# Forecasting distribution shifts using oceanographic indices: the spatially varying effect of cold-pool extent in the Eastern Bering Sea

James Thorson

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# Spatially-varying effects

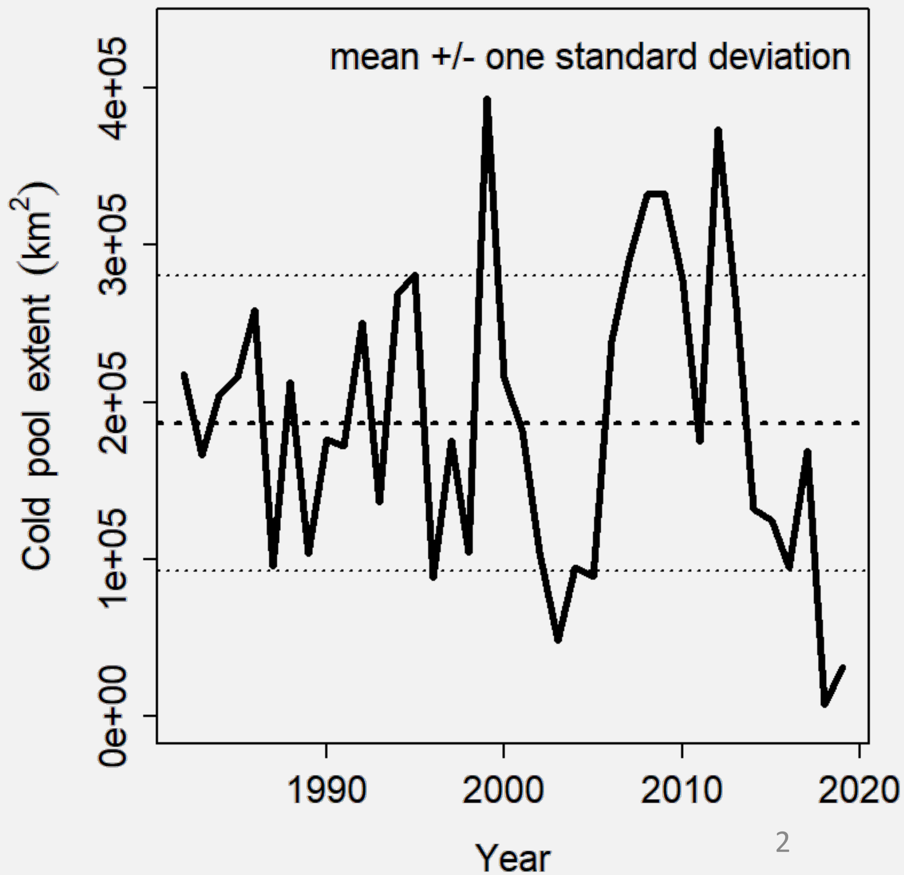
## Question

*How to identify the impact of oceanographic indices (e.g., PDO) on fish distribution*

## Approach

Develop model with "spatially varying coefficients"

- Represents localized impact of regional oceanographic index on local density
- Estimates "map" of response to regional conditions



# Spatially-varying effects

**Three interpretations of a spatially-varying coefficient model:**

1. Varying slope model
2. Regression of spatio-temporal variation $\varepsilon(s,t)$ on covariate $X(s,t)$ for each location $s$
3. Map of “teleconnections” for nonlocal environmental conditions on local density

# Spatially-varying effects

**What is a spatially-varying coefficient model:**

- Conventional linear model

$$Y(s) = \beta + \gamma X(s) + \varepsilon(s)$$

- Model with spatially varying slope $\gamma(s)$ for covariate $X(s)$ when predicting variable $Y(s)$

$$Y(s) = \beta + \gamma(s)X(s) + \varepsilon(s)$$

- Extension to spatio-temporal models

$$Y(s,t) = \beta(t) + \gamma(s)X(s,t) + \varepsilon(s,t)$$

- … which can be used for effect of regional conditions

$$Y(s,t) = \beta(t) + \gamma(s)X(t) + \varepsilon(s,t)$$

Where

- $Y(s)$ is response and $X(s)$ predictor at location $s$
- $\beta$ is intercept and $\gamma(s)$ a slope term
- $\varepsilon(s)$ is residual error

# Spatially-varying effects

## Case study methods:

- Fit to multispecies survey
  - 17 groundfish and crabs
  - Eastern Bering Sea
- Compare four models
  1. No covariates ("None")
  2. Local temperature effect ("Temp")
  3. Spatially-varying cold pool effect ("Cold pool")
  4. Both temperature and cold pool ("Both")

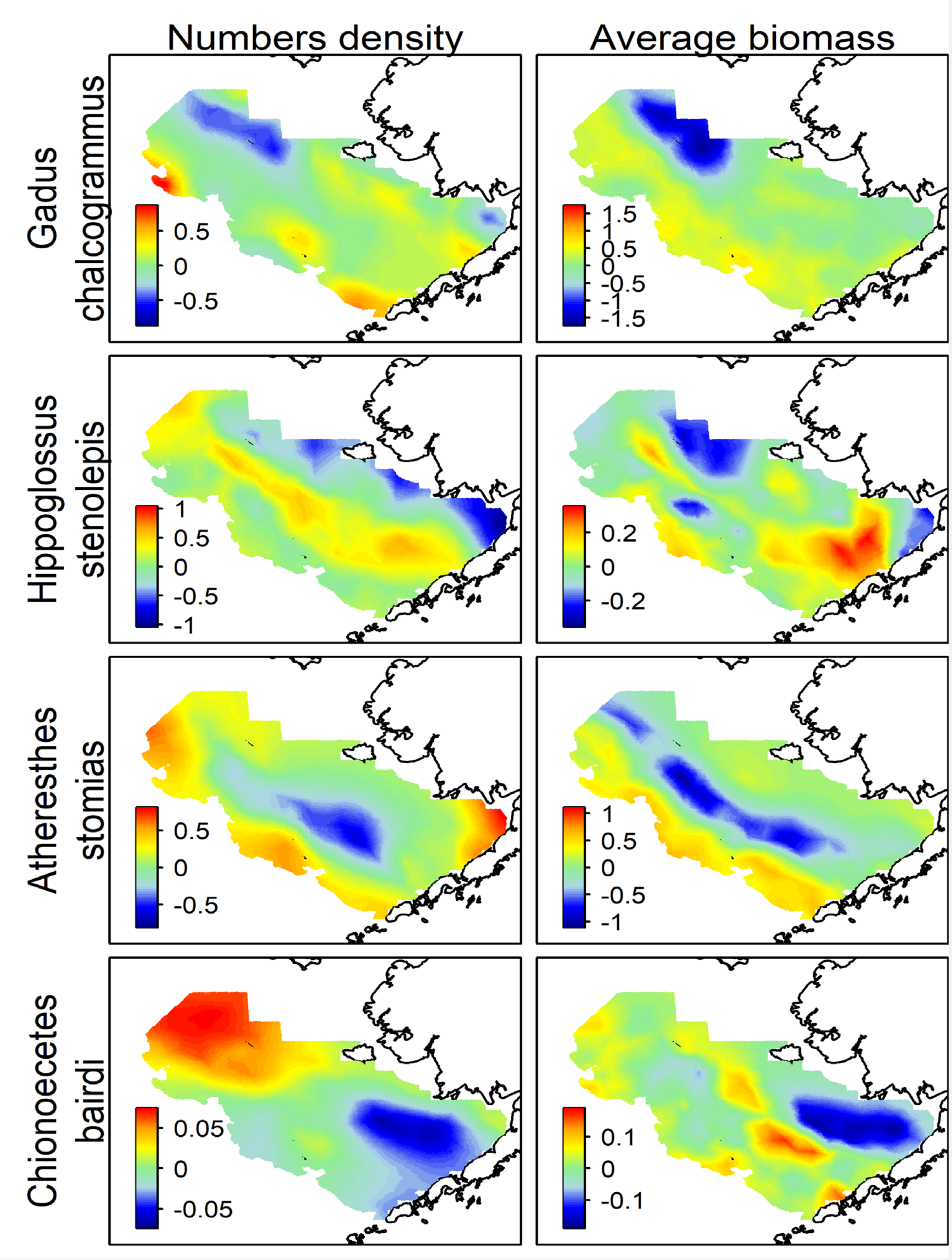
AIC for model fits (best fit in **Bold**)

| | None | Temp | Cold Pool | Both |
|---|---|---|---|---|
| Gadus chalcogrammus | 239.4 | 68.2 | 138.5 | **0.0** |
| Gadus microcephalus | 528.6 | 134.4 | 363.8 | **0.0** |
| Hippoglossoides elassodon | 175.5 | 6.2 | 142.6 | **0.0** |
| Chionoecetes opilio | 38.4 | **0.0** | 37.8 | 0.5 |
| Hippoglossus stenolepis | 260.9 | 87.5 | 178.4 | **0.0** |
| Limanda aspera | 79.8 | 6.4 | 67.4 | **0.0** |
| Pleuronectes quadrituberculatus | 70.3 | 37.4 | 20.7 | **0.0** |
| Chionoecetes bairdi | 0.8 | 6.5 | **0.0** | 5.8 |
| Podothecus accipenserinus | 212.3 | 7.4 | 157.5 | **0.0** |
| Atheresthes stomias | 475.4 | 34.6 | 365.8 | **0.0** |
| Hyas coarctatus | 31.5 | 11.0 | 17.3 | **0.0** |
| Myoxocephalus polyacanthocephalus | 85.5 | 19.5 | 47.3 | **0.0** |
| Lycodes palearis | 98.4 | 8.5 | 62.4 | **0.0** |
| Myoxocephalus jaok | 104.5 | 26.4 | 70.1 | **0.0** |
| Hyas lyratus | **0.0** | 4.3 | 2.2 | 6.7 |
| Paralithodes camtschaticus | 32.4 | 9.1 | 23.1 | **0.0** |
| Lycodes brevipes | 8.1 | **0.0** | 11.2 | 2.8 |

# Spatially-varying effects

**Case study results:**

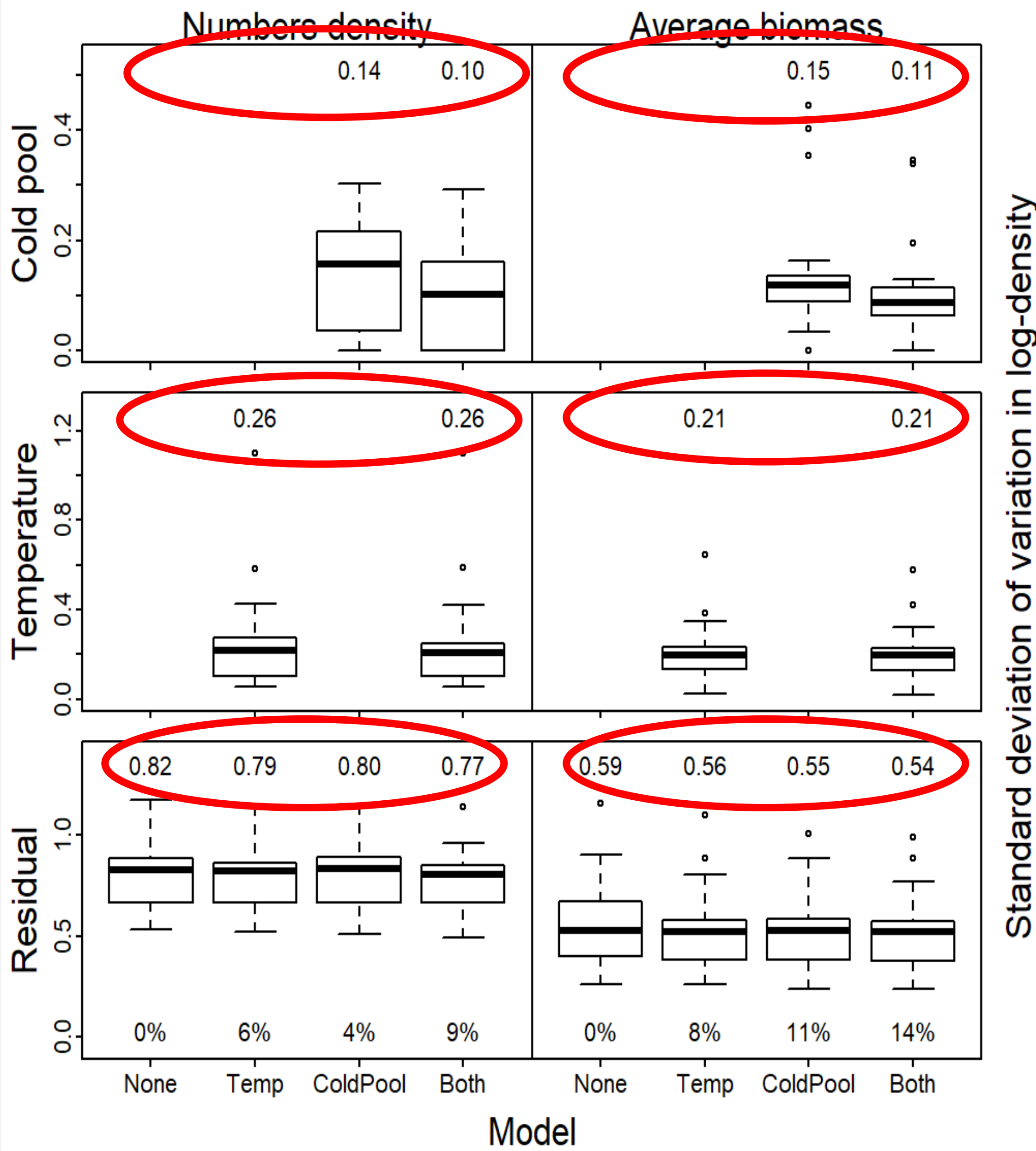
- Spatially varying effect of cold pool is different for each species
  - Distribution is not a simple function of temperature
- Most species show at least some variance associated with cold pool



# Case study results:

- Temperature reduces spatio-temporal variance
  - 6-8% reduction on average
- Both temperature and cold-pool have larger reduction
  - 9-14% reduction on average

Standard deviation of log-density variation for a given process



**Residual variance explained**

# Case study results:

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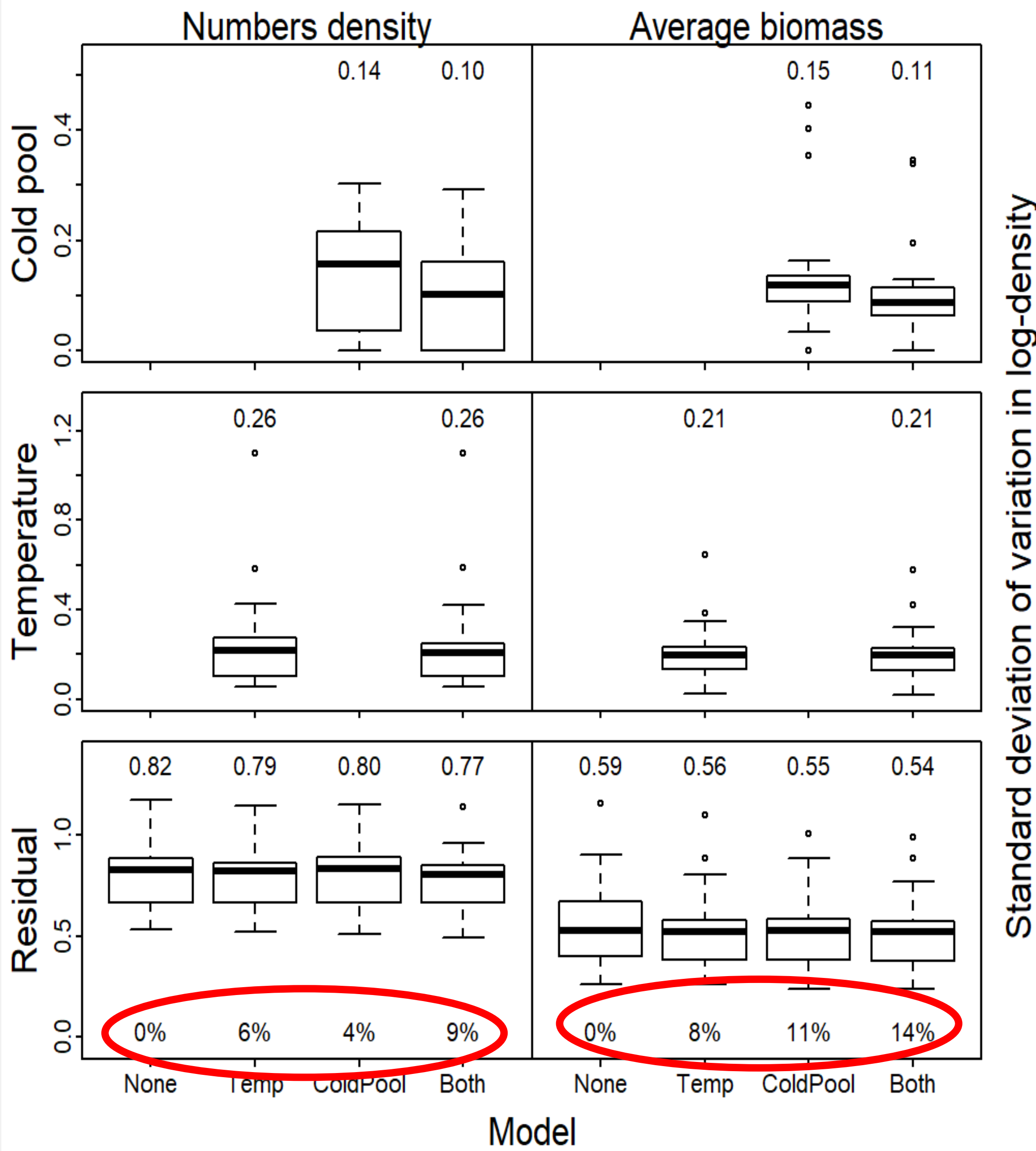


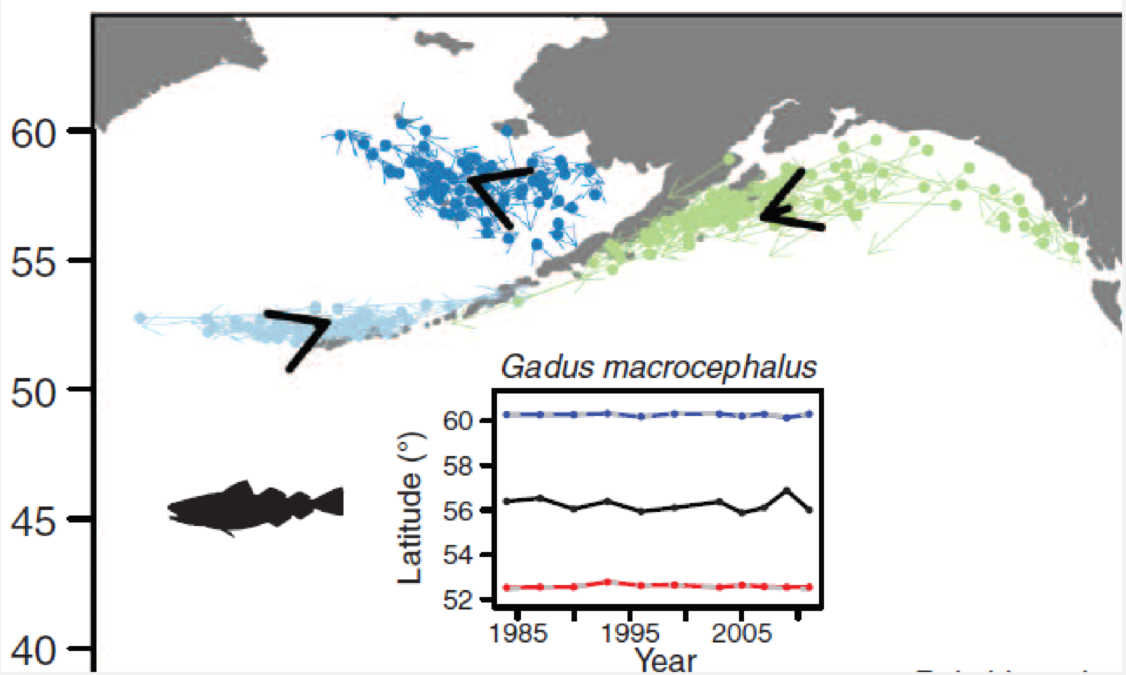
# Spatially-varying effects

Does spatially varying effect of cold pool improve forecasting?

**Skill-test experiment**

1. Run with data through year T
2. Forecast center-of-gravity in year T+1, T+2, …
3. Compare with later measurements

Published hindcast of distribution shifts for Alaska fishes

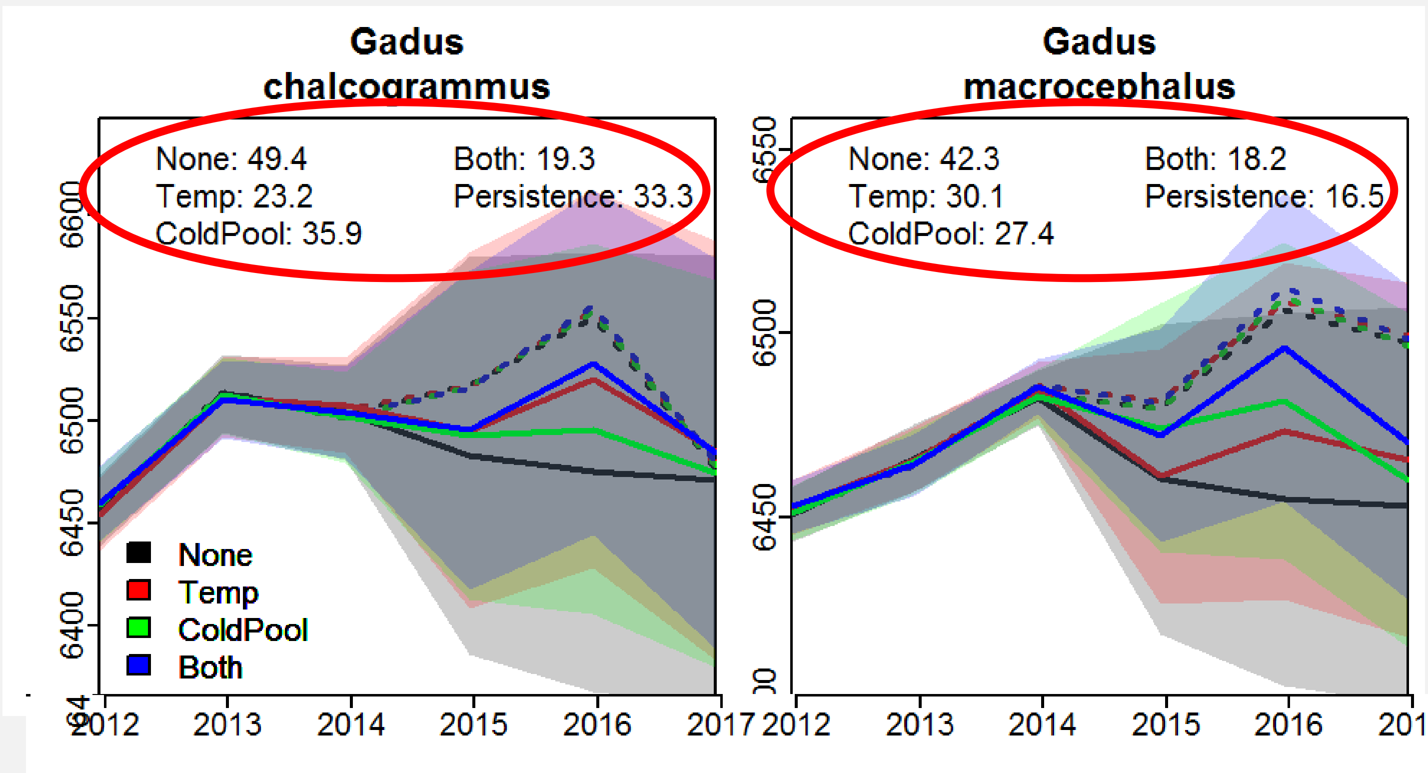



Pinsky et al. 2013 *Science* “Marine taxa track local climate velocity”

# Spatially-varying effects

- Temperature and cold-pool improve forecasts of distribution fitting through 2015 and forecasting 2016/2018
  - Temperature helps with *G. chalcogrammus*
  - Cold pool helps with *G. macrocephalus*

**Error in 3-year forecast**

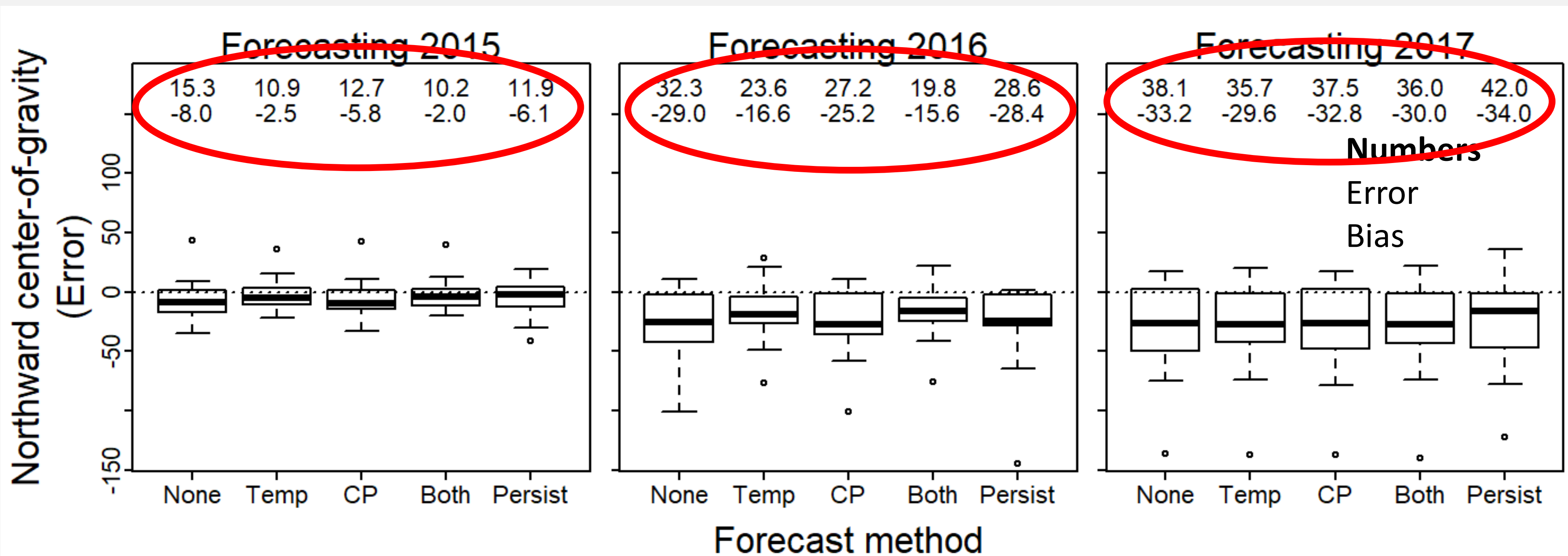


# Spatially-varying effects

**Case study results:**

- Including both temperature and cold-pool reduce errors in northward center-of-gravity relative to a persistence forecast

**Error in 3-year forecast,**
**Averaged across all species**



# Spatially-varying effects

**Other potential uses**

1. Spatially varying effect of calendar date
   - Useful to inter-calibrate samples collected in different months
2. Identify locations with largest changes over time
   - Estimate spatially-varying coefficient associated with year
3. Include regional effects during index standardization
   - Easy method to include non-local environmental conditions in models being used in stock assessment

# Combining multiple surveys

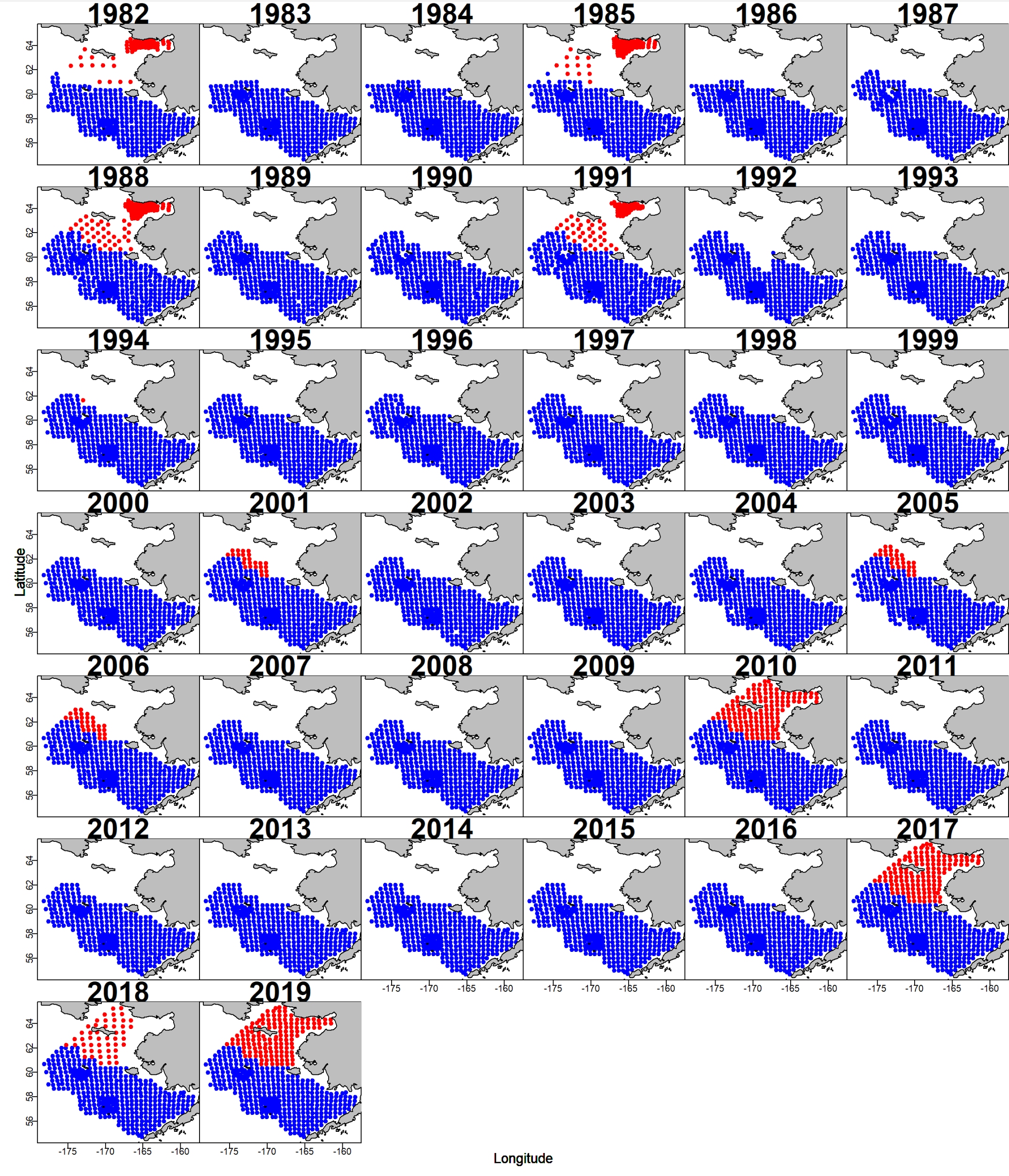
**Photo**: Chris Miller, csmphotos.com

Cecilia O'Leary, Jim Ianelli, Jim Thorson, Stan Kotwicki

# Combining multiple surveys

## Background

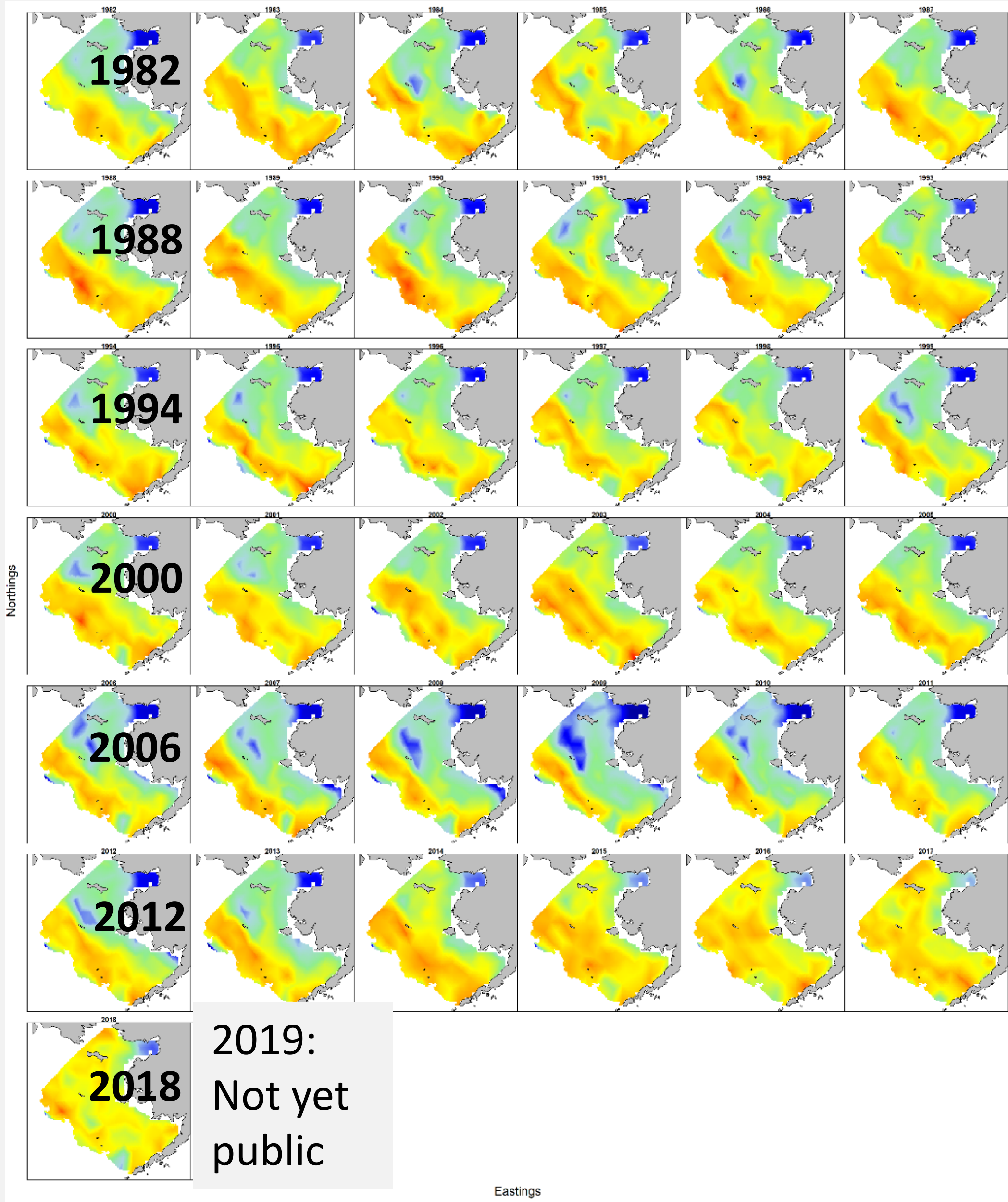
- **Eastern Bering Sea** surveyed 1982-2019
- **Northern Bering Sea** surveyed sporadically, and 2010, 2017-2019



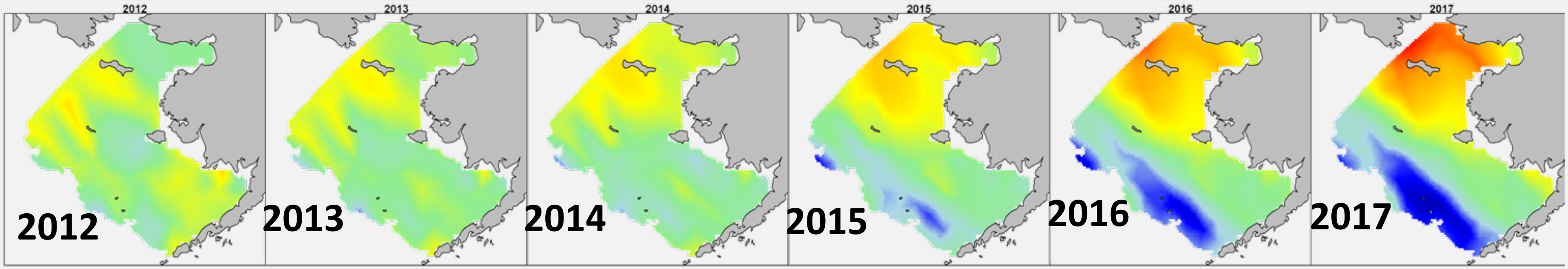
# Combining multiple surveys

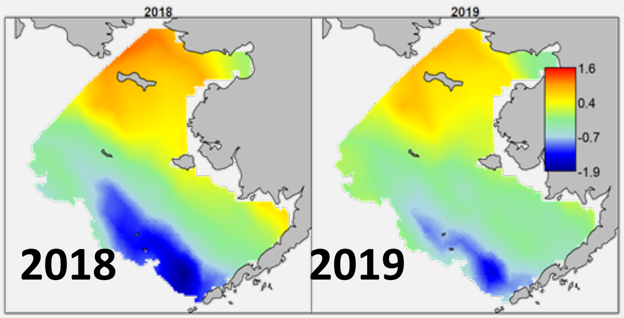
## Background

- Spatio-temporal model (VAST) used to combine eastern and northern Bering Sea for pollock assessment in 2018
- How to improve estimates in northern Bering Sea in unsampled years?

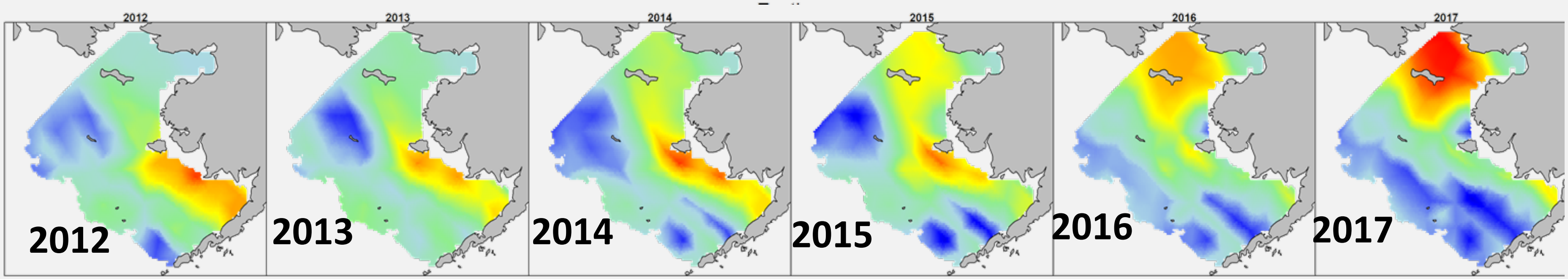


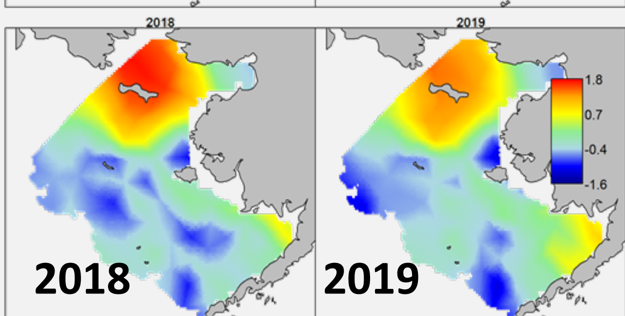
# Combining multiple surveys




**Effect of cold-pool extent on density for pollock**




**Effect of cold-pool extent on density for pollock**

# Spatially-varying effects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