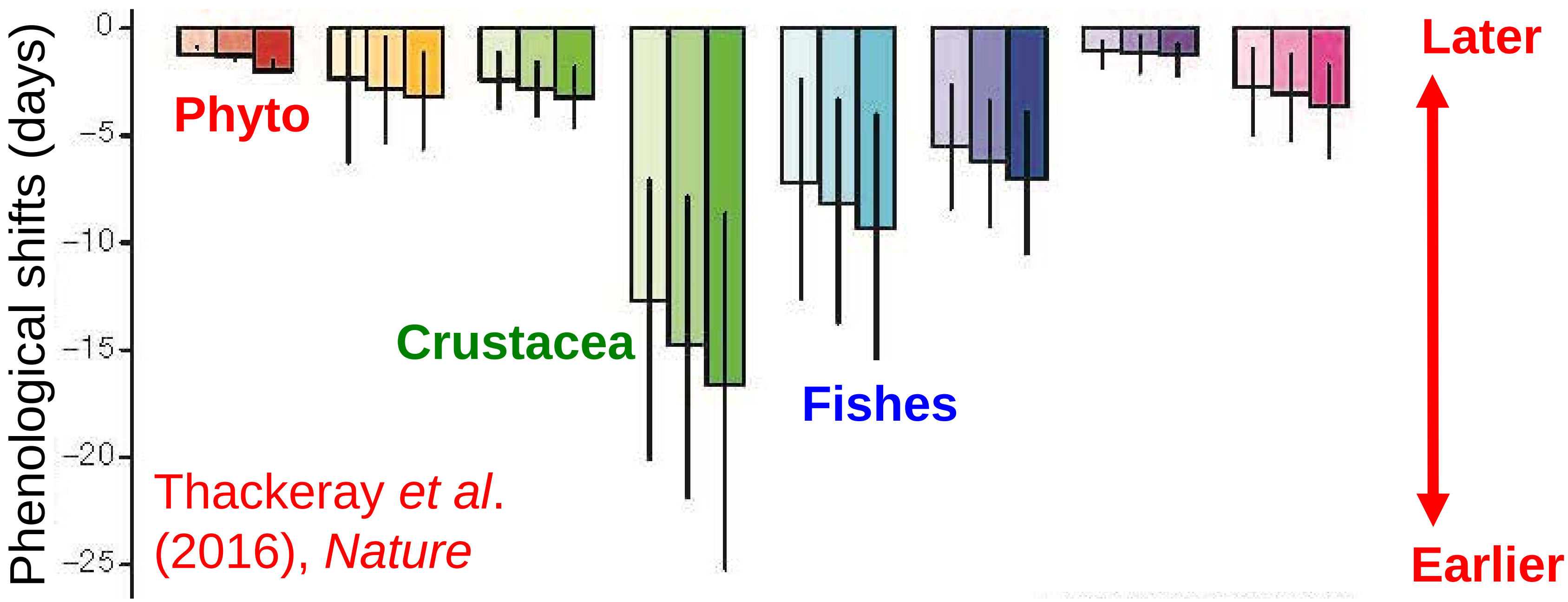
Poloczanska *et al*. (2013), *Nature Climate Change*

Trends from the California Current Ecosystem





Trends in UK Ecosystems



Hypotheses

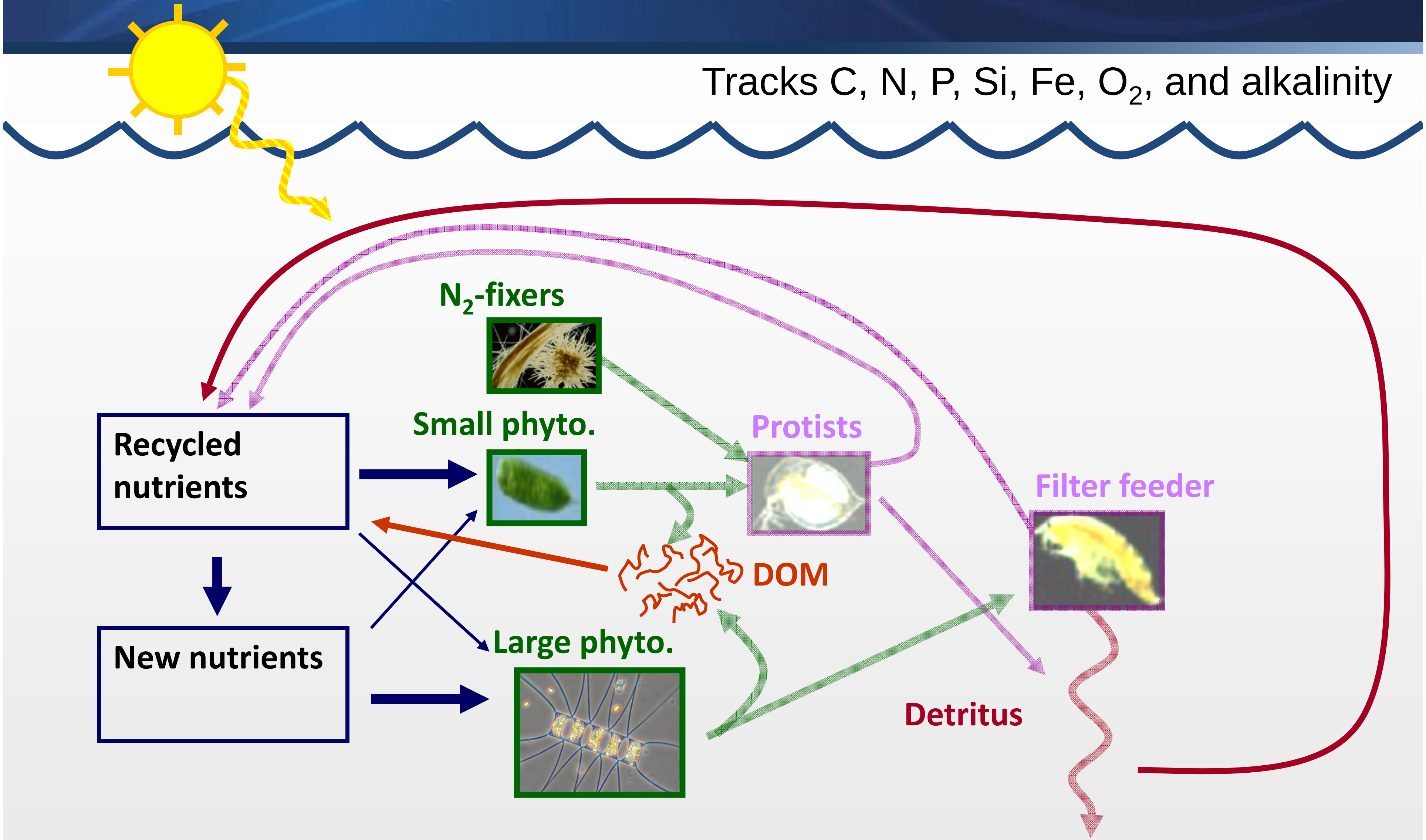
- Climate change will lead to both ***earlier phytoplankton blooms and fish spawning***

- Sensitivity to climate change will differ among trophic levels, leading to a greater frequency of ***seasonal mismatches***

- ***Range shifts*** among fishes may ameliorate the extent of seasonal mismatches

Ocean Ecology in the GFDL ESM2M Model

Tracks C, N, P, Si, Fe, O_2, and alkalinity



Tracers of Ocean Phytoplankton with Allometric Zooplankton (TOPAZ)

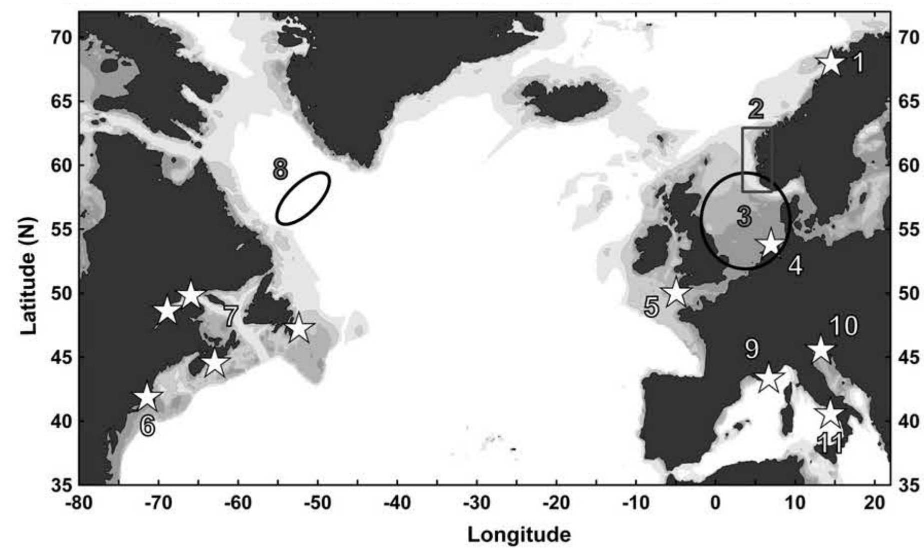
Slide available courtesy of John Dunne, GFDL

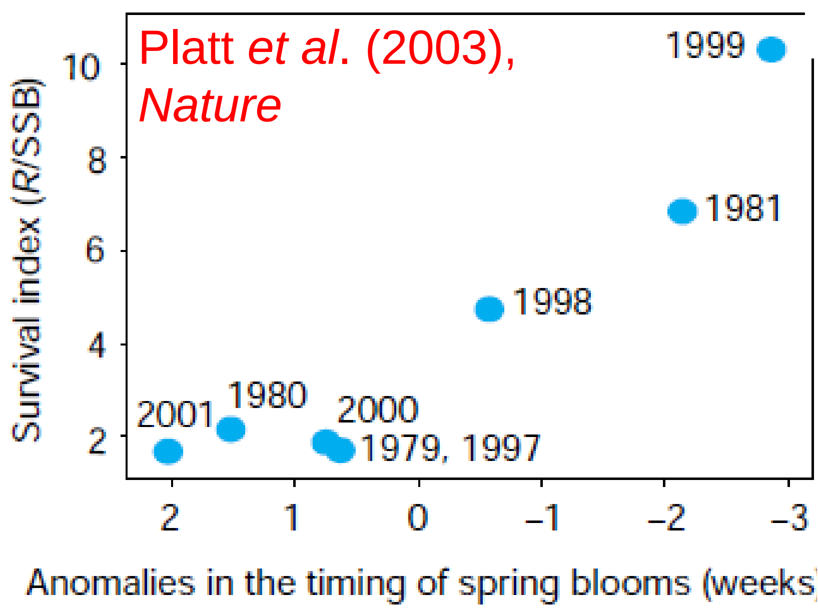
Why Examine Phytoplankton Phenology?

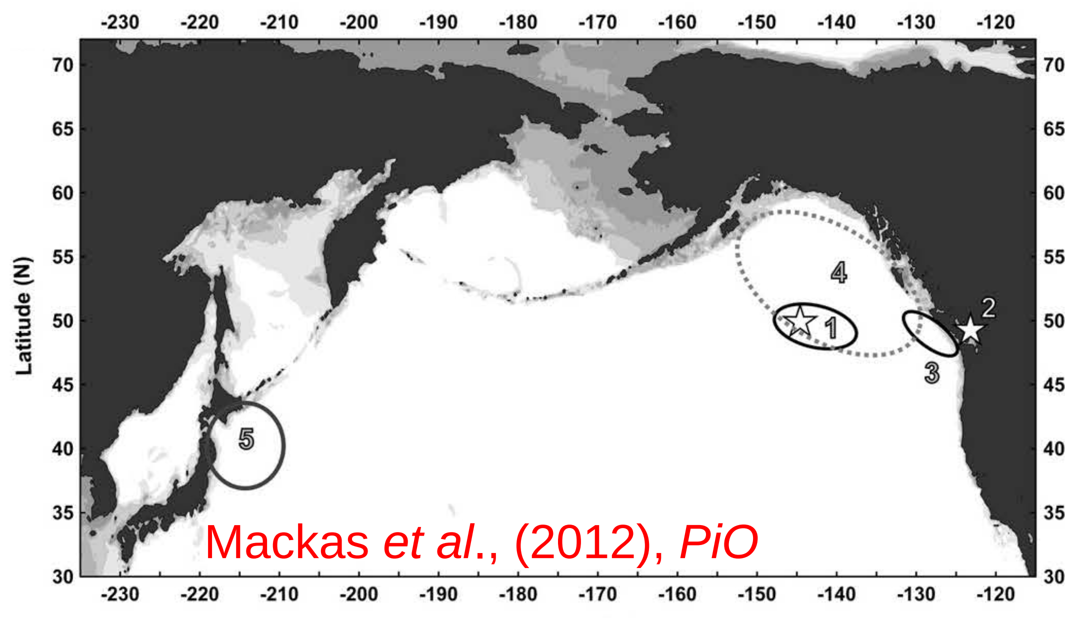
- Growing season changes affect annual primary production and export production

- Models can be validated globally with ocean color data

Locations of Zooplankton Phenology Time Series

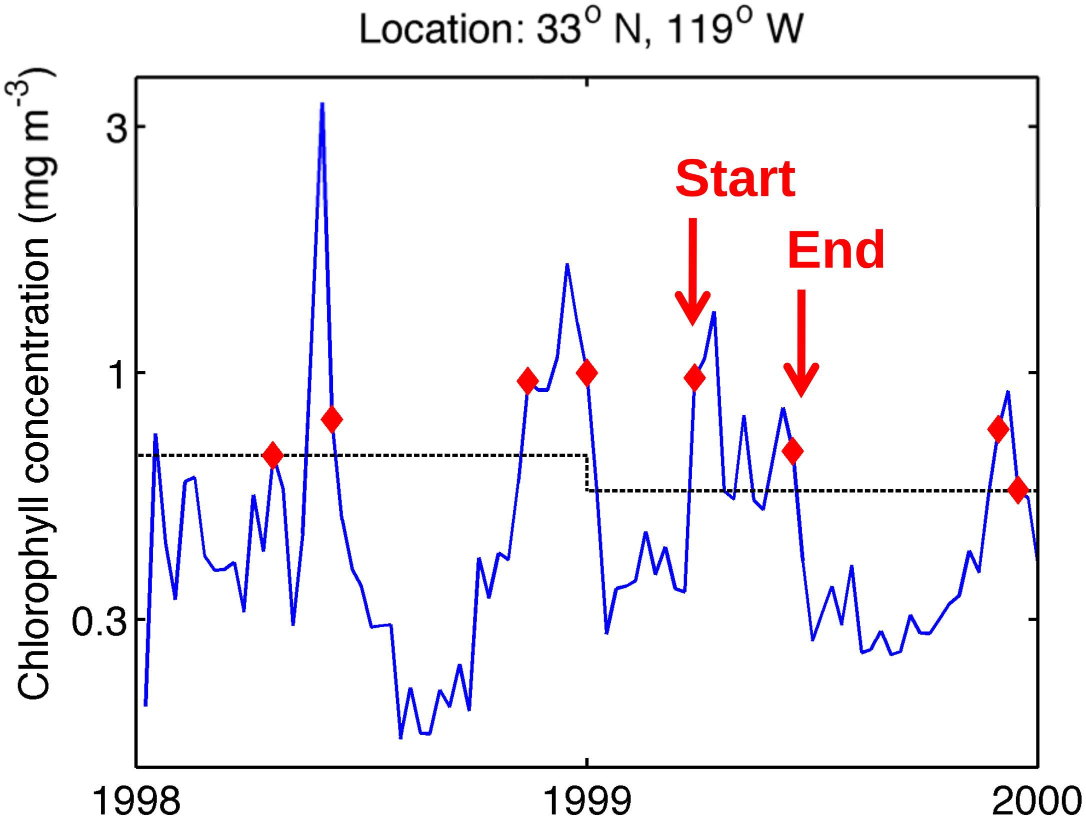






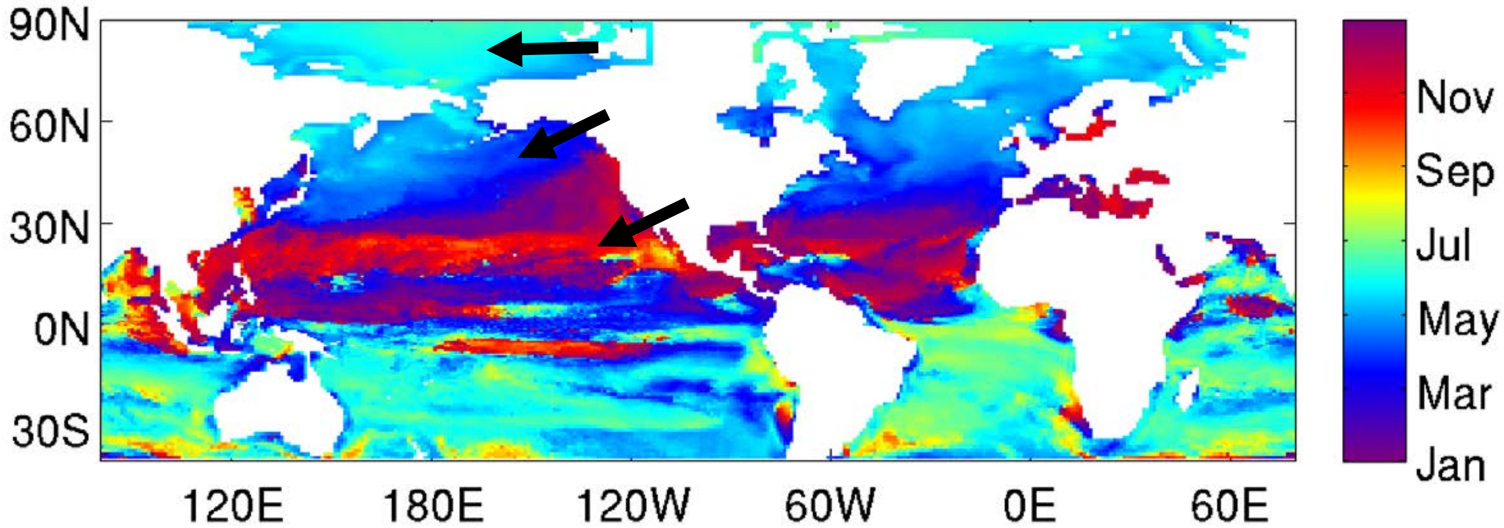
Detection of Phytoplankton Blooms

- **Bloom initiation:** Date when time series first exceeds 75th quantile of annual range
- **Bloom termination:** Time series drops below threshold for > 5 time steps
- **Other metrics:** Bloom midpoint, Bloom duration, Bloom magnitude
- Focus on first bloom of the year
- Emissions scenario: RCP 8.5
- Years: 1862-2099

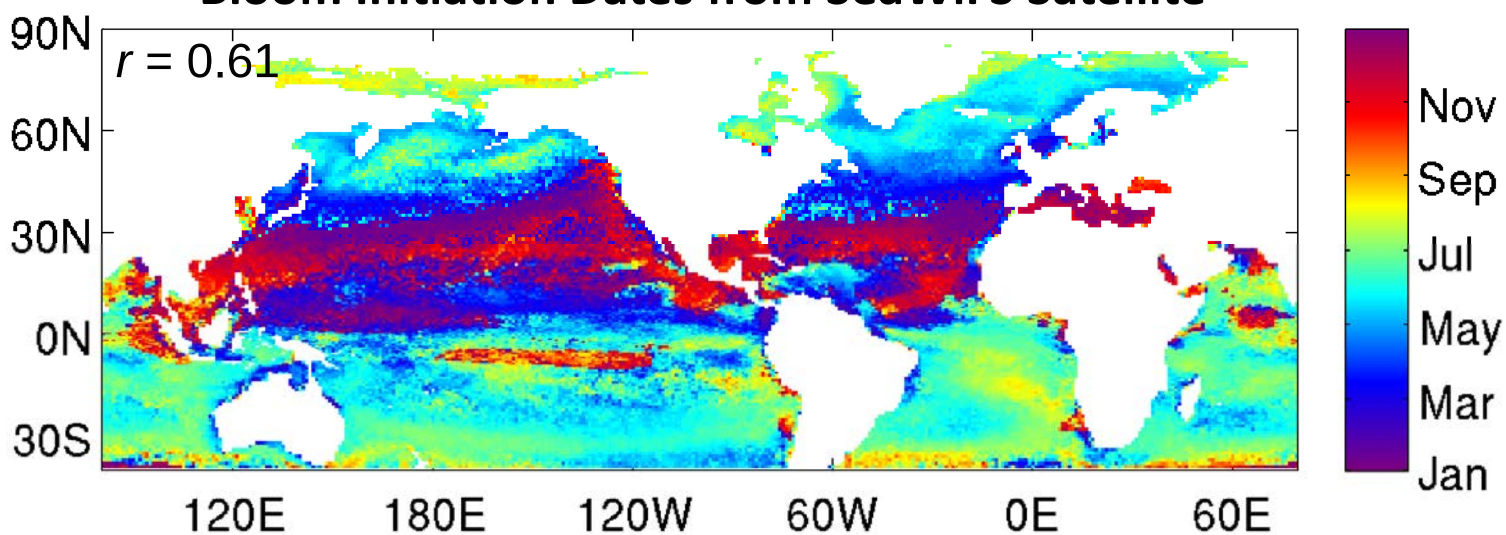


How Well Does the Model Work?

Bloom Initiation Dates from GFDL ESM2M Model



Bloom Initiation Dates from SeaWiFS Satellite

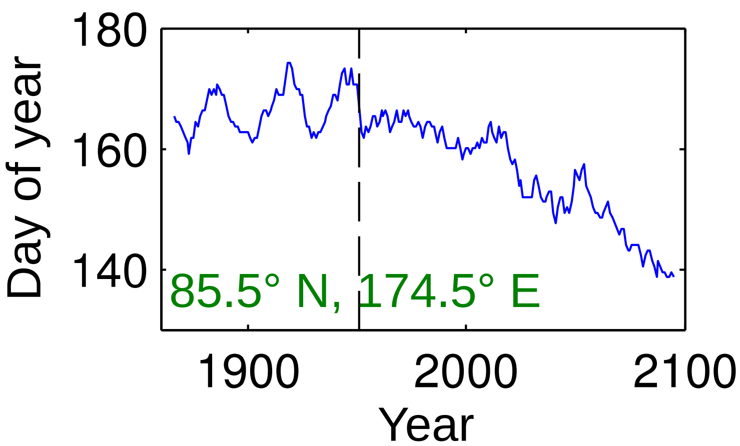


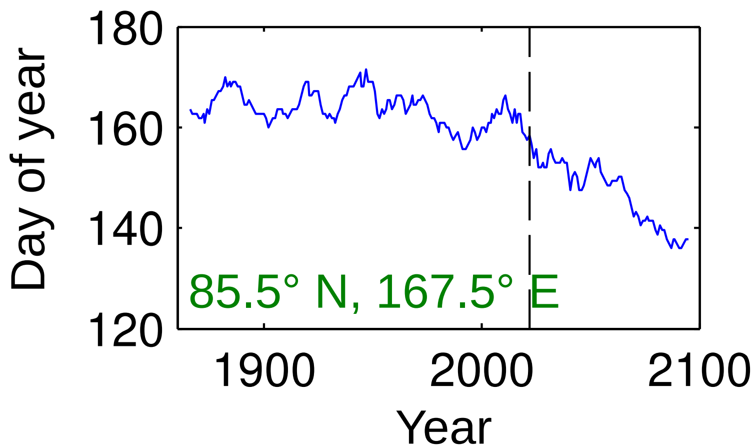
Midpoint: r = 0.67; End: r = 0.65; Duration: r = 0.33; Magnitude: r = 0.74

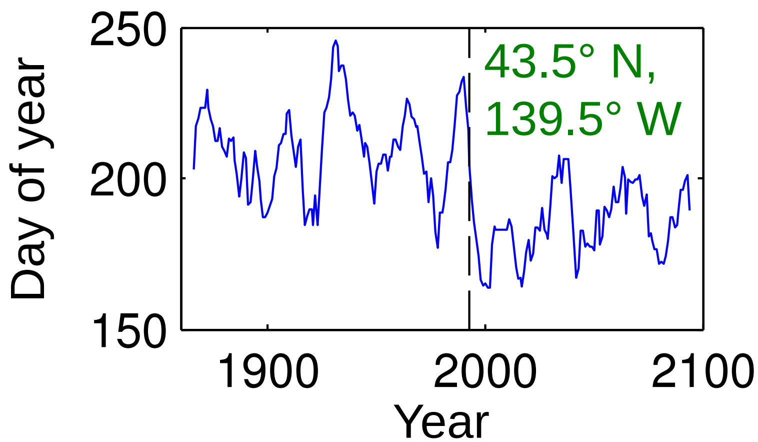
Are There "Thresholds" in Time Series of Phytoplankton Phenology?

- Bayesian change point detection algorithm (Ruggieri, 2013)
- Can detect changes in slope, mean, and variance

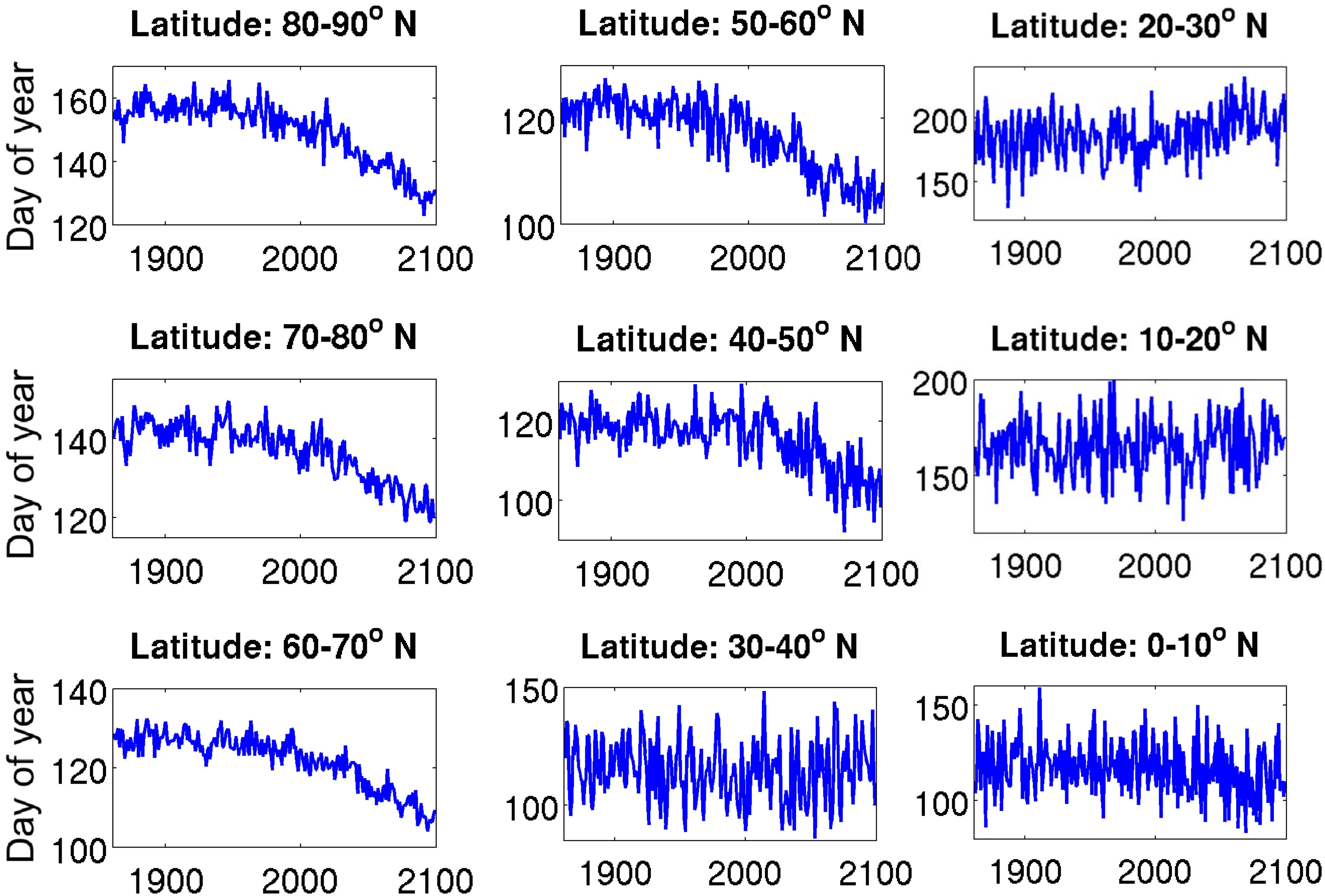
Examples of Changes in Bloom Initiation Dates



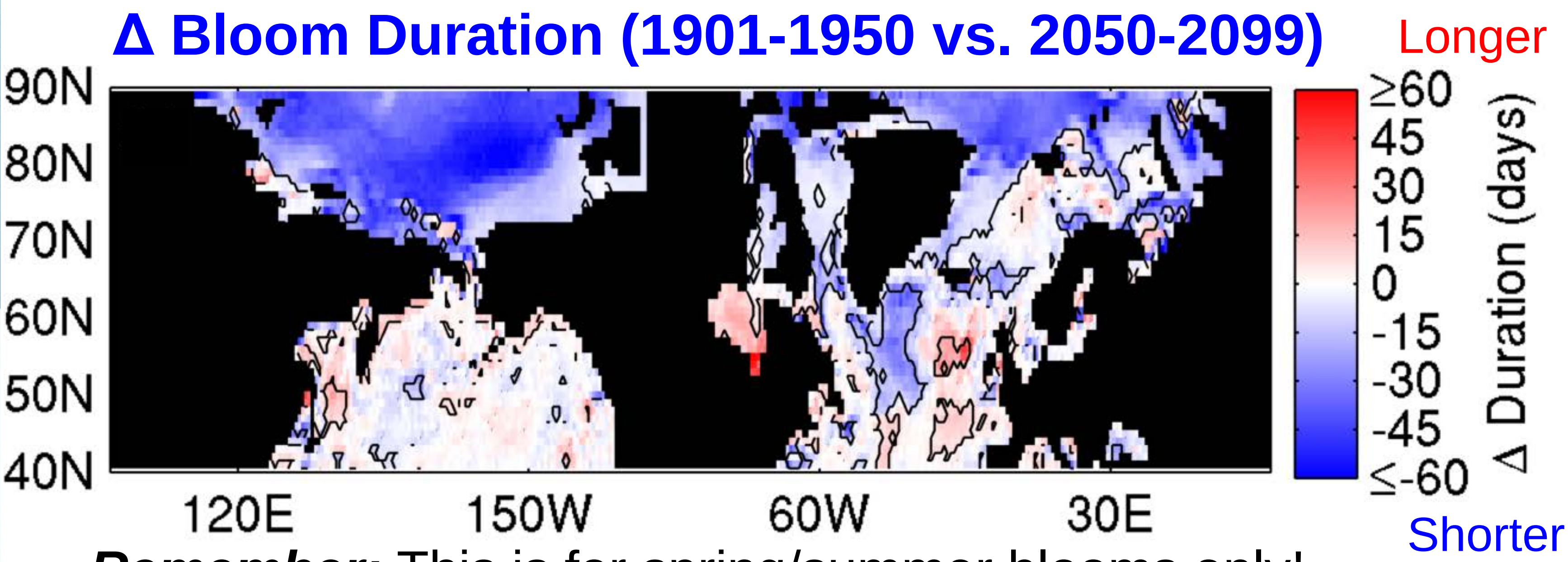




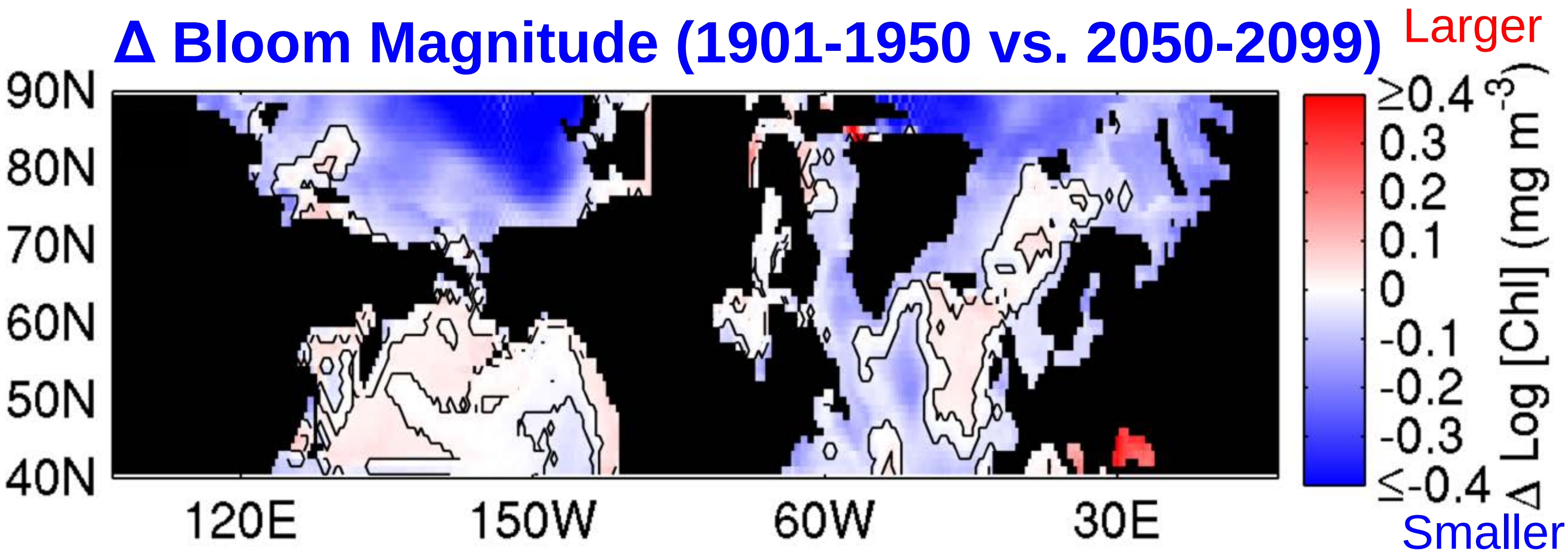
Trends in Bloom Initiation Dates



Changes in Other Bloom Characteristics



- ***Remember:*** This is for spring/summer blooms only!



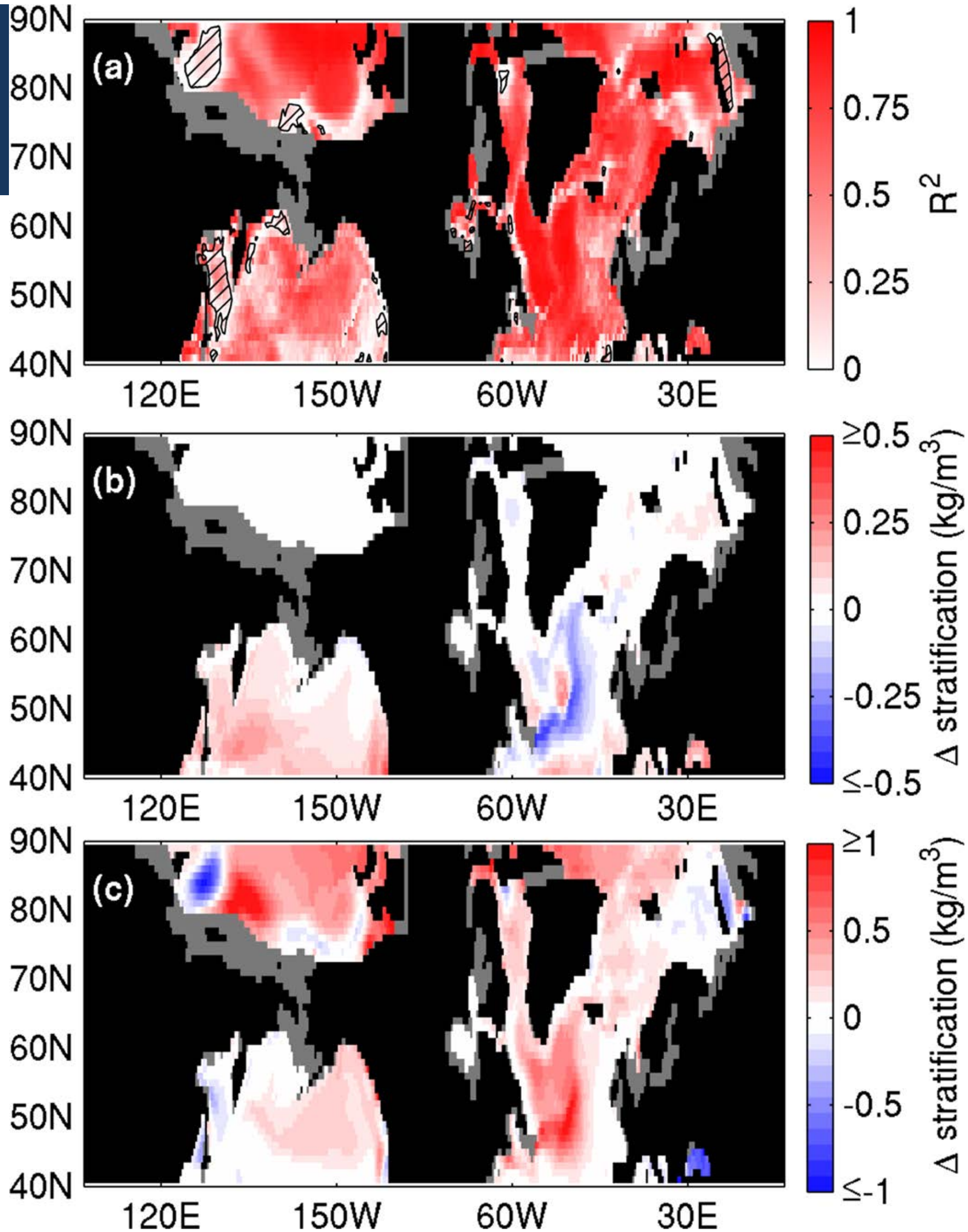
Influences on Bloom Timing

Correlations between bloom initiation & stratification between 0 m & 100 m

Contribution of temperature to stratification changes

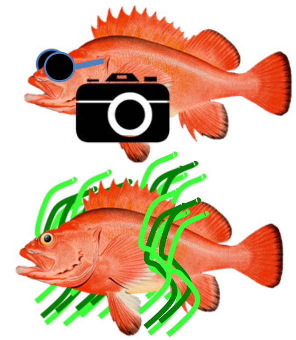
Contribution of salinity to stratification changes

Bloom timing depends on multiple oceanographic factors



Modeling the Spawning Phenology of Temperate, Epipelagic Fishes

<u>Model Framework</u>:



1. Geographically based and environmentally based spawners (Reglero *et al*., 2012)

2. During a baseline period (1901-1950), on average fishes spawned coincident with the first phytoplankton bloom of the year.

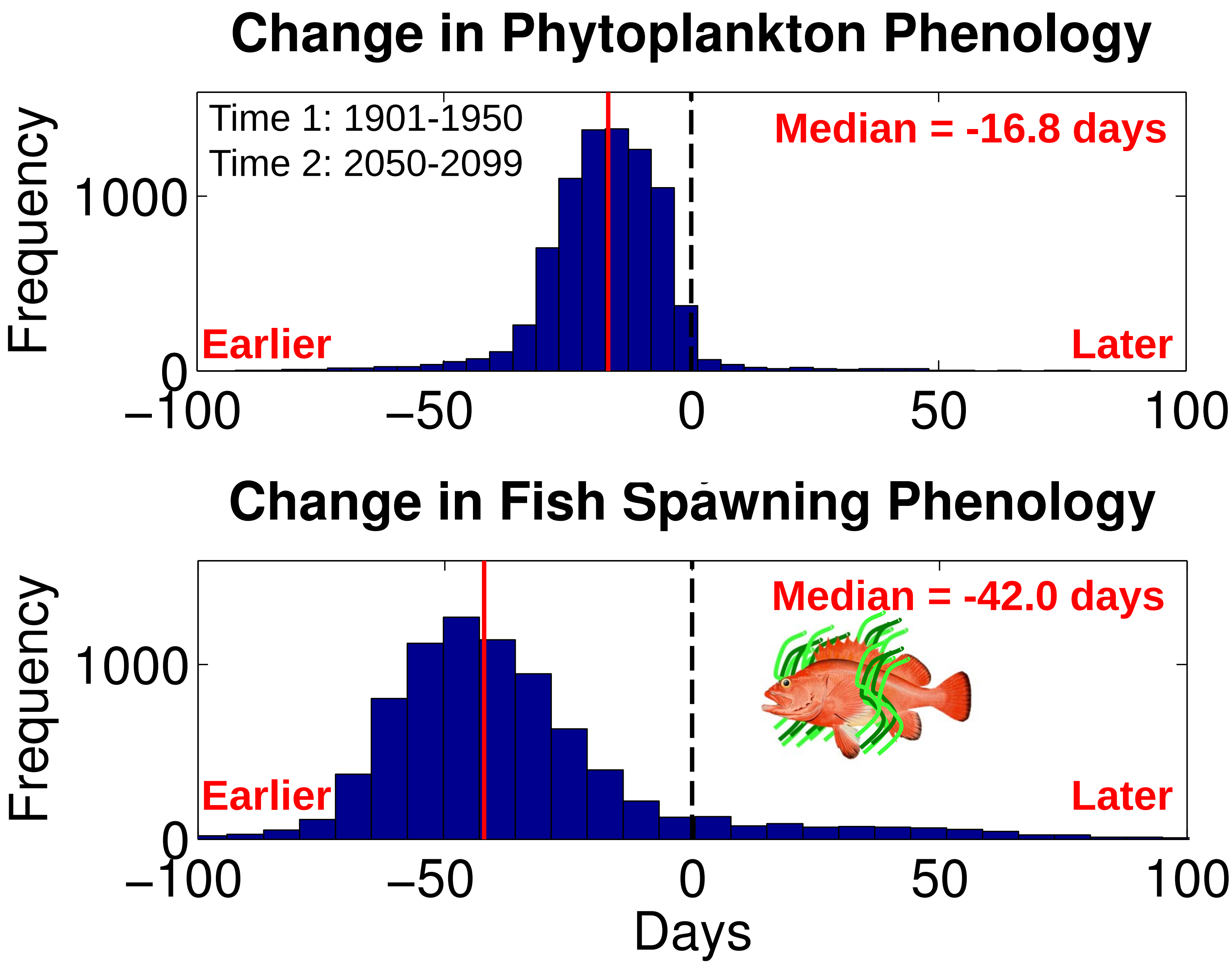
3. Interannual variability in spawning reflects cumulative degree days (°D).

$$^{\circ}D_t = {}^{\circ}D_{t-1} + \max[T_t - T_0, 0]\text{, where}$$

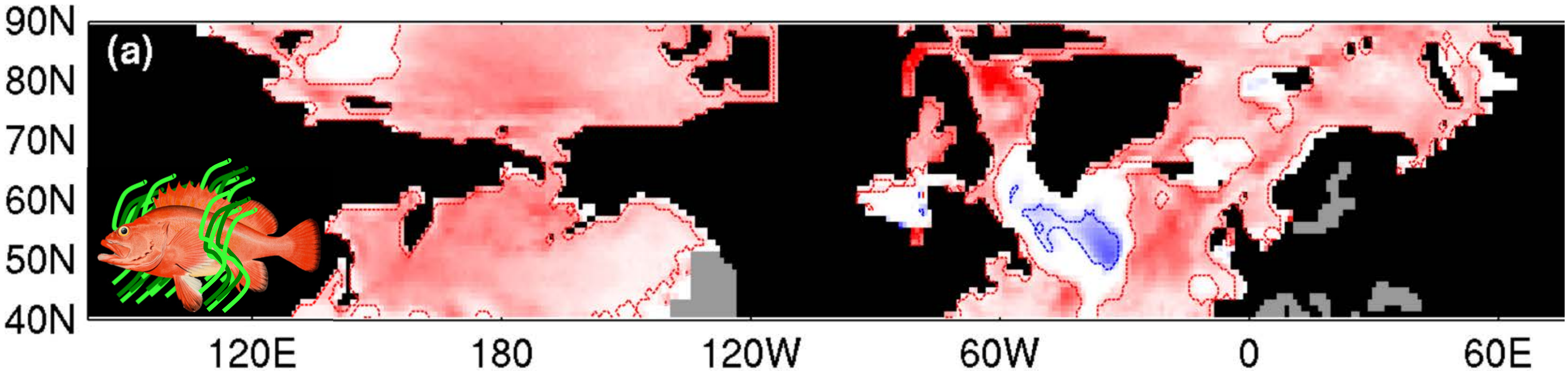
T = temperature, T_0 = base temperature, and t = time step (day)

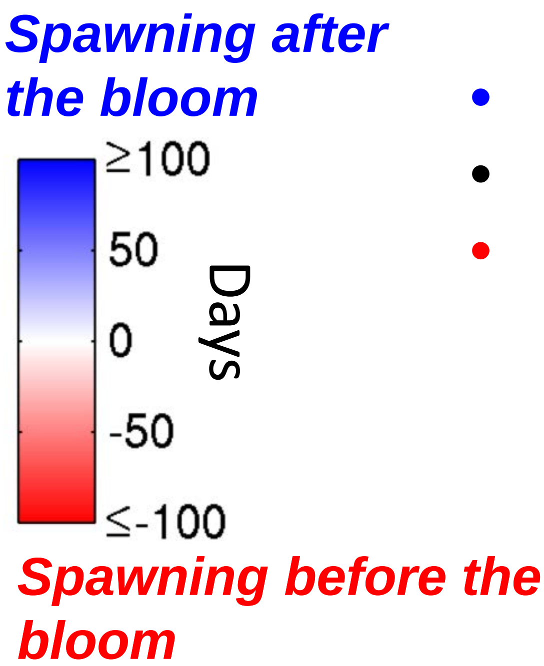
4. No genetic or behavioral adaptation → Degree day threshold for spawning remains constant in 2050-2099.

How Do Rates of Change Compare Amongst Phytoplankton & *Geographic* Spawners?



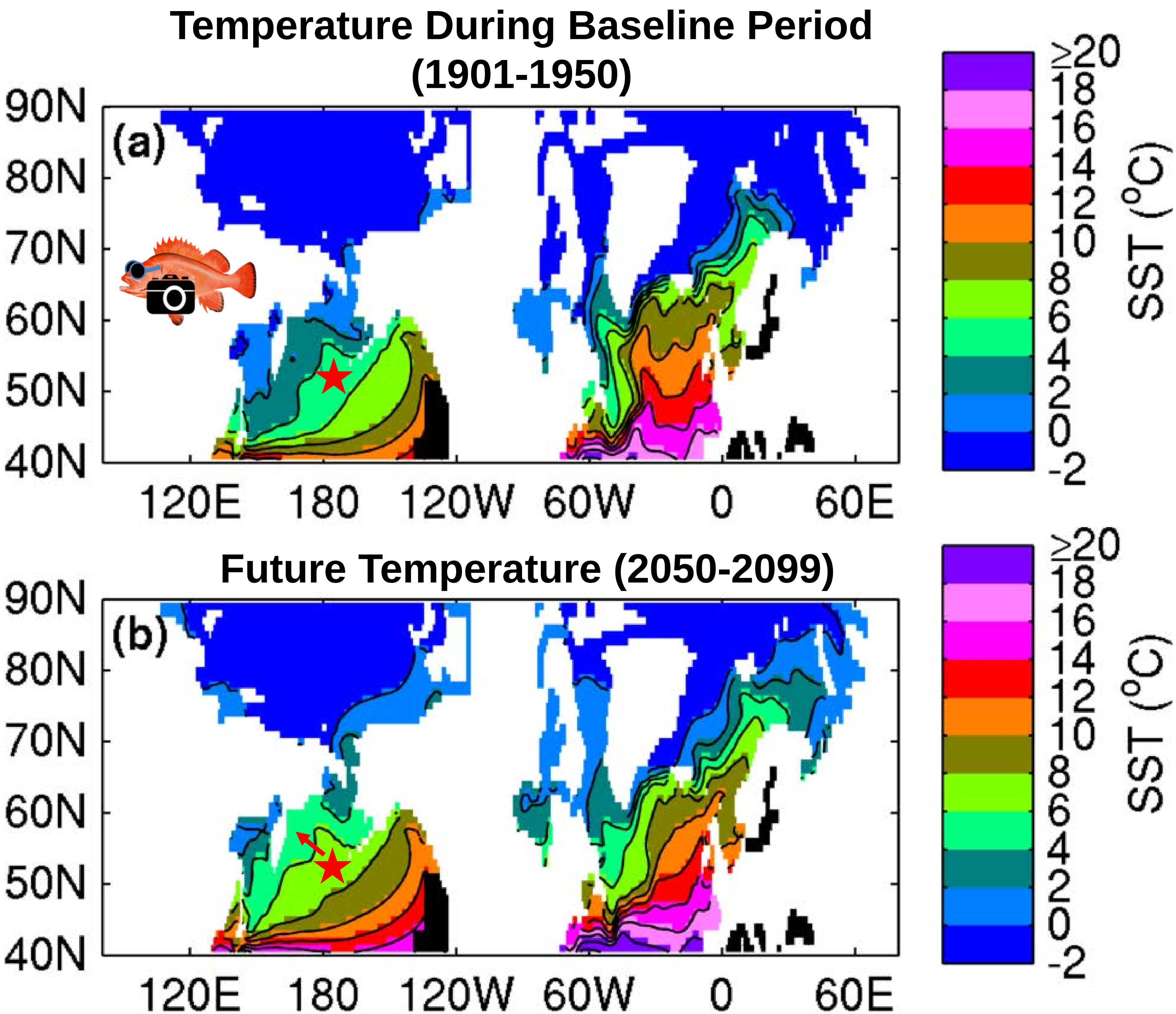
Mean Projected Mismatch between *Geographic* Spawners & Phytoplankton in 2050-2099



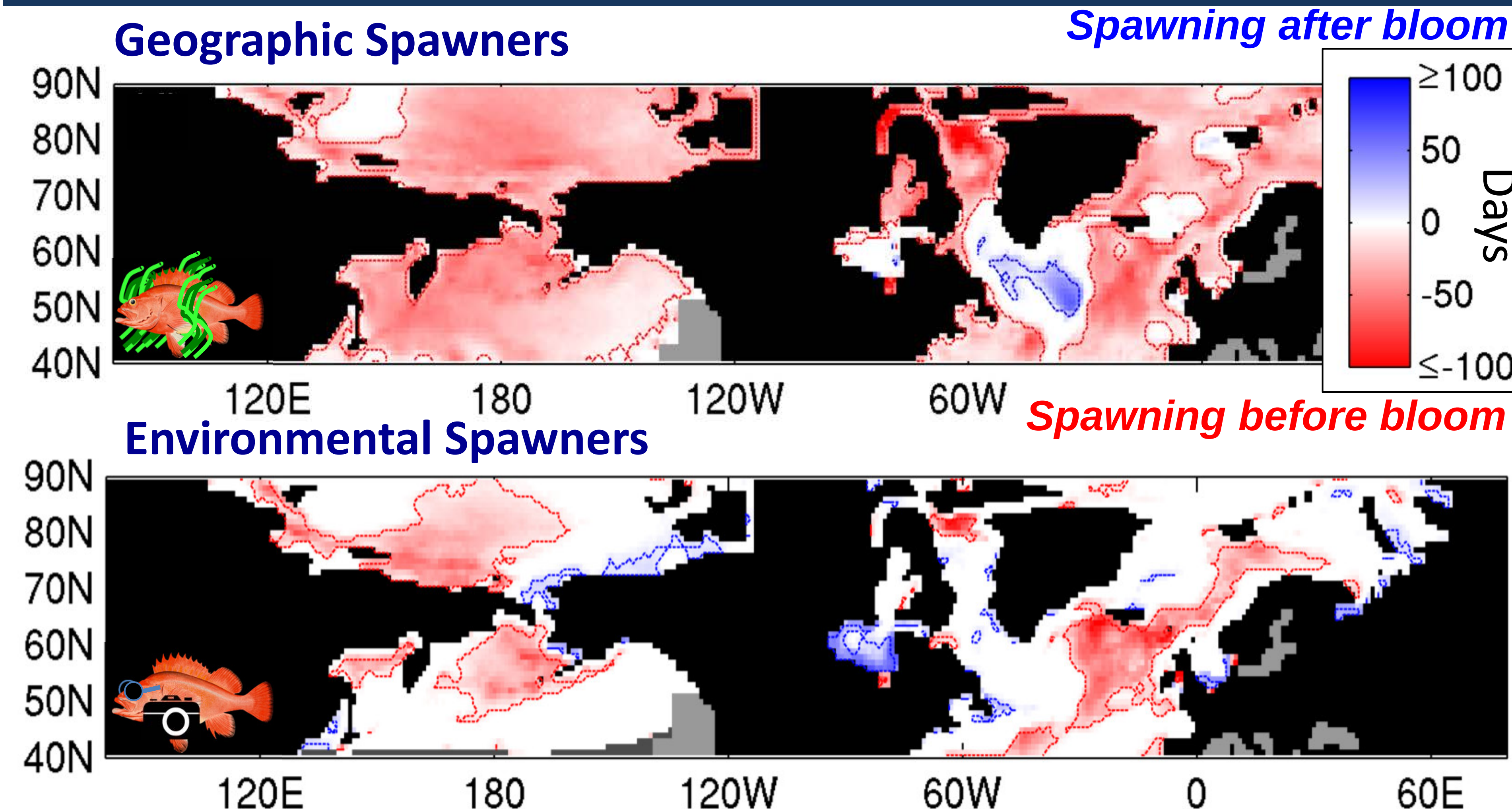


- Spawning after bloom ended – 4.0%
- Spawning during bloom – 9.8%
- Spawning before bloom started – 86.2%

Where Will *Environmental* Spawners Move to?

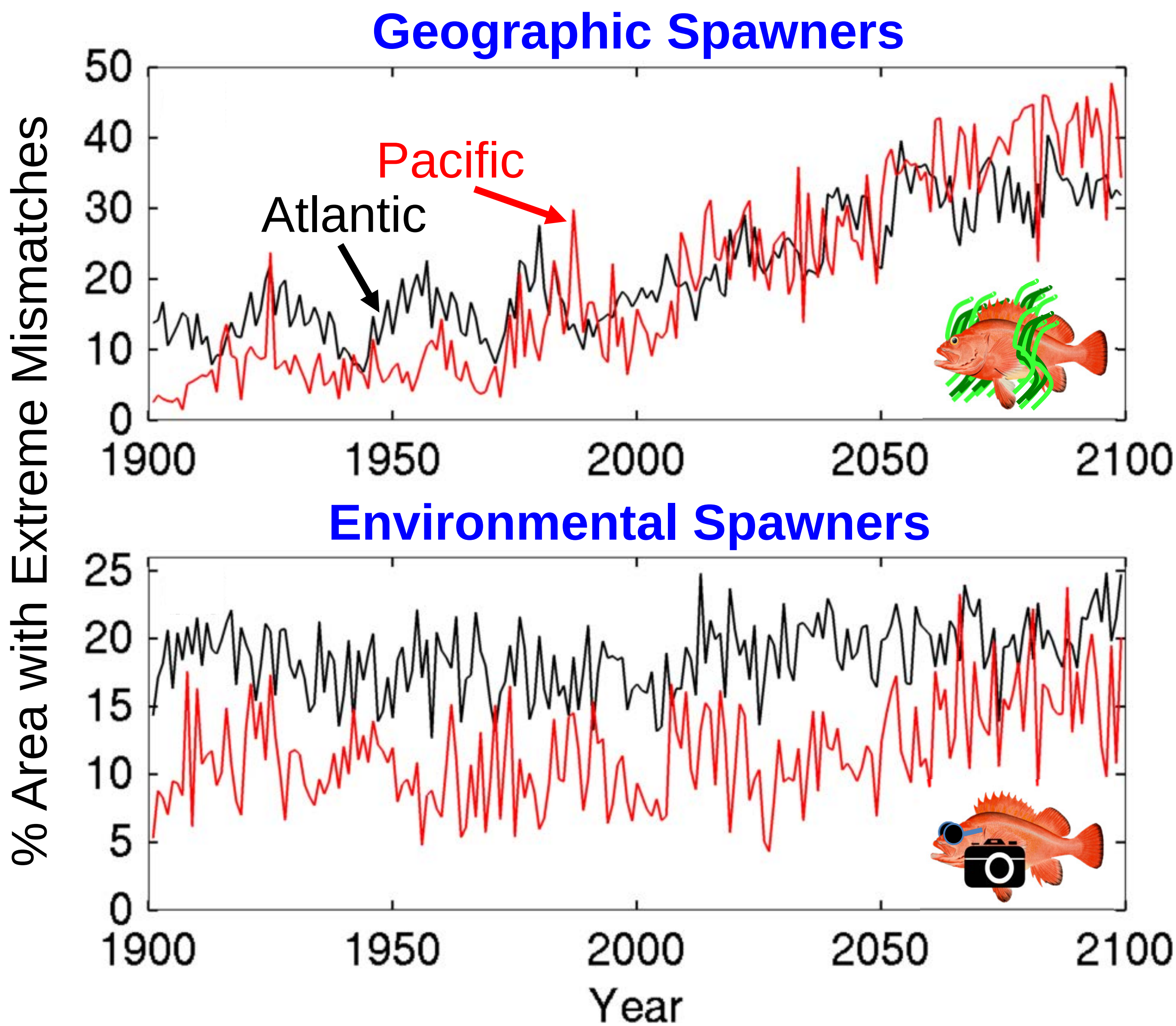


How do Future Mismatches Differ between Geographic and Environmental Spawners?



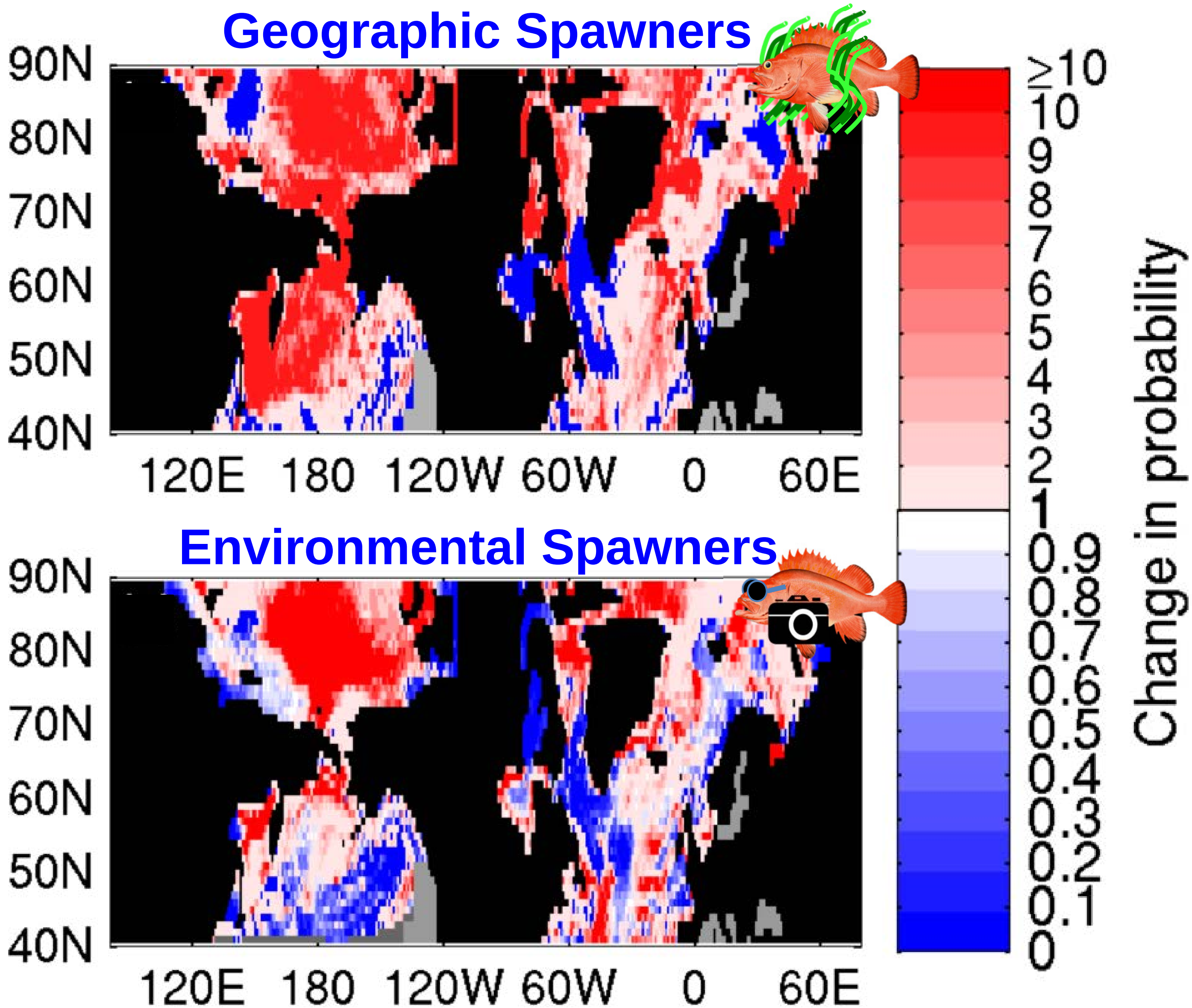
• Spawning after bloom ended	Geo: 4.0%	Env:1.8%
• Spawning during bloom	Geo: 9.8%	Env: 60.3%
• Spawning before bloom started	Geo: 86.2%	Env: 37.9%

“Extreme Events”: Mismatches > 1 Month



“Extreme Events”: Mismatches > 1 Month

- Ratios between future & baseline probabilities of extreme mismatches
- Ratio = 2 → Probability of extreme mismatches doubles
- Ratio = 0.5 → 50% reduction in probability of extreme mismatches





Hypotheses

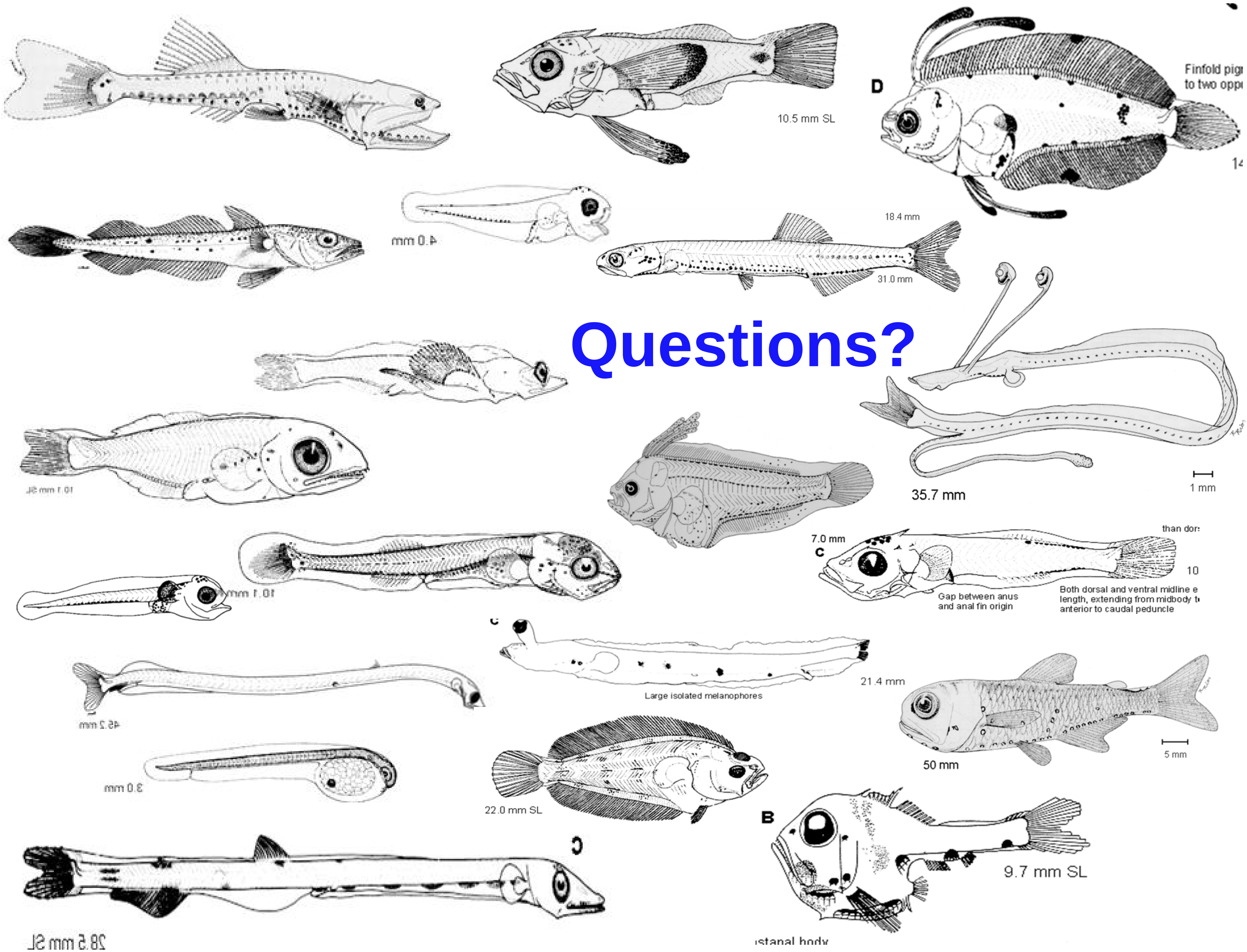
- Climate change will lead to both earlier phytoplankton blooms and fish spawning – Yes
- Sensitivity to climate change will different among trophic levels, leading to a greater frequency of seasonal mismatches – Most likely
- Range shifts among fishes may ameliorate the extent of seasonal mismatches – Yes, but not in all regions



Broader Implications

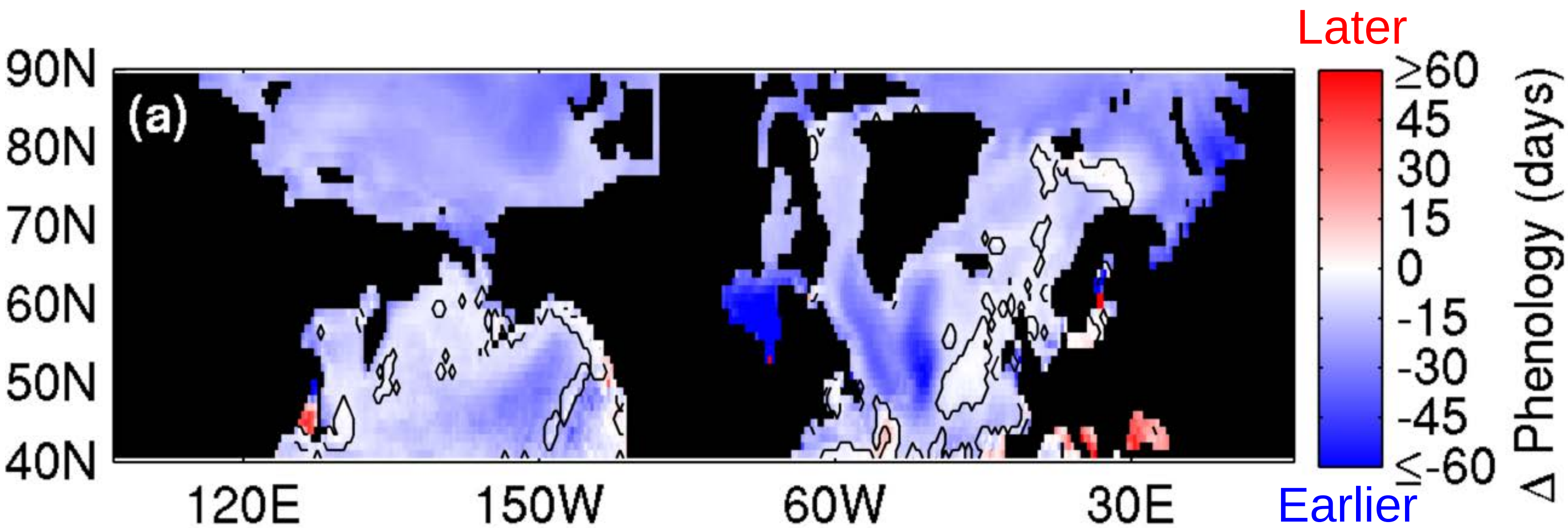
- Species with fixed spawning grounds may be particularly vulnerable to future changes.
- “Extreme events” deserve greater consideration when addressing the biological impacts of climate change.
- Approach is relevant to other organisms beyond fishes.

Questions?



10.5 mm SL
D
18.4 mm
31.0 mm
35.7 mm
1 mm
7.0 mm
C
Gap between anus and anal fin origin
21.4 mm
Large isolated melanophores
50 mm
5 mm
22.0 mm SL
B
9.7 mm SL

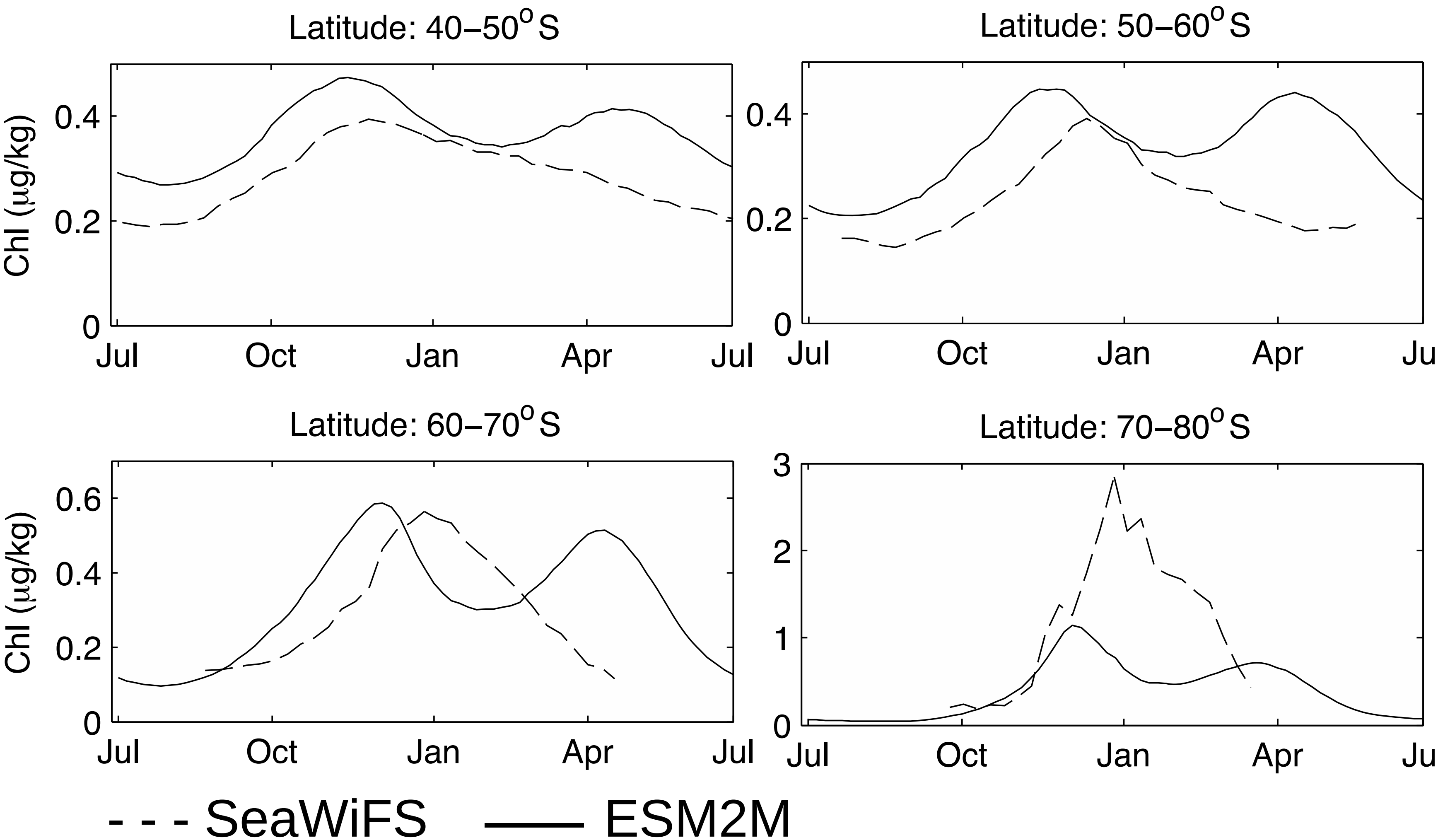
Changes in Bloom Initiation Dates



- Compares baseline (1901-1950) and future (2050-2099) periods
- Contour lines separate areas with significant and non-significant changes at $p < 0.05$

Southern Ocean Phenology

Climatology for 1998-2007



- Differences attributable to overly shallow MLD, Fe limitation, and changes in Chl:C ratio in ESM2M

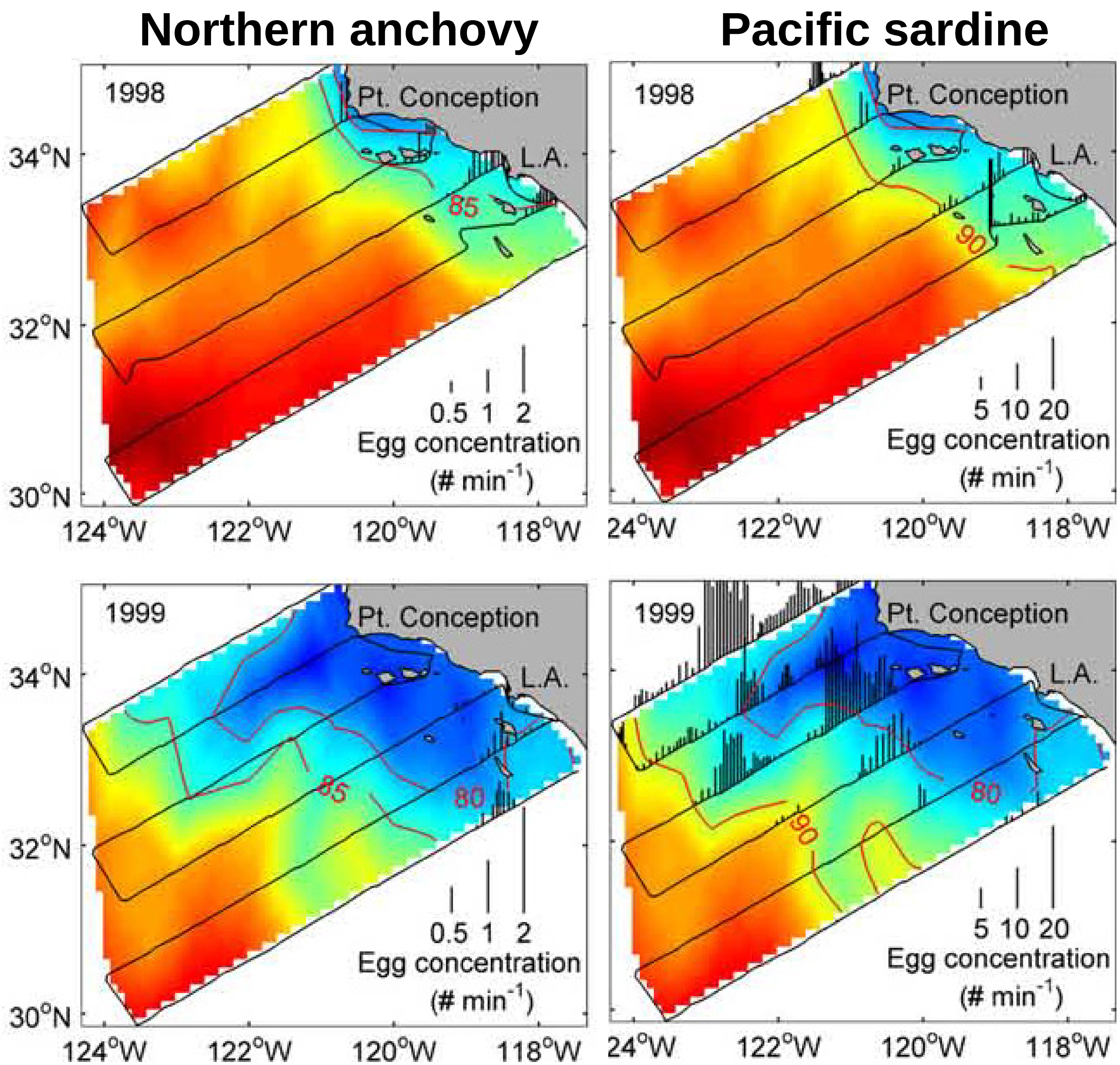
Modeling Spawning Phenology of Temperate, Epipelagic Fishes

<u>Model Framework</u>:

1. Two categories of spawning behavior:

   → Geographically based spawning

   → Environmentally based spawning **(Reglero *et al*., 2012)**



Asch and Checkley (2013)

Change in Temperature between 1901-1950 and 2050-2099