Predator-prey spatial distribution patterns and spatial overlap in relation to climate driven environmental variability

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Some Attributes of Ecosystem Mixing

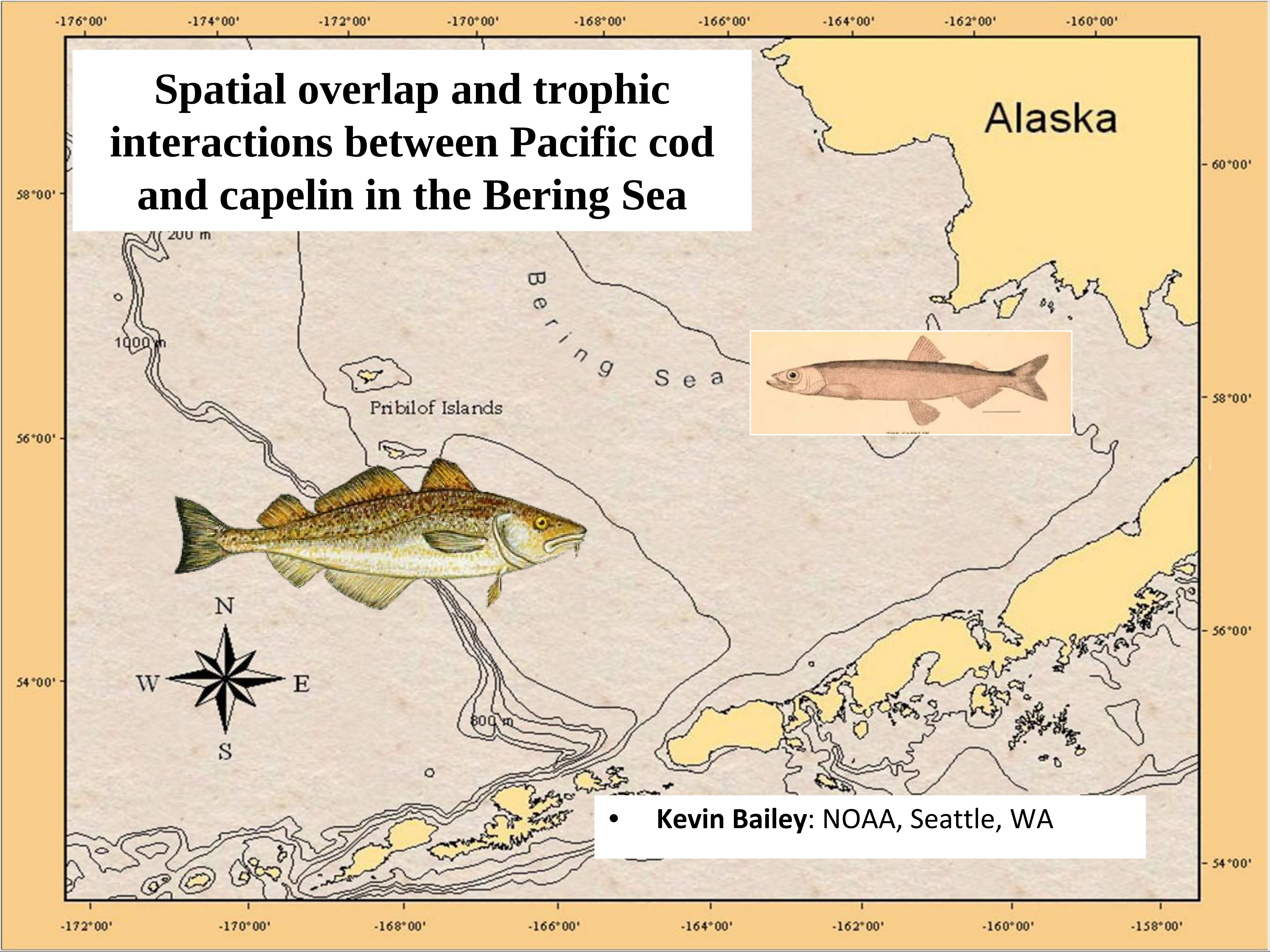
- Involve a change of one or more species distribution and their spatial overlap
  - Quantification of spatial dynamics for each species
  - Quantification of spatial overlap between two species
- Happens across scales
  - Changes of species 'range' (multidecadal)
  - Changes of species 'distribution' (interannual)
- Caused by different processes and have different degree of reversibility
  - Range: colonization of new feeding and spawning grounds and establishments of local adaptations. Hard to reverse
  - Distribution: linked to interannual changes of environmental forcing and demography. Reversible
- Species life history strategies affect the scale of ecosystem mixing
- How hard are we (were we) looking?

Changes of species distribution

- Ultimate cause of ecosystem mixing
- Needed to make inference about future outcome

1. Cod and capelin in the Bering Sea
   - Thermal gateways: conduit for predator-prey interactions
2. Arrowtooth flounder and juvenile pollock in the Bering Sea
   - Demography and hydrography affect distribution and overlap

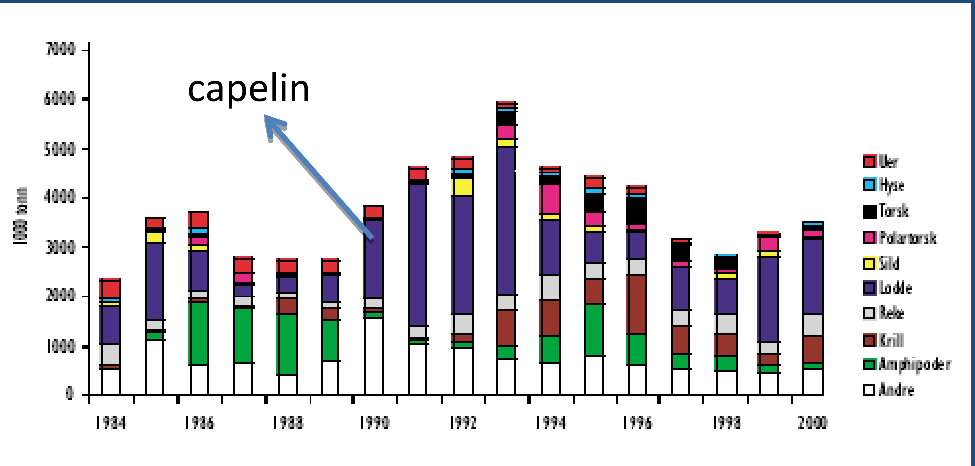
Spatial overlap and trophic interactions between Pacific cod and capelin in the Bering Sea



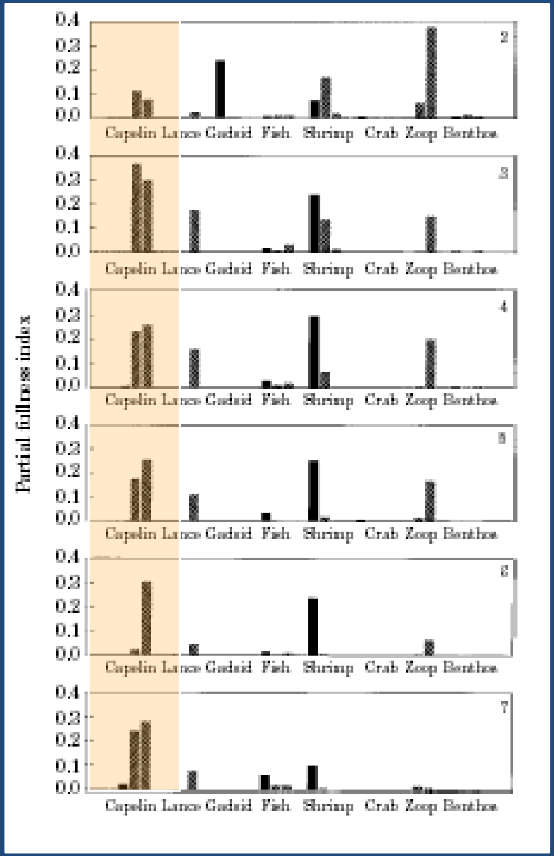
- **Kevin Bailey**: NOAA, Seattle, WA

Cod and capelin trophic interactions

Barents Sea



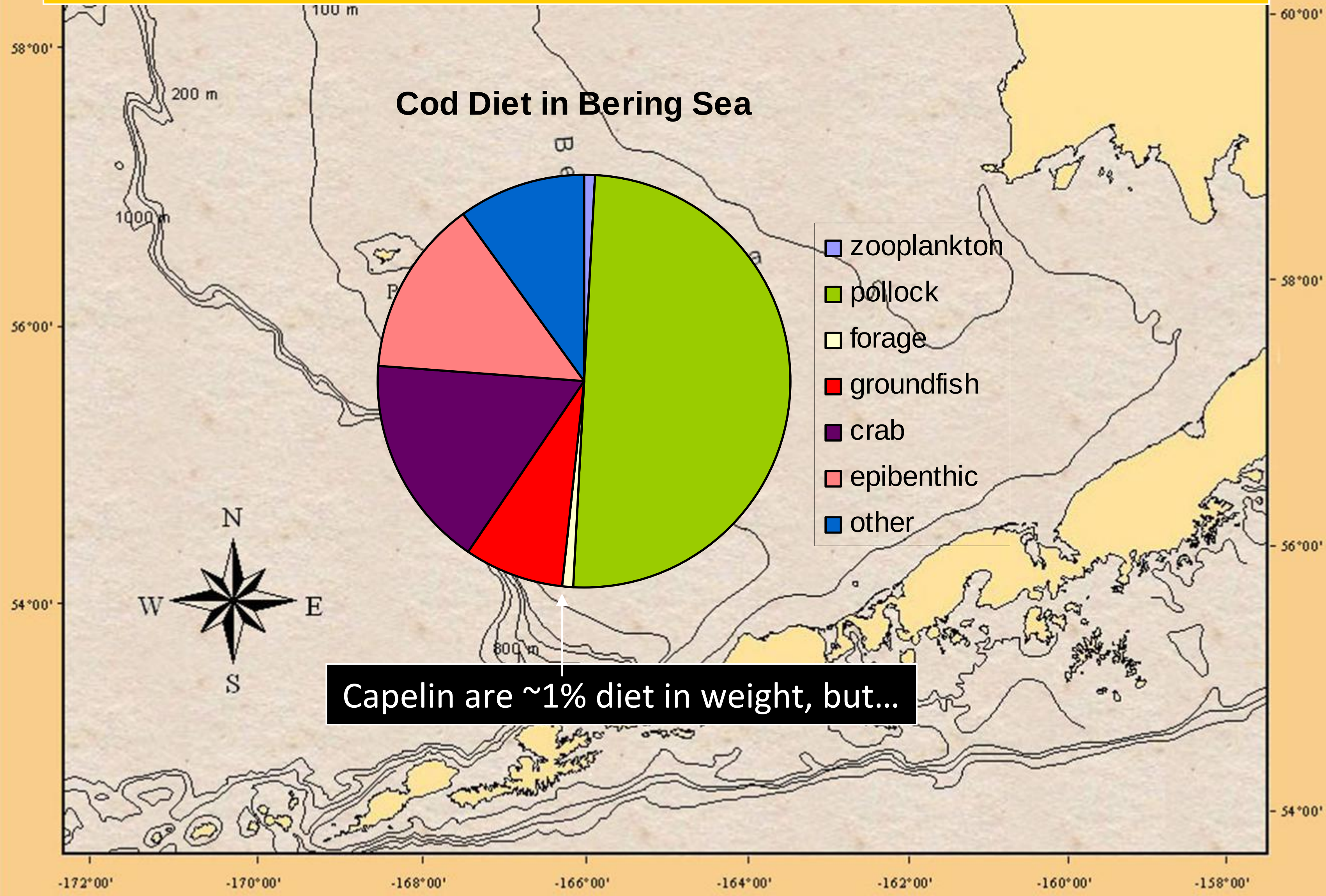
Labrador and Newfoundland



Iceland Sea

Average 50%
Range 25-90%

Cod and capelin trophic interactions

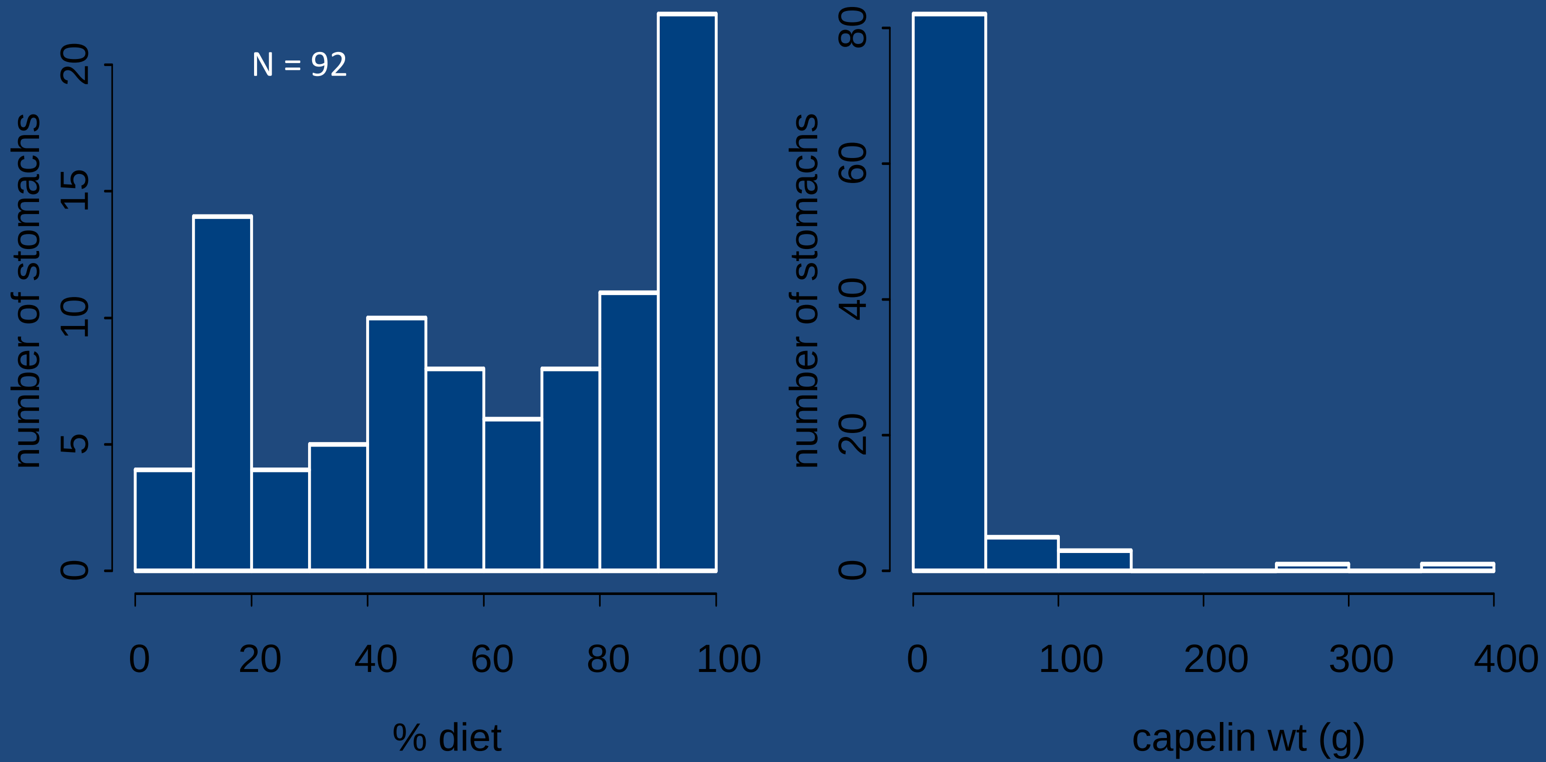


Cod and capelin trophic interactions

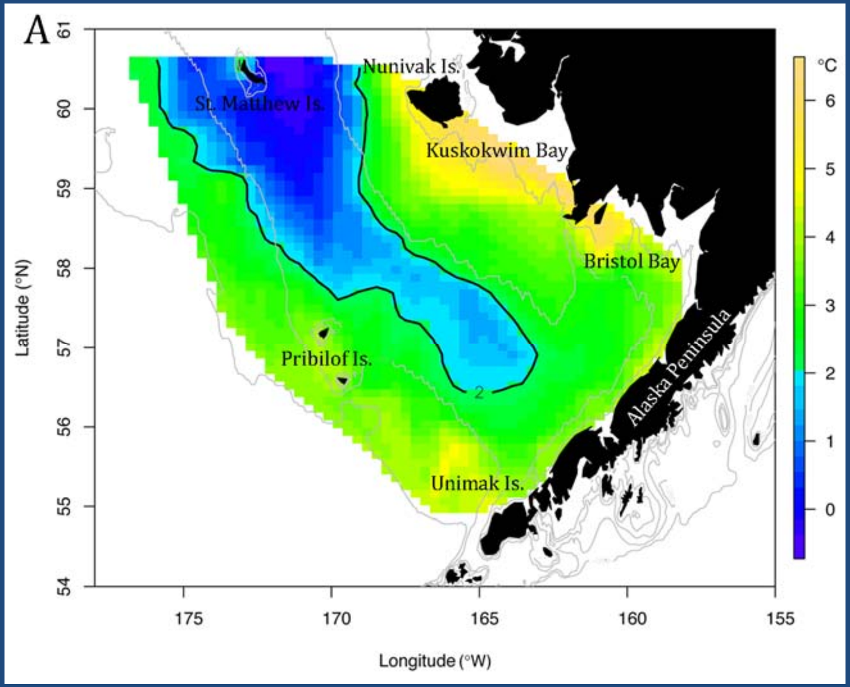
….whenever available, cod can actively feed on capelin

Average % capelin in + cod diet = 59.20%

and mean weight = 26.20 g

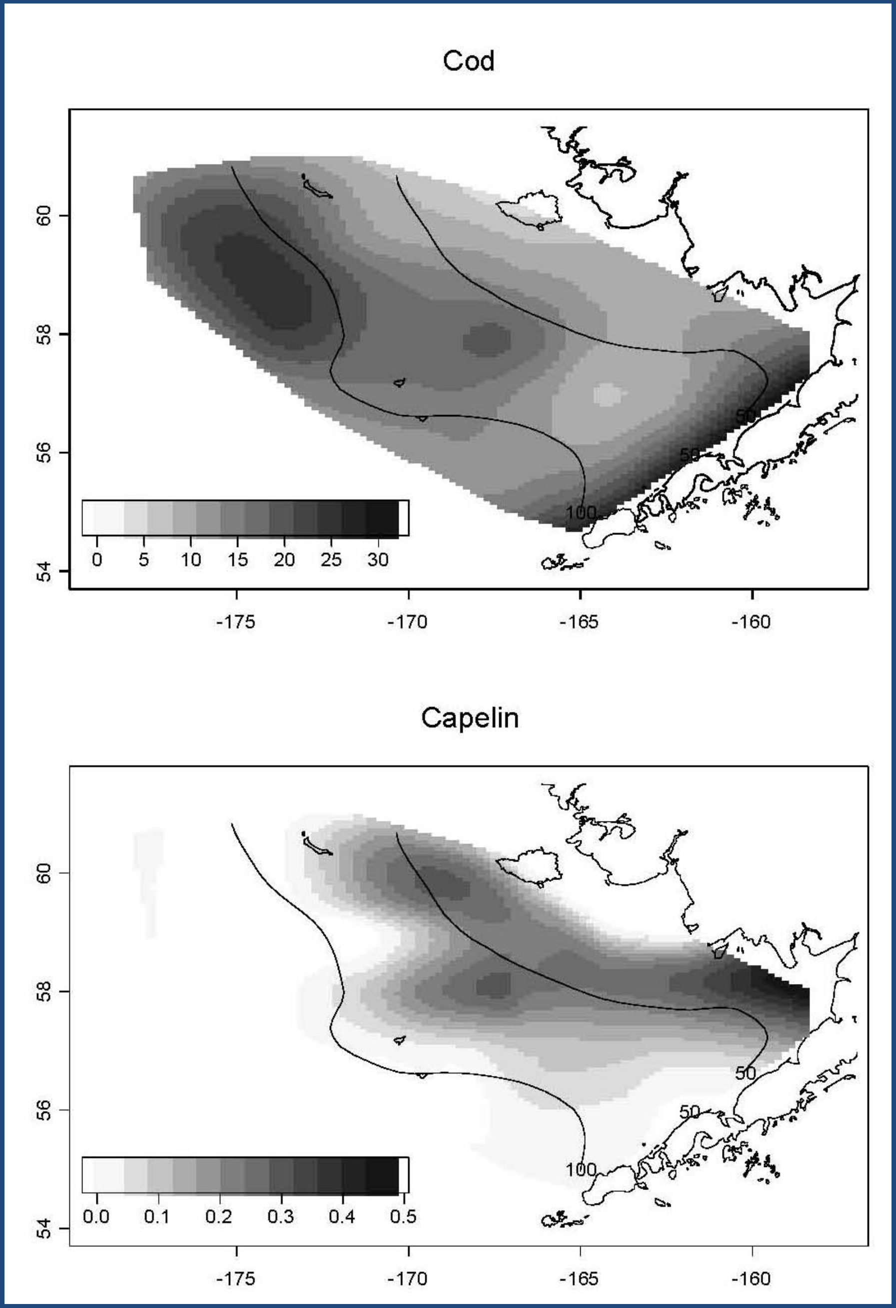


What keeps them apart, and do they have the potential to more strongly interact?

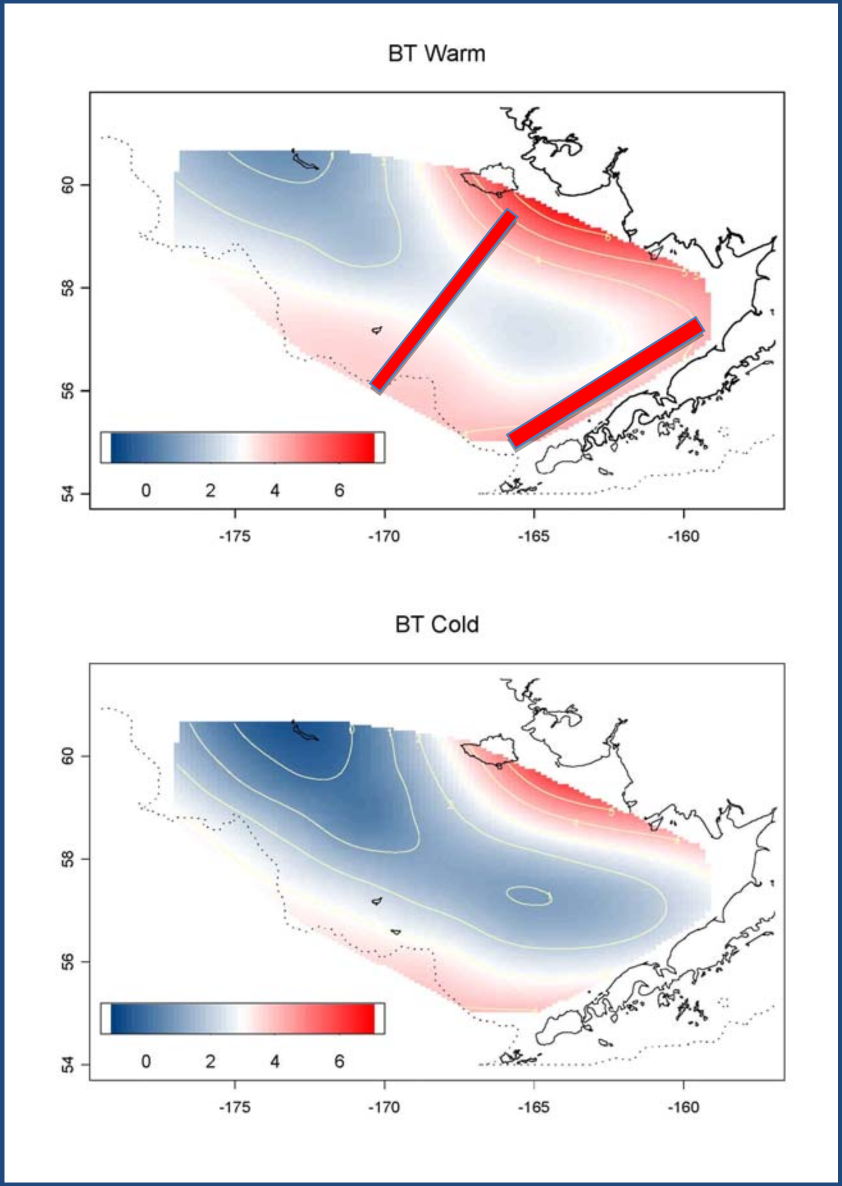


The cold pool is a 'permanent' feature of the Bering Sea shelf, and affect the biogeography of many potentially interacting species.

The intensity of the cold pool is subject to high interannual variability



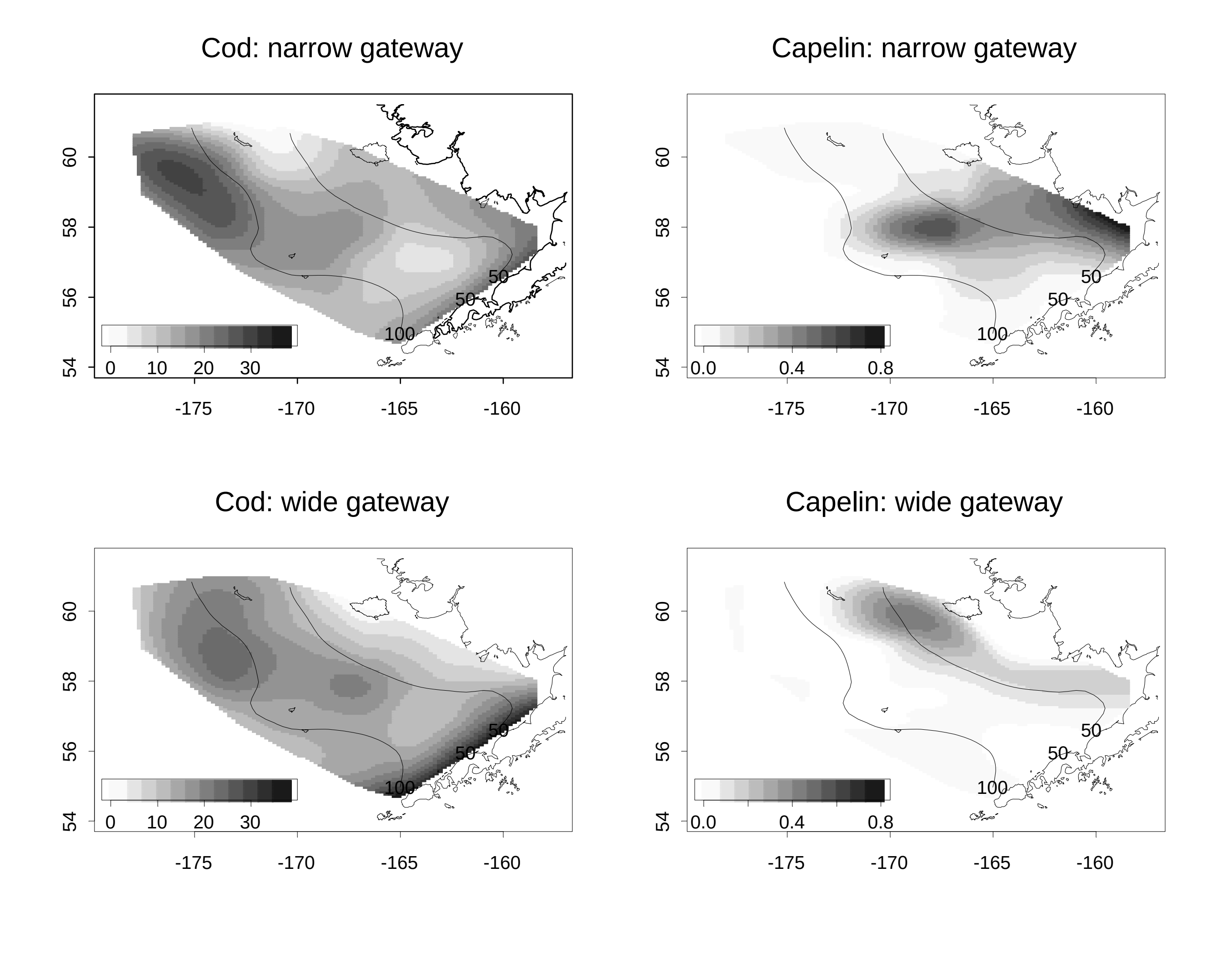
Thermal gateways



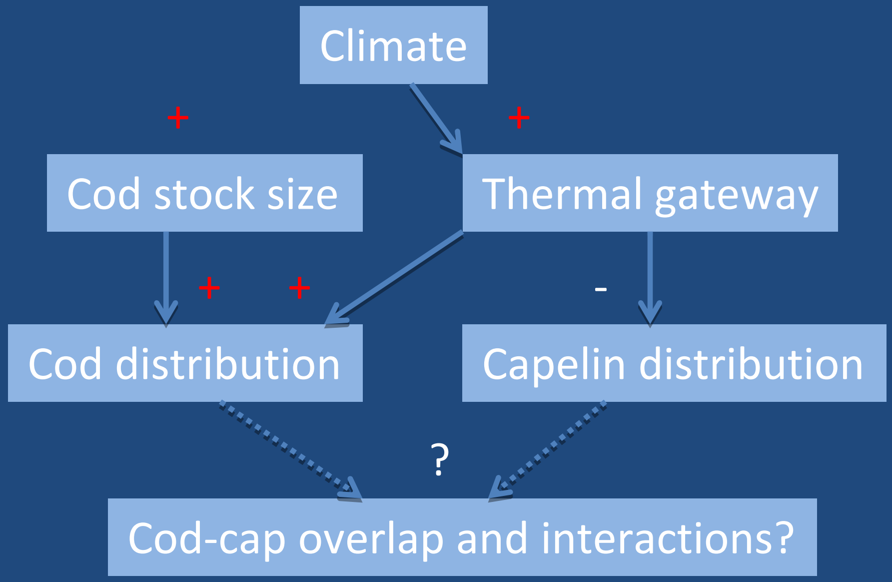
During warm years the cold pool retreats and bubbles up, freeing up ‘thermal gateways’ (>2^{o}C) across the shelf.

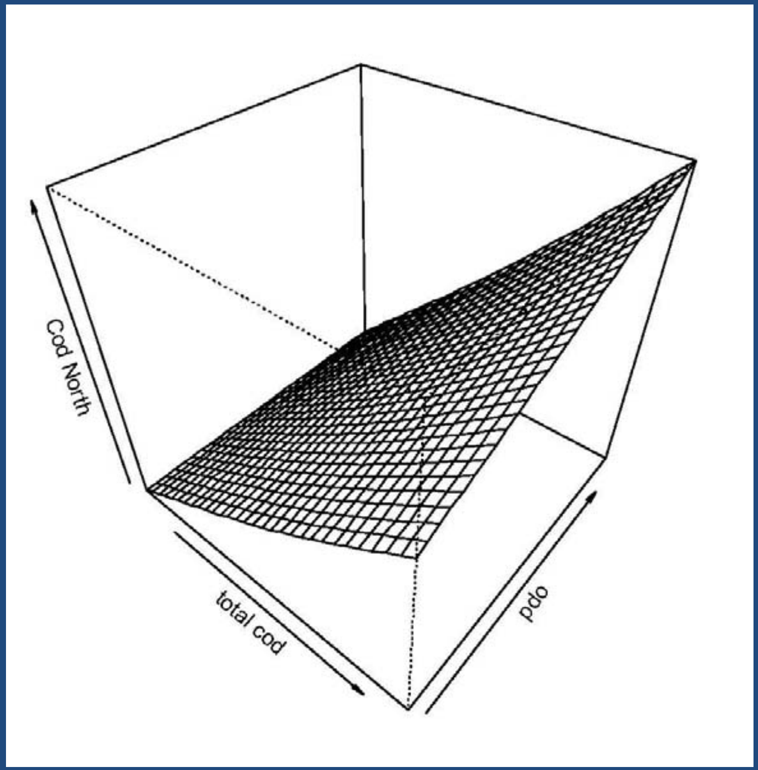
Thermal gateways can place in closer proximity species that live at the either side of the pool

Interannual variability of thermal gateways and PDO: p = 0.034, r = 0.39



Cod incursions to the middle and inner shelf ('Cod North') are positively correlated with PDO and with the overall abundance of the cod stock, R^2=84.7%





Predator-Prey overlap

Desirable features of overlap index *(P)*:
1)retain quantitative information and 2)convey location information

$$P_{a,t} = F(X_{(a \pm d\max,t)}, Y_{(a \pm d\max,t)}, d)$$

X = prey biomass
Y = predator biomass
d = distance between X and Y
a = location; t = time, dmax=radius

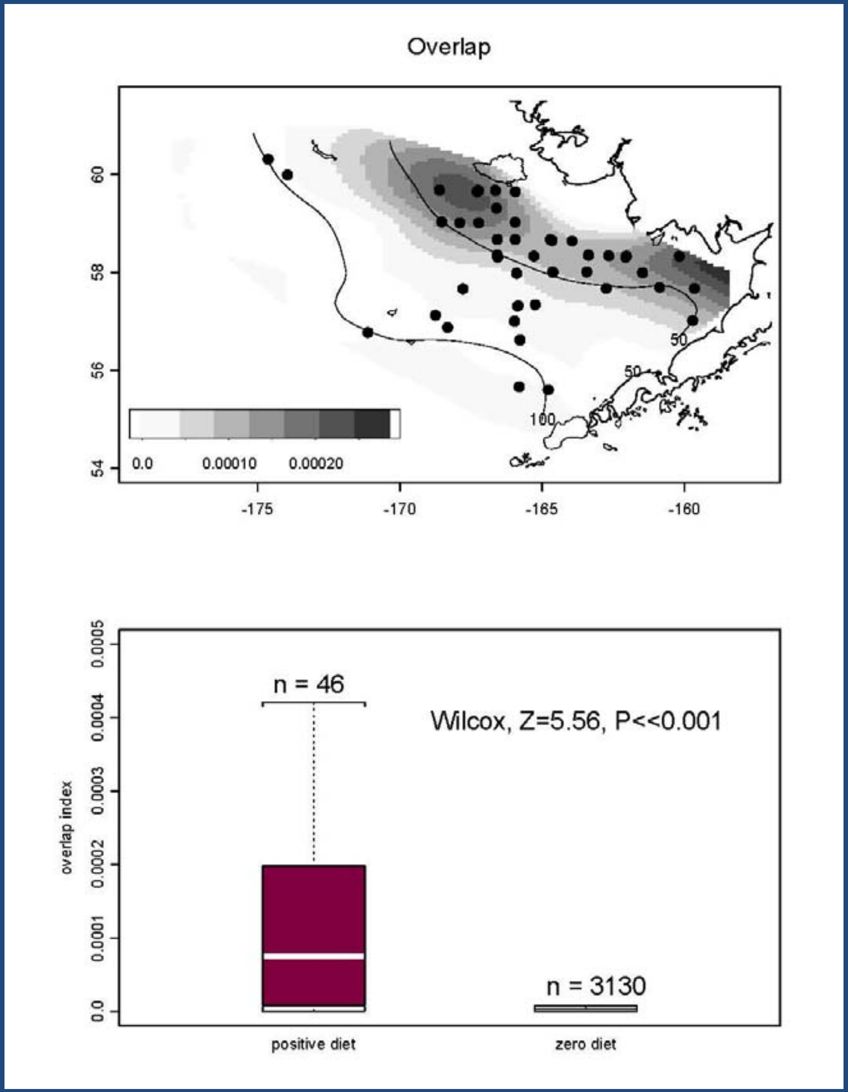
$$P_{a,t} = \ln(\overline{X}_{a,t} \overline{Y}_{a,t})$$

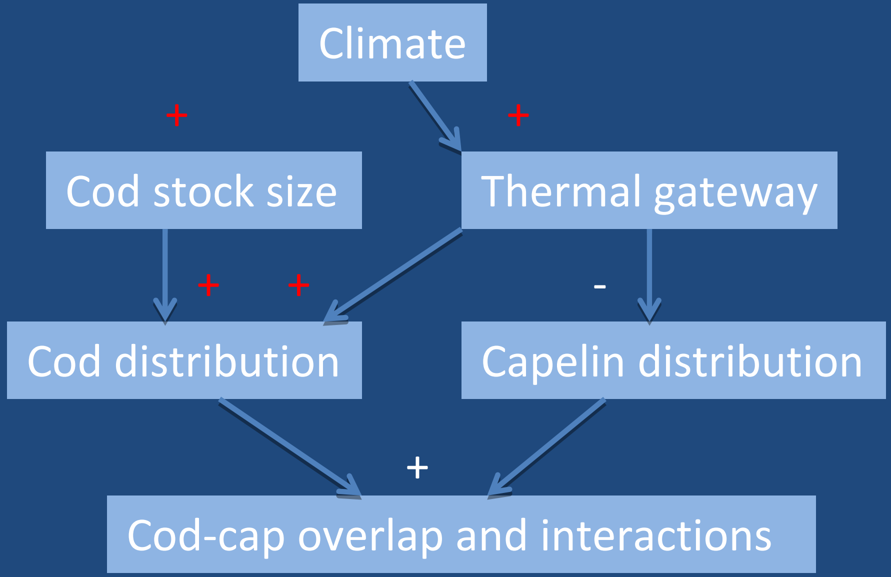
$\overline{X}_{a,t}$ = weighted mean prey biomass at time *t*, within a circle centered in *a* of radius = dmax = 50 km

$$\overline{X}_{a,t} = \frac{\sum_{i=1}^{N} I_i w_i X_{a,t,i}}{\sum_{i=1}^{N} I_i w_i}$$

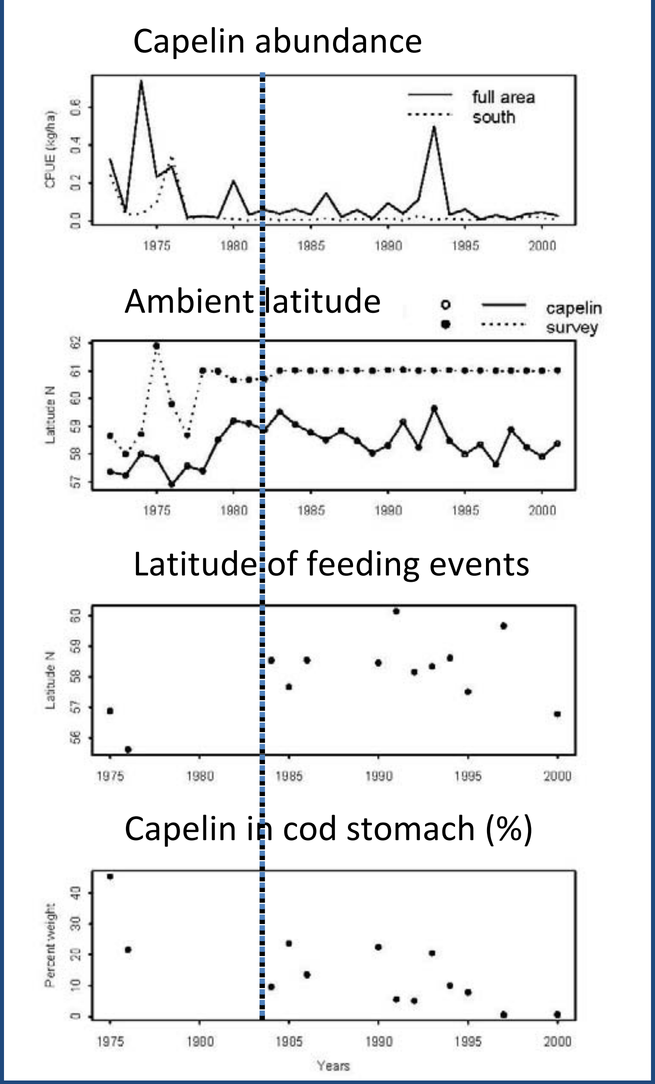
I_i = indicator variable
W_i = weighting term $1/(1+d_i)$
I = 0 if d(a,i) < dmax
I = 1 if d(a,i) >= dmax

Interannual variability of overlap index with PDO: p = 0.026; r = 0.40





Historical perspective: 'ecosystem severing'



Over time cod and capelin have grown further apart.

In the 1970s capelin were more abundant….

….especially in the middle and outer shelf

Feeding incidence of cod and capelin were also southerly displaced

And cod as well as other predators (e.g., black-legged kittiwakes) more intensely feed on capelin

What happened to the capelin stock after the 1970s?

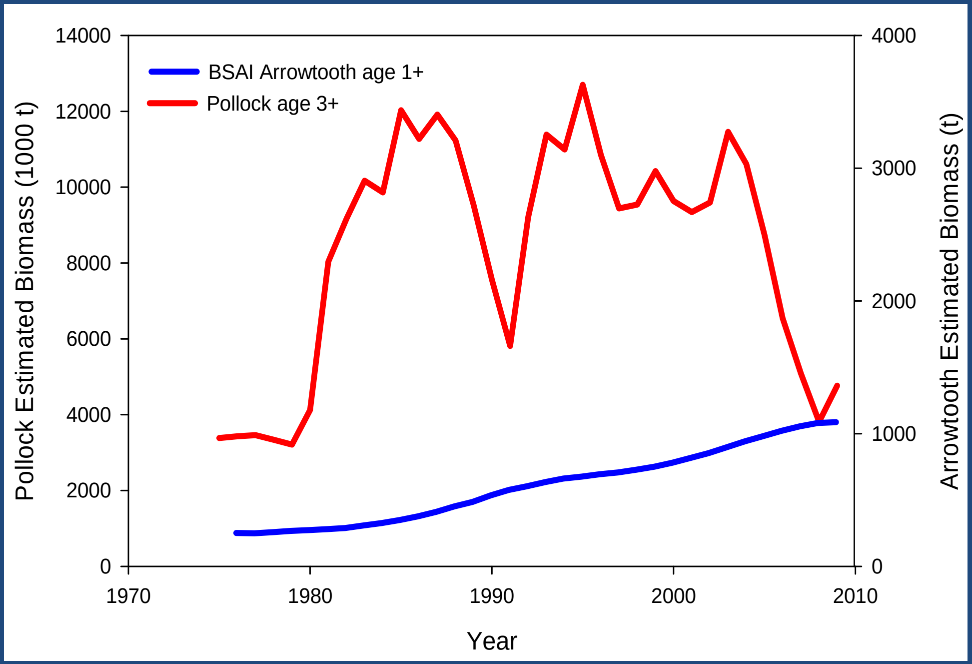
Summary of cod-capelin

- Permanent hydrographic features of the Bering Sea (cold pool) prevent cod and capelin interactions
- However, interannual variability of cold pool intensity may pose the two species in closer proximity
- Over time we have seen ‘ecosystem severing’
- Historical information and current events can inform us about future outcome

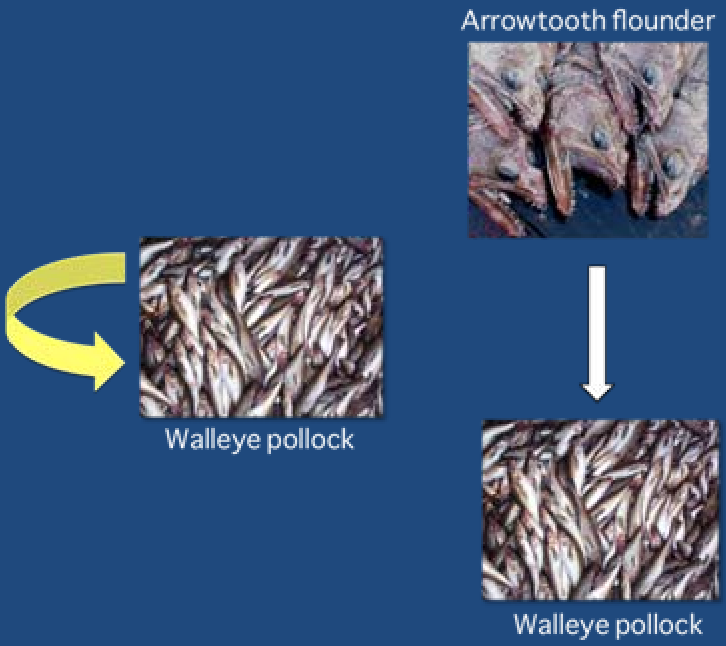
Pollock and Arrowtooth flounder

S Zador, AFSC, NOAA

Eastern Bering Sea



Estimates from 2009 stock assessments
Pollock: Ianelli et al. 2009
Arrowtooth flounder: Wilderbuer et al. 2009



Could an increasing ATF stock and a changing hydrography affect the distribution of pollock and ATF and their overlap and interactions?

Approach

- Quantify the degree of spatial overlap (horizontal)
  - Arrowtooth flounder (>20 cm) & pollock (≤ 20 cm)
- Identify factors that might dictate overlap
  - biotic (stock size) and abiotic (bottom temperature) variables

Spatial Overlap Indices

Method:

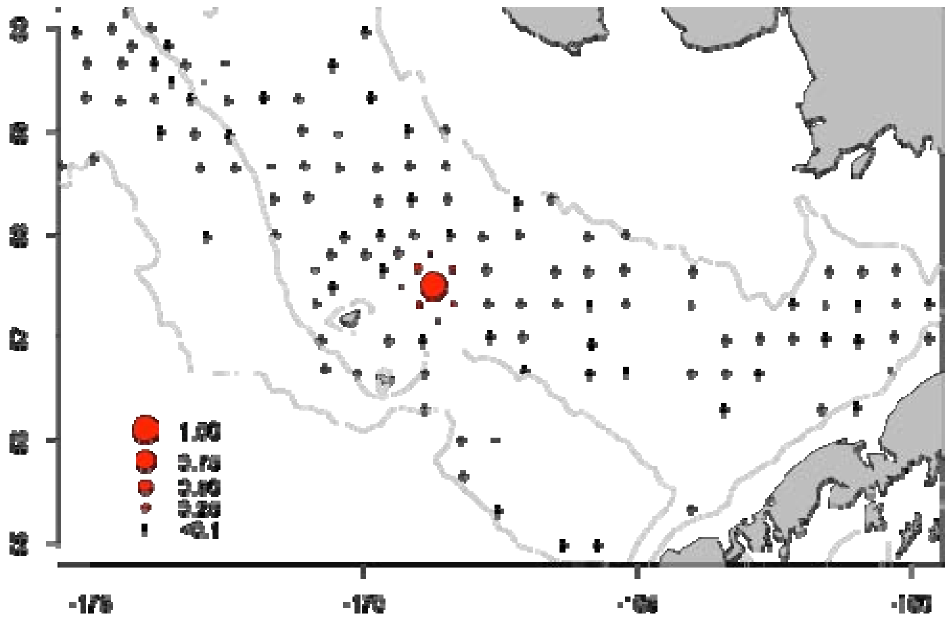
- Calculate the spatial overlap at each survey station by taking into account the overlap at a target station and the influence of its neighboring stations

$$w_{z,i} = e^{-\frac{1}{2\sigma^2} d_{z,i}^2}$$

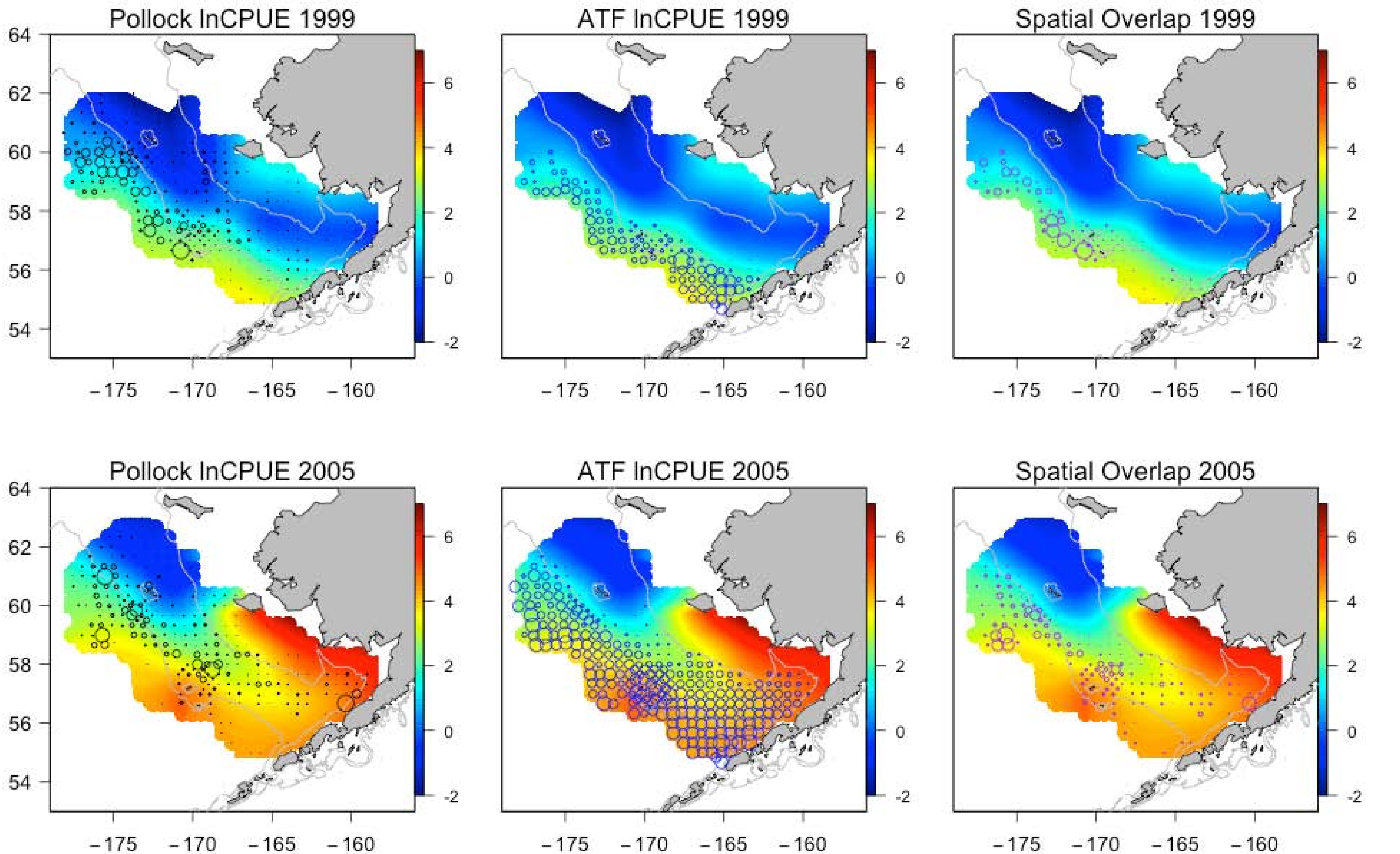
$$w_{CPUE,z} = \frac{\sum_{i=1}^{n} \left(CPUE_i * w_{z,i}\right)}{\sum_{i=1}^{n} w_{z,i}}$$

$$\ln(w_{PollockCPUE,z} * w_{ArrowtoothCPUE,z})$$

Influence of neighboring stations on the target



Some observations



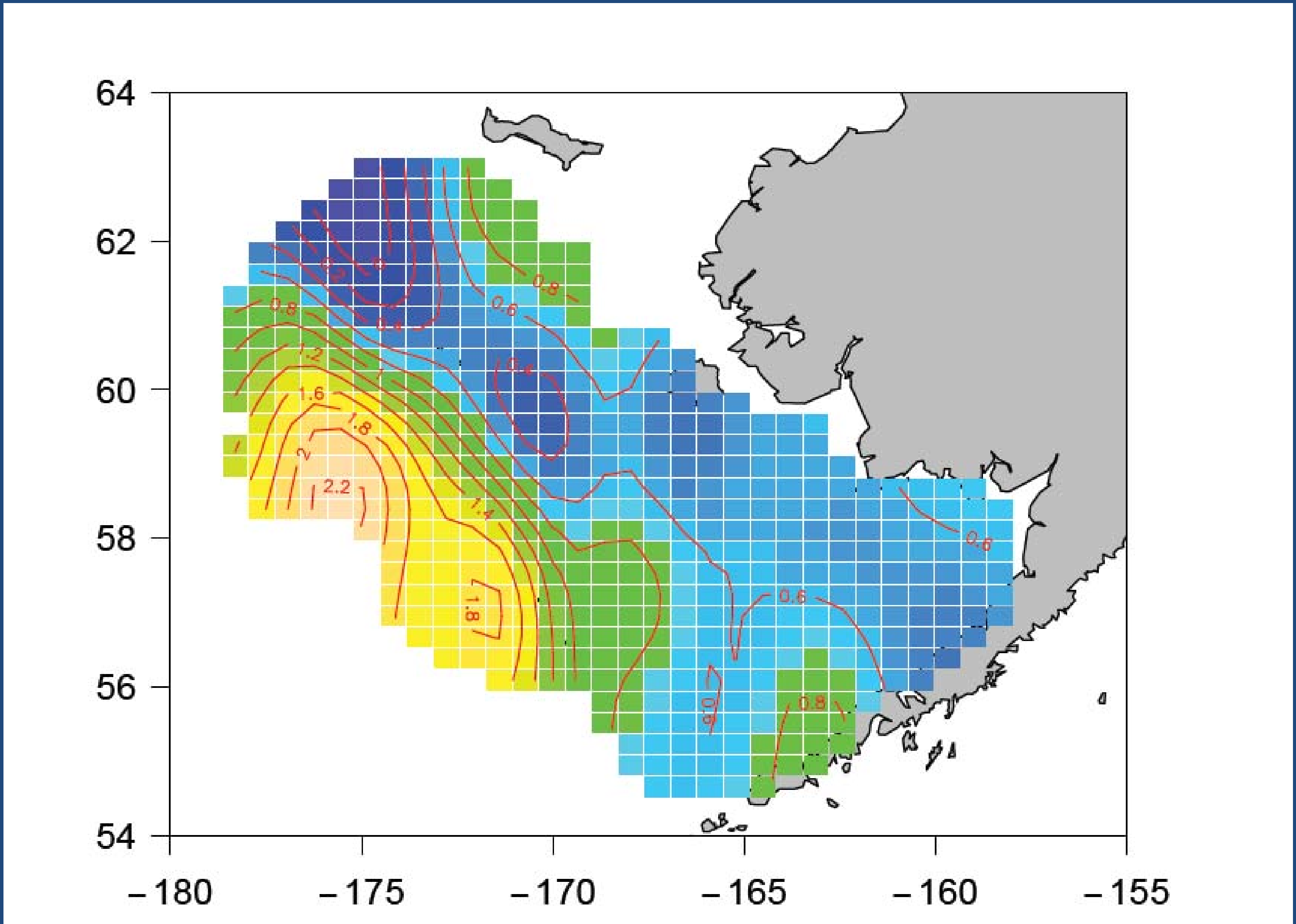
Eastern Bering Sea

➢ Variable Coefficient Generalized Additive Models

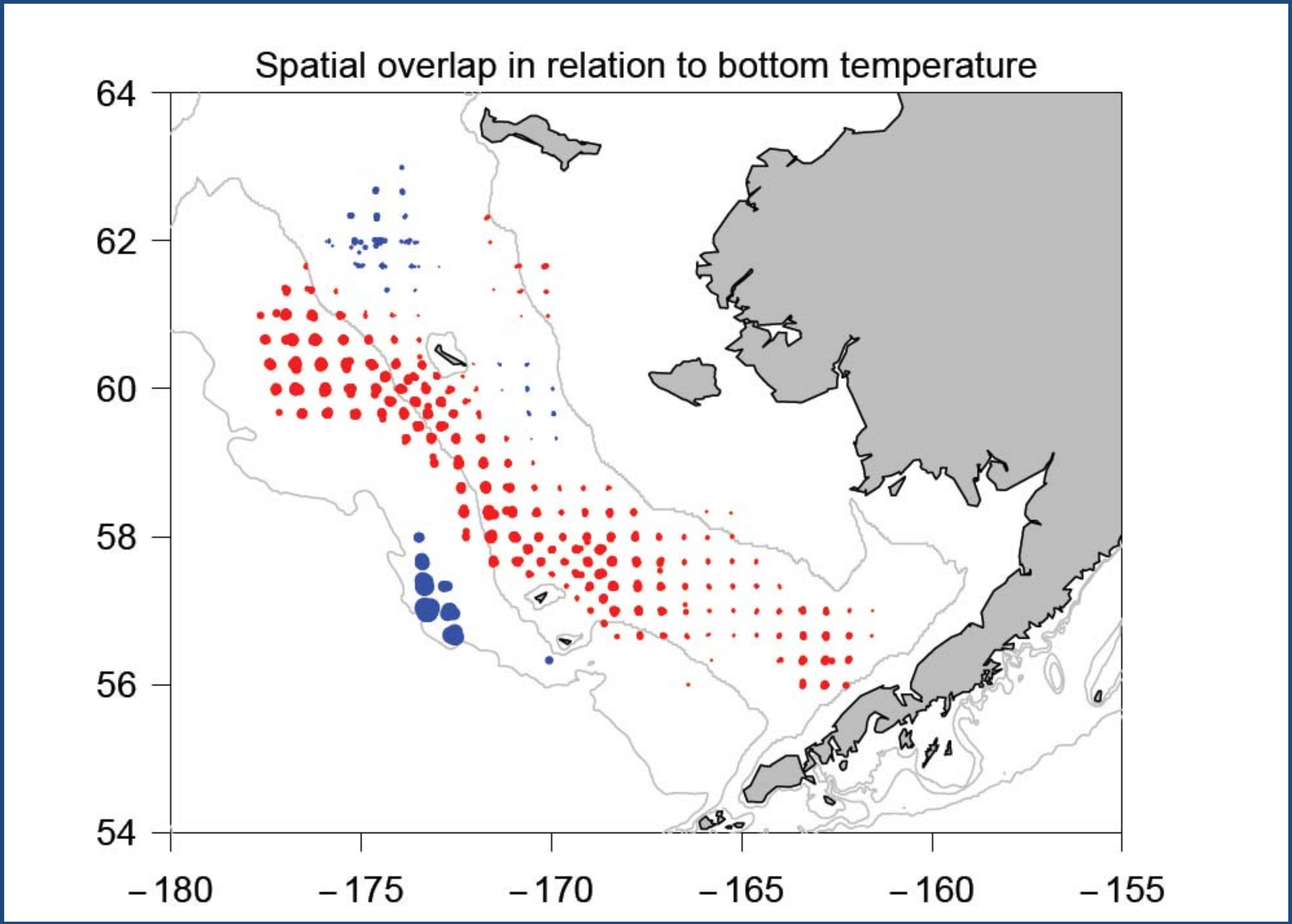
- Response: Spatial overlap of adult ATF and juvenile POL
- Years: 1982-2008
- Covariates: Year as factor, ATF stock size, Age-1-2 Pollock stock size, spatial location (lat, lon), bottom depth, and gear (bottom) temperature

$$SpO = Year + s_1\,(lat, lon) + s_2(depth) + s_3\,(lat, lon) * temp + s_4\,(lat, lon) * ATF + s_5\,(lat, lon) * POL \quad \varepsilon$$

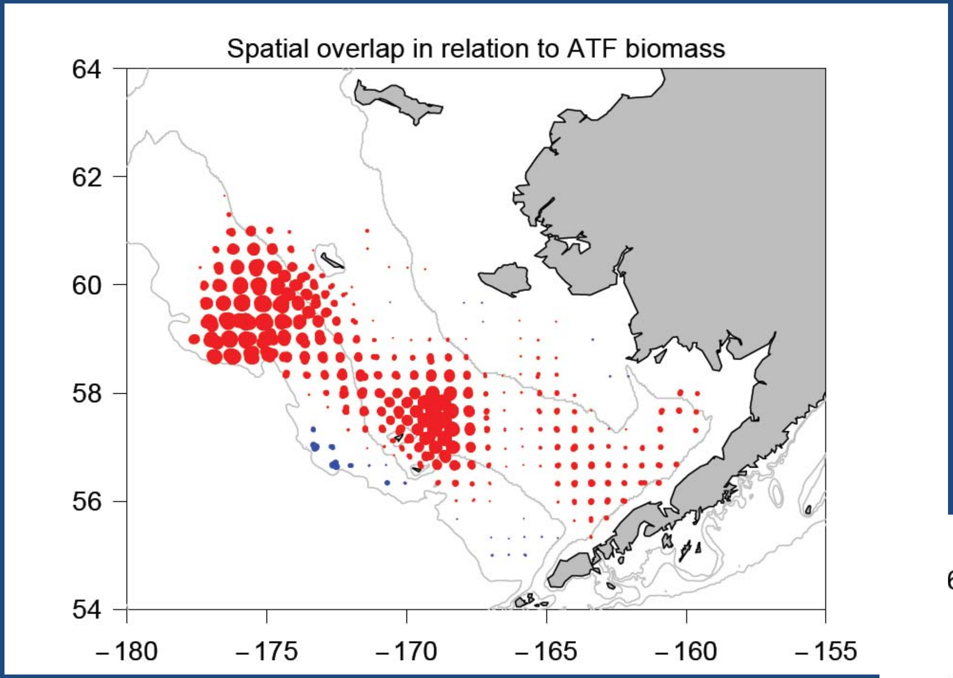
Location of Spatial Overlap

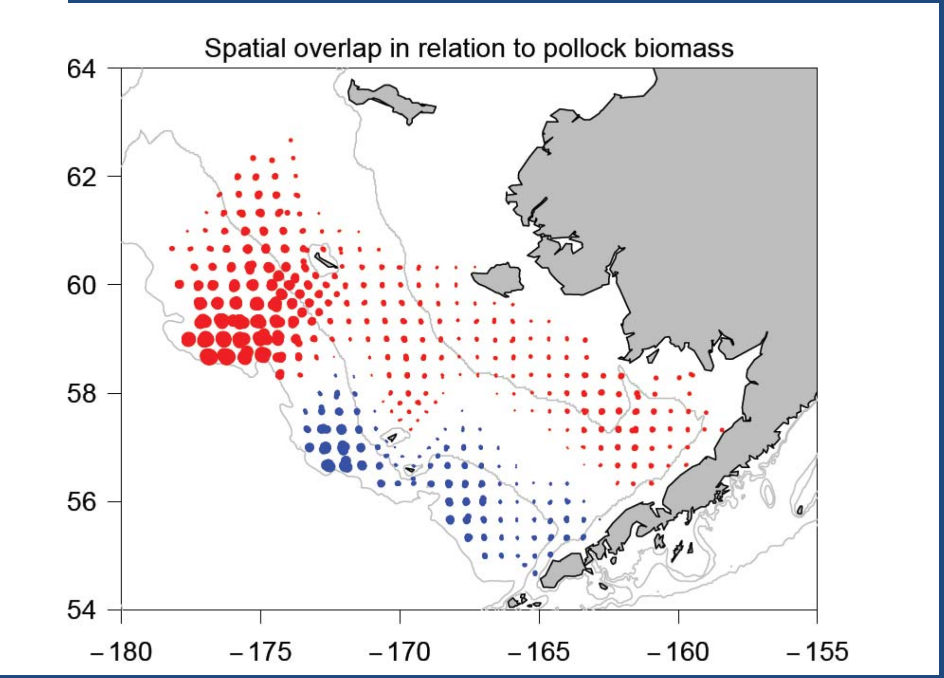


Spatial Effects of Temperature

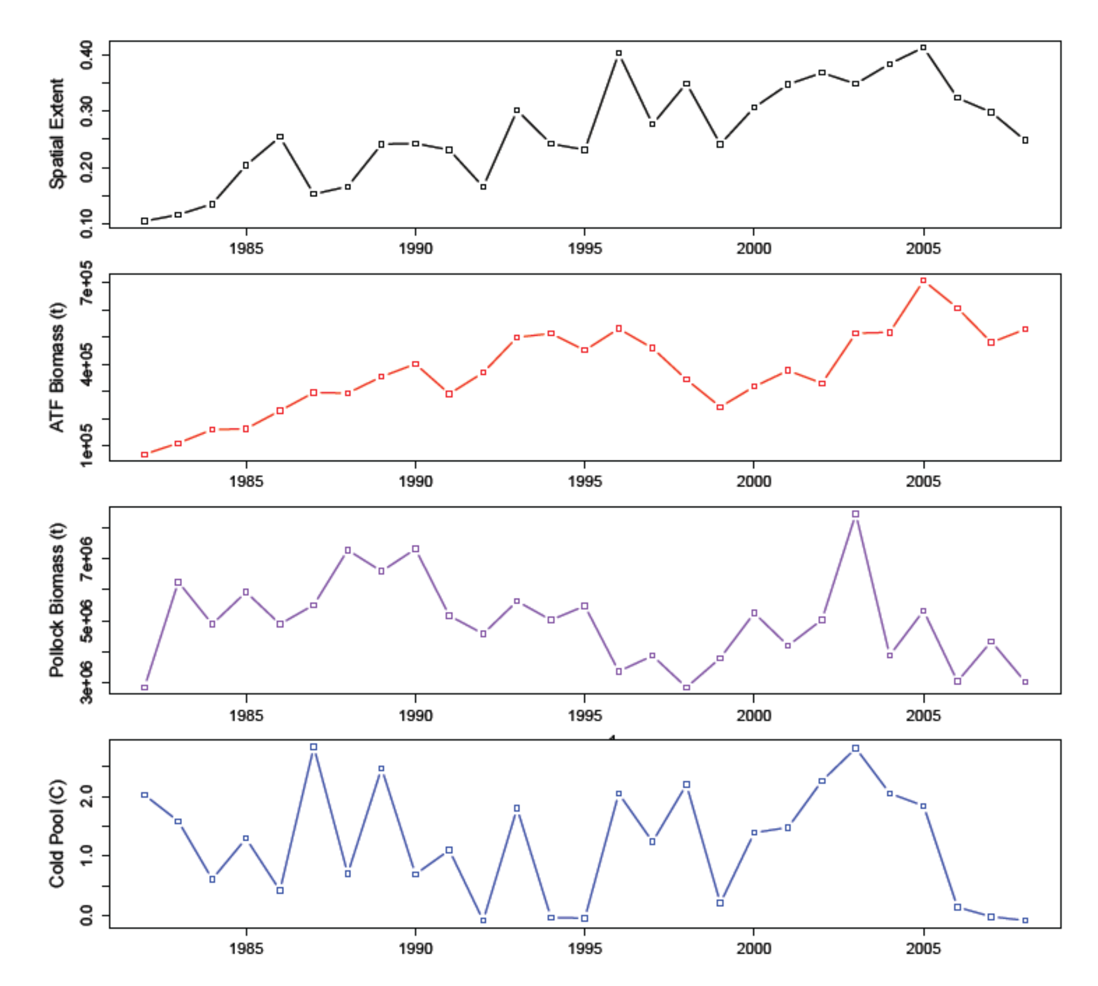


Spatial Effects of Stock Size





Time series analysis



Years **1982-2008** correlation coefficients:

Spatial extent and Cold pool index; 0.27
Spatial extent and ATF biomass; 0.73
Spatial extend and POL biomass; -0.17

Years **1991-2008** Correlations coefficients:

Spatial extent and Cold pool index; 0.77
Spatial extent and ATF biomass; 0.42
Spatial extend and POL biomass; 0.001

Summary of ATF-pollock

- Importance of density-independent and density-dependent forcing on species distribution and overlap
- Cold pool still play a dominant role in Bering Sea species interactions
- Northwest region of sampling area is most susceptible to changes of ATF-POL overlap
- This also the area where ATF have larger body sizes and fuller stomachs in comparison to other regions (S Zador and K Aydin unpublished)

Overall Summary

- Ecosystem mixing requires quantification of predator-prey overlap and spatial distribution and a study of their variability
- Temperature and stock biomass are the main drivers of changes in overlap in the two case studies examined
- Interannual dynamics can be precursors for long-term more permanent changes