The roles of temperature, abundance and advection in modifying the spatial dynamics of groundfish at the Subarctic-Arctic boundary in the eastern Bering Sea

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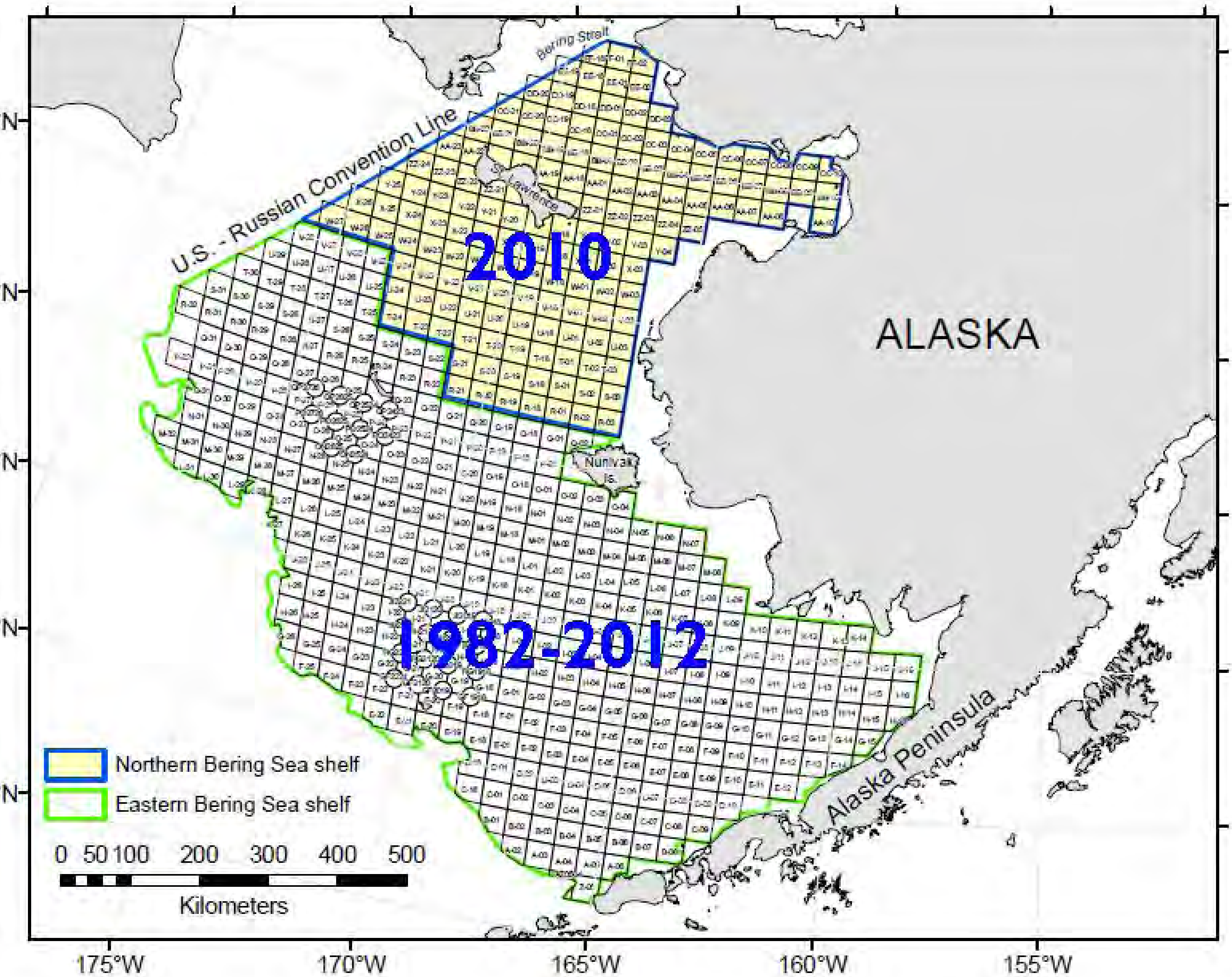
Outline

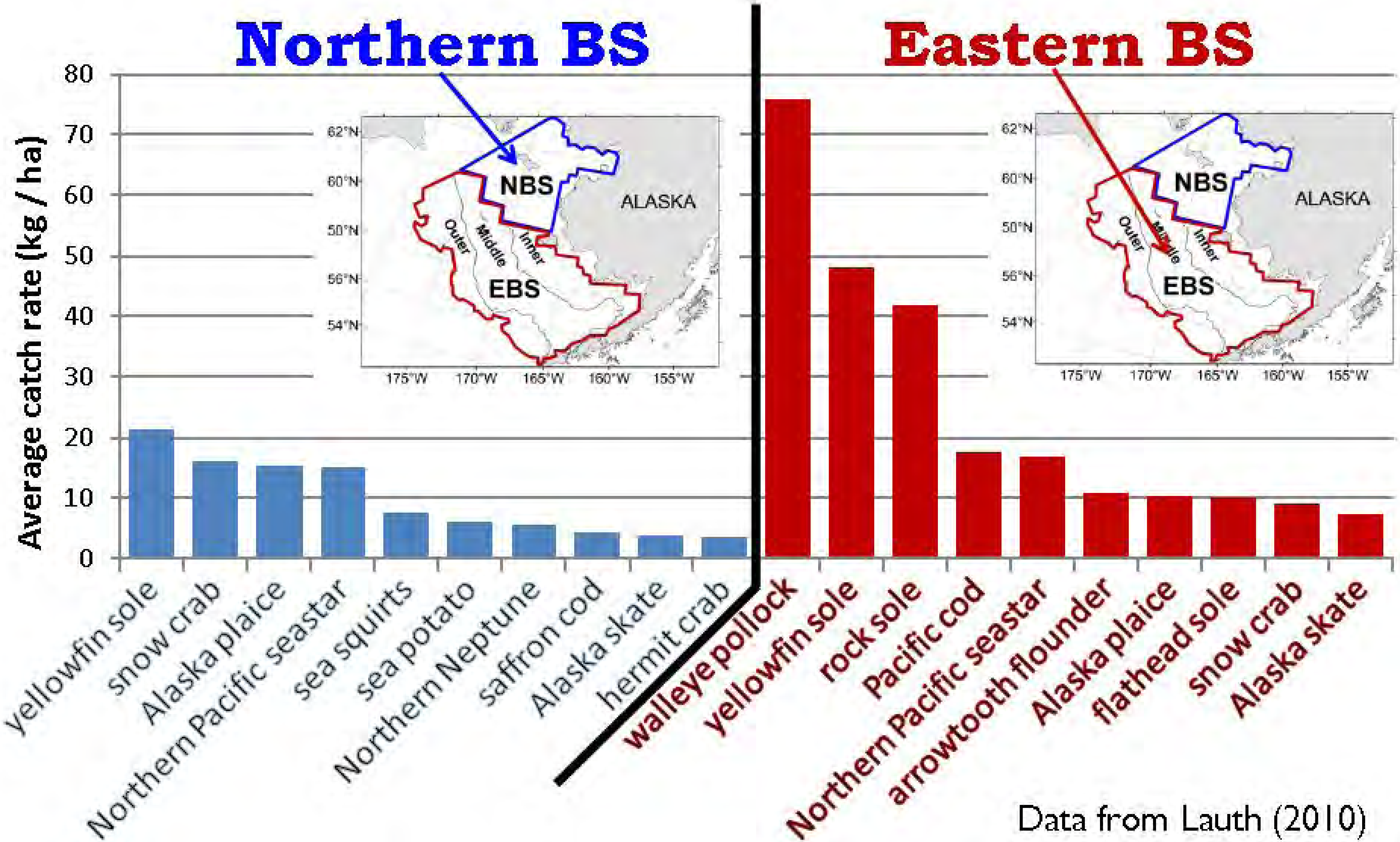
- Review of distributional changes in fishes based on changes in average distribution ("center of gravity")
- Alternative measure of spatial distribution
- Effects of temperature, density-dependence, **advection** and fishery removals on spatial distribution

- Implications for the northern Bering Sea

Study region w/ survey grid



Most abundant species by region



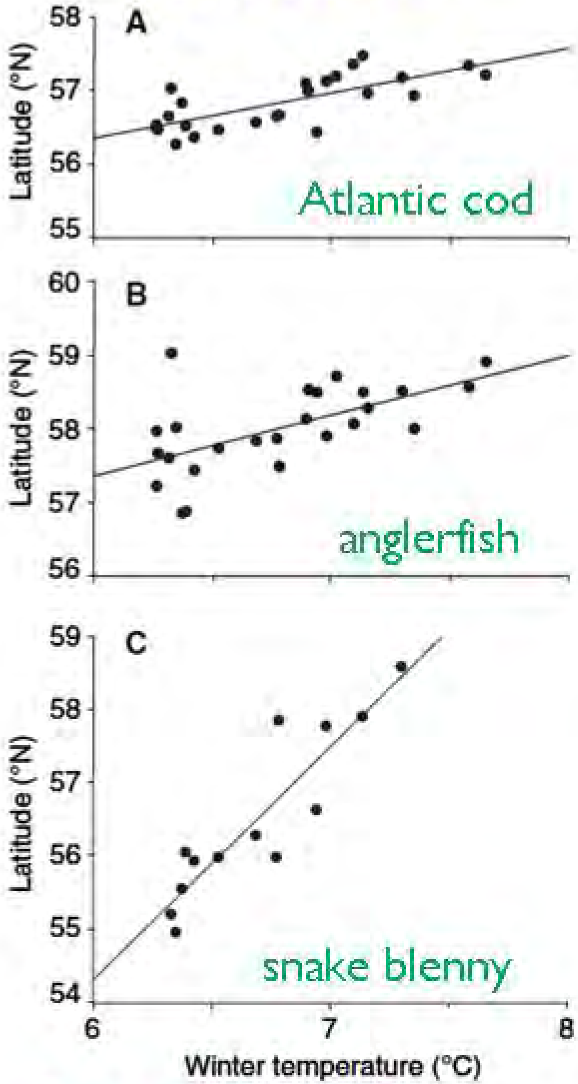
Data from Lauth (2010)

Observed changes in distribution

- Poleward shifts in response to warming
  - large variability across taxa (incl. equatorward shifts)
  - northward shifts without warming (e.g. Nye et al. 2009)
  - non-linear response to warming (e.g. Mueter & Litzow 2008)
- Movement to deeper waters in response to warming
  - Opposite response in Bering Sea!

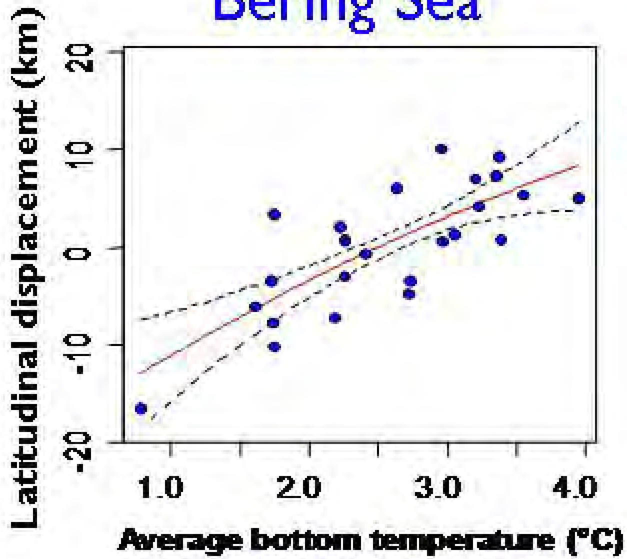
North-South shifts and temperature

North Sea



Perry et al (2005)

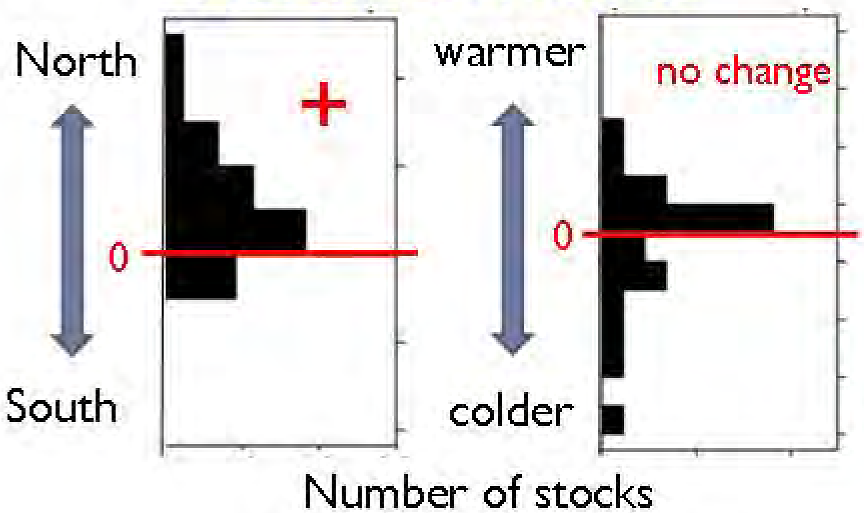
Bering Sea



Average N-S displacement across 40 taxa

Mueter & Litzow (2008)

Northwest Atlantic

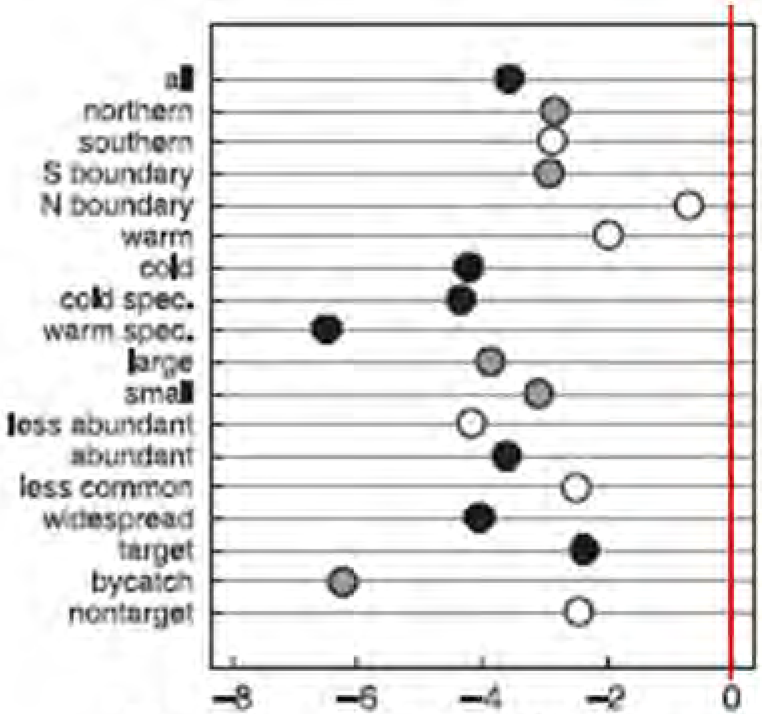


Nye et al (2009)

Changes in depth distribution

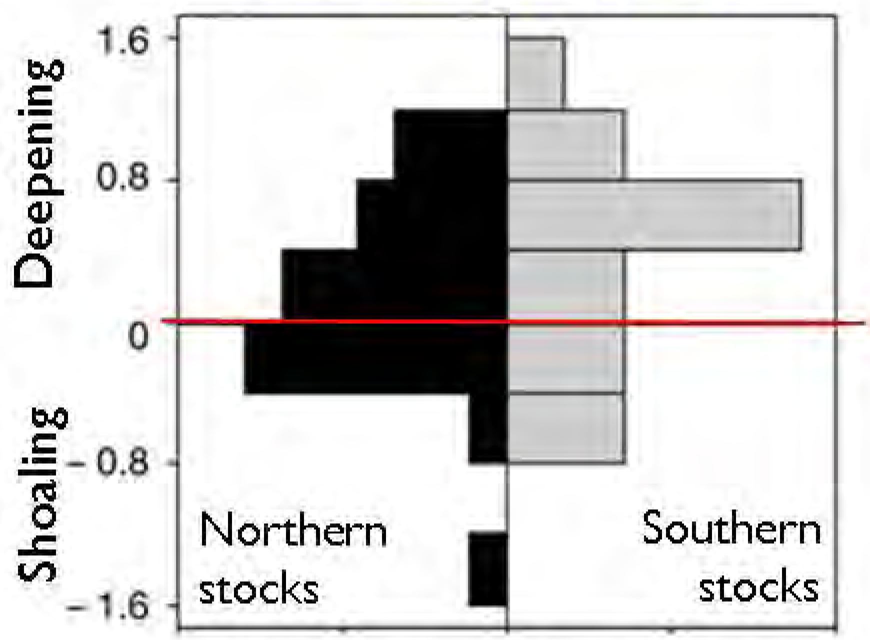
- Expectation: shift to deeper waters!

North Sea



Deepening (m) per °C change in T for various assemblages

Northwest Atlantic



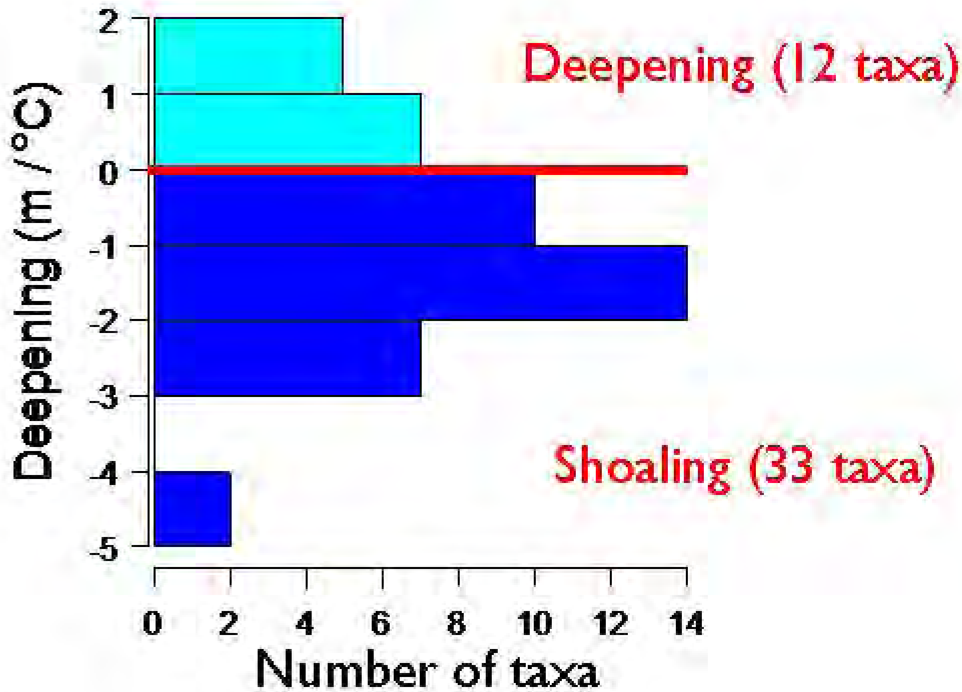
Number of stocks (36 total)

From: *Dulvy et al (2008)* *Nye et al. (2009)*

Changes in depth distribution across 46 taxa in Eastern Bering Sea

Temperature-related change by taxon

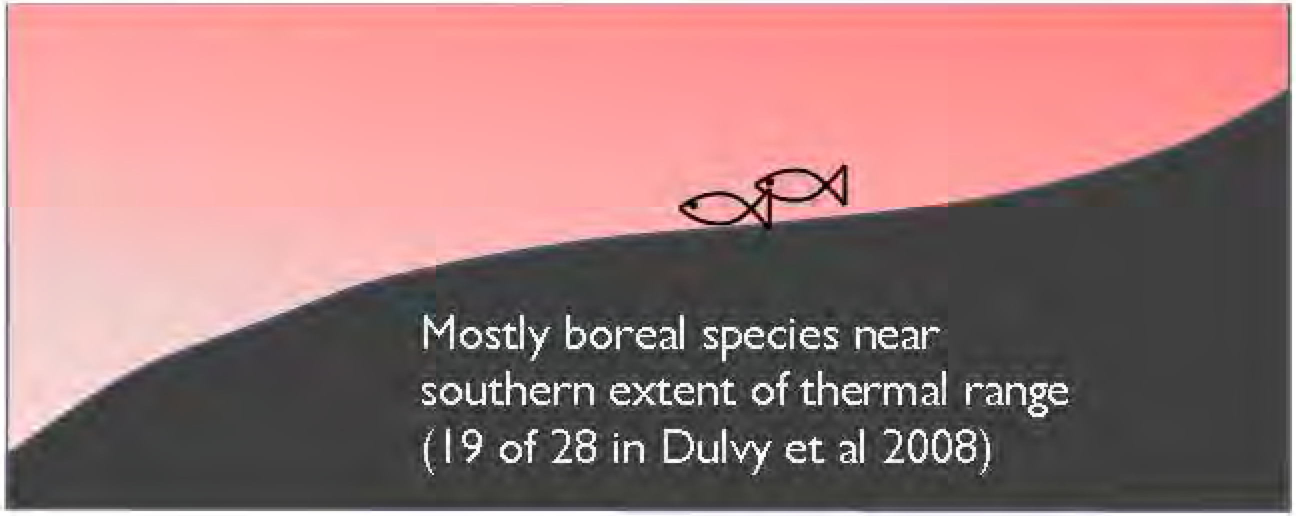
(Slope of mean depth on annual mean T)



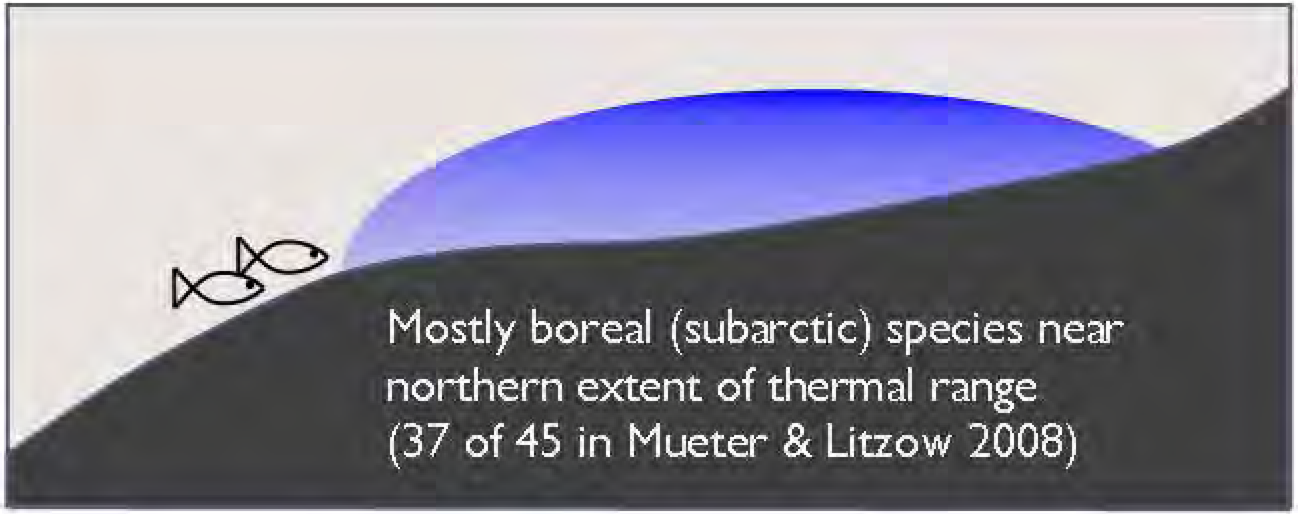
- Unexpected shoaling: Depth response in Bering Sea differs from other areas → Why?

Changes in depth distribution

North Sea

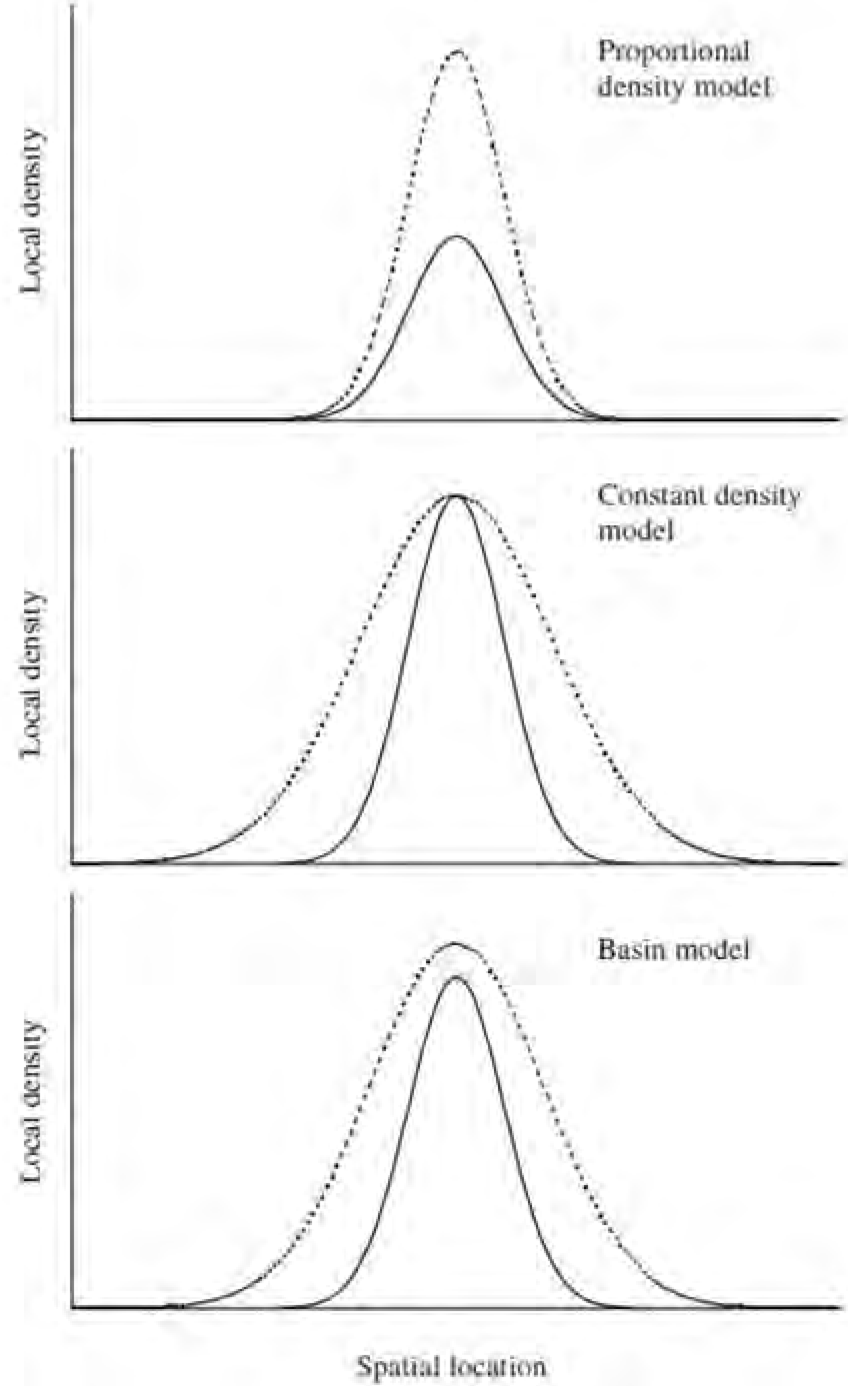


Bering Sea



Importance of density dependence

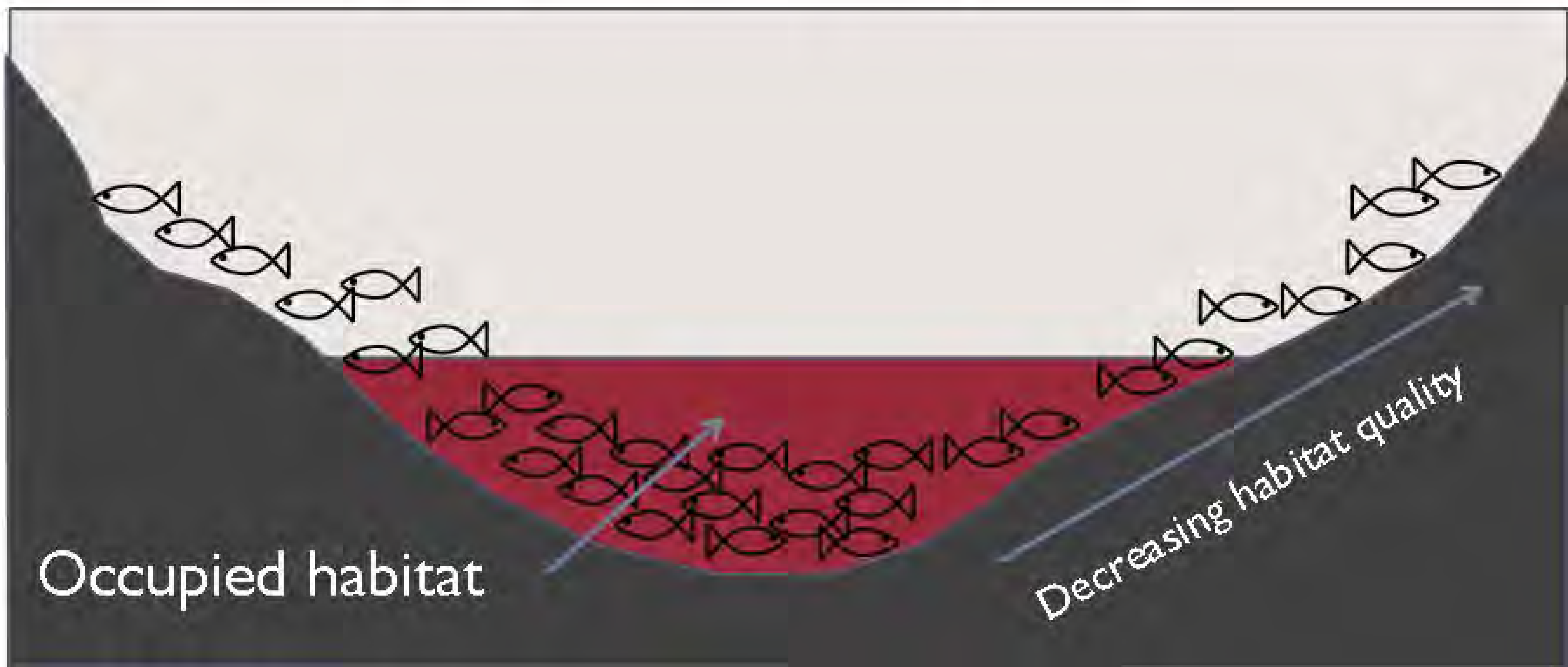
- Many possible responses to increase in abundance
- Center of distribution ("center of gravity") NOT affected by these "idealized" changes
- Reality much more complex
  - Coastlines
  - Islands
  - Topographic features



Effects of density (abundance)

"Basin" model (MacCall 1990):

- Increased density in core area + expansion into "marginal" habitat
- Center of gravity invariant to expansion



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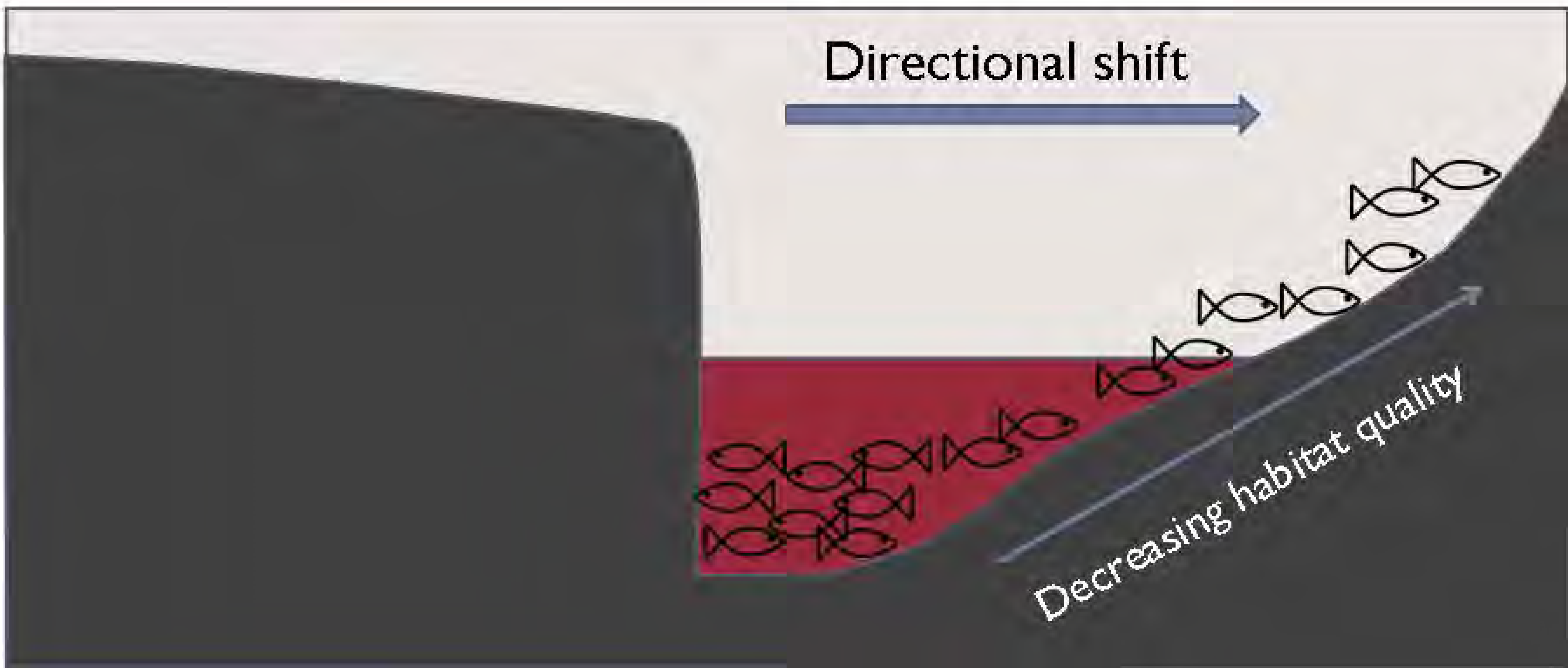
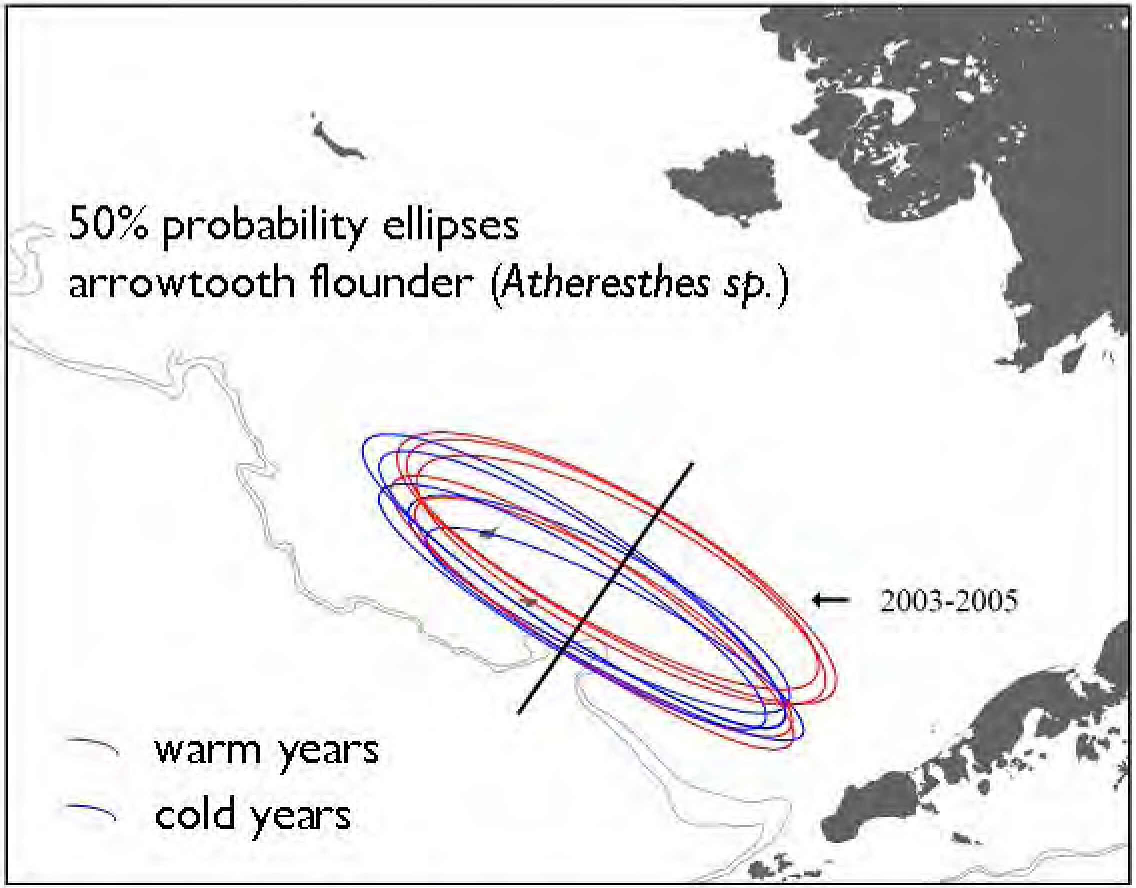
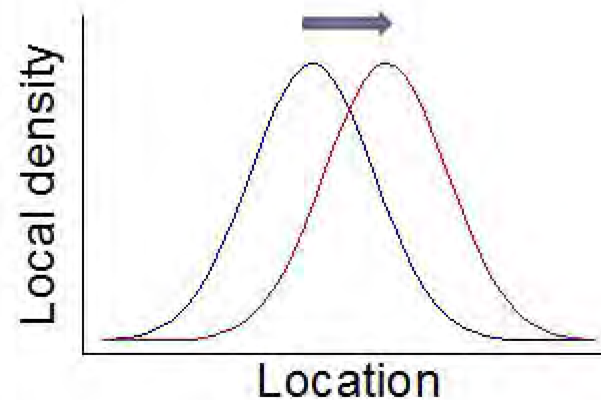
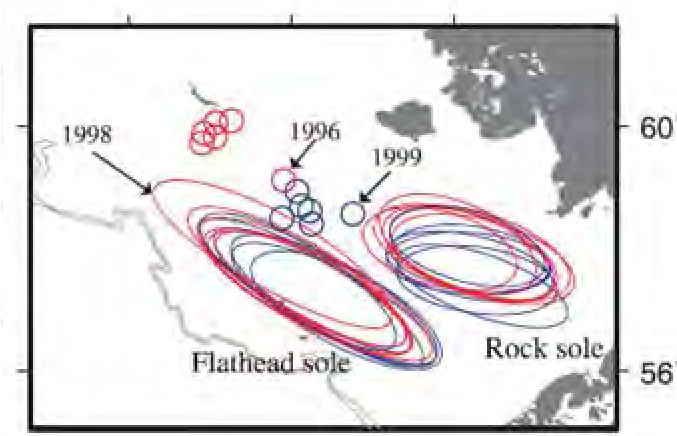


Idealized changes in spatial distribution





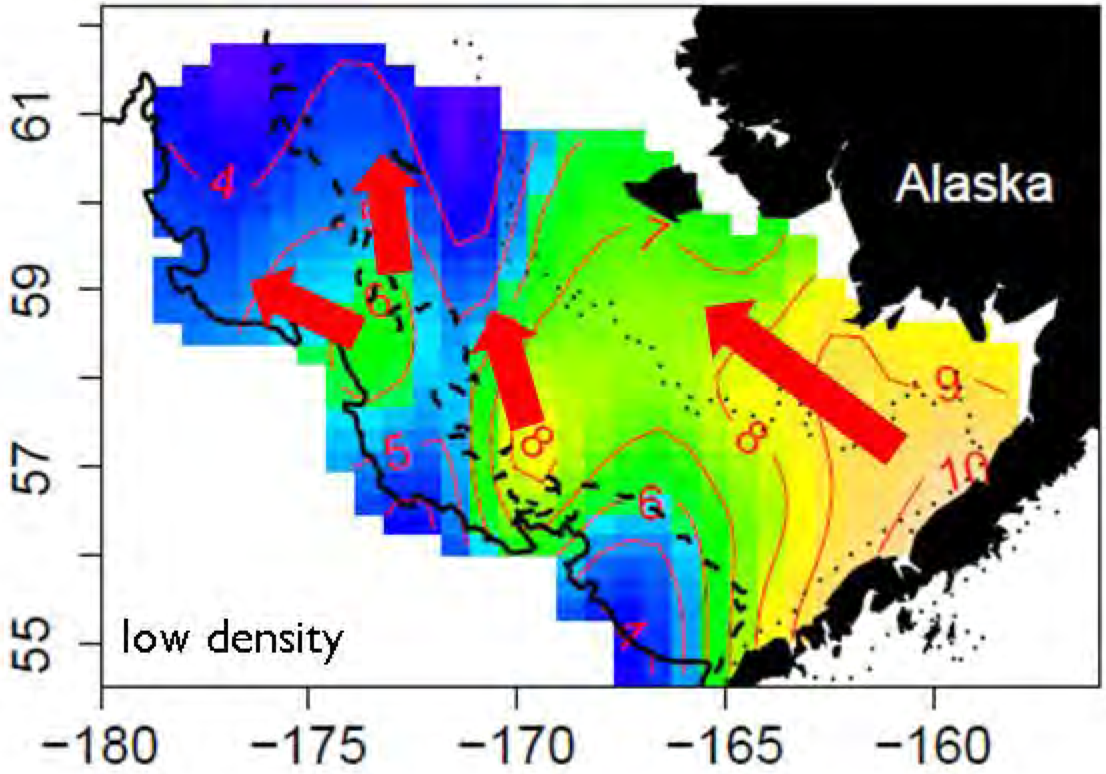


Spencer et al (2008)

Rock sole (*Lepidopsetta* spp.)

density-dependent expansion/contraction:

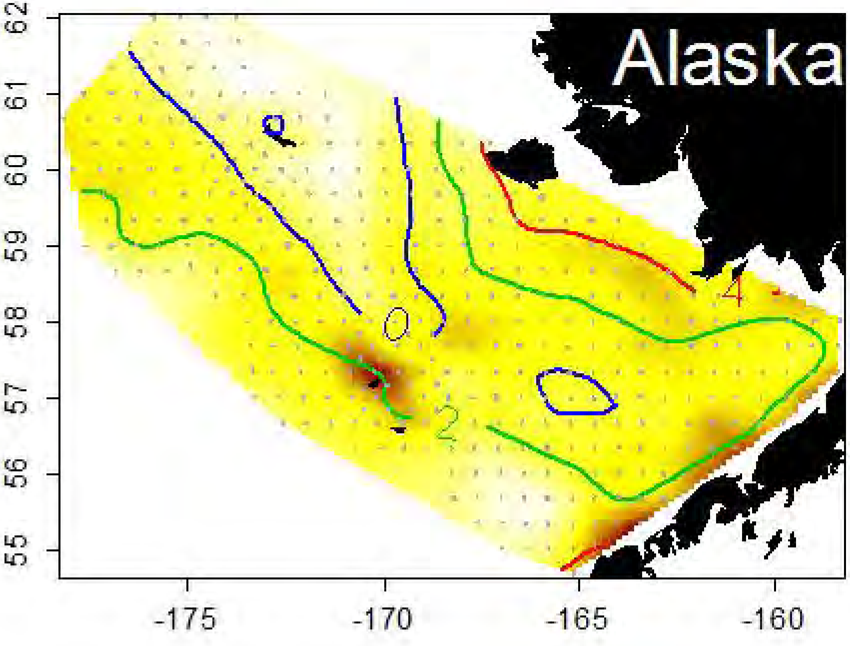
- spreading northwestward from Bristol Bay / Pribilofs



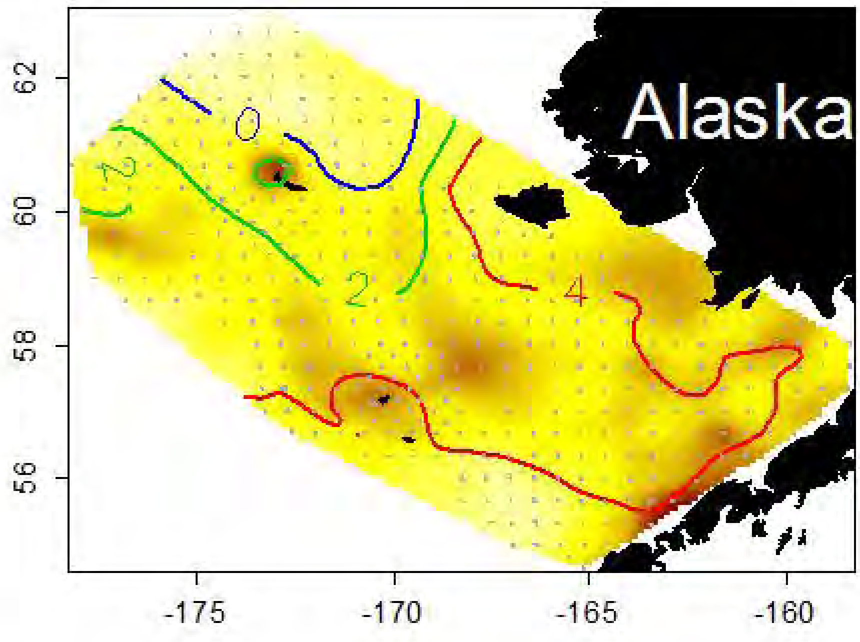
In Bering Sea, majority of species respond to changes in density, secondarily to temperature!

Distribution of total density (all taxa)

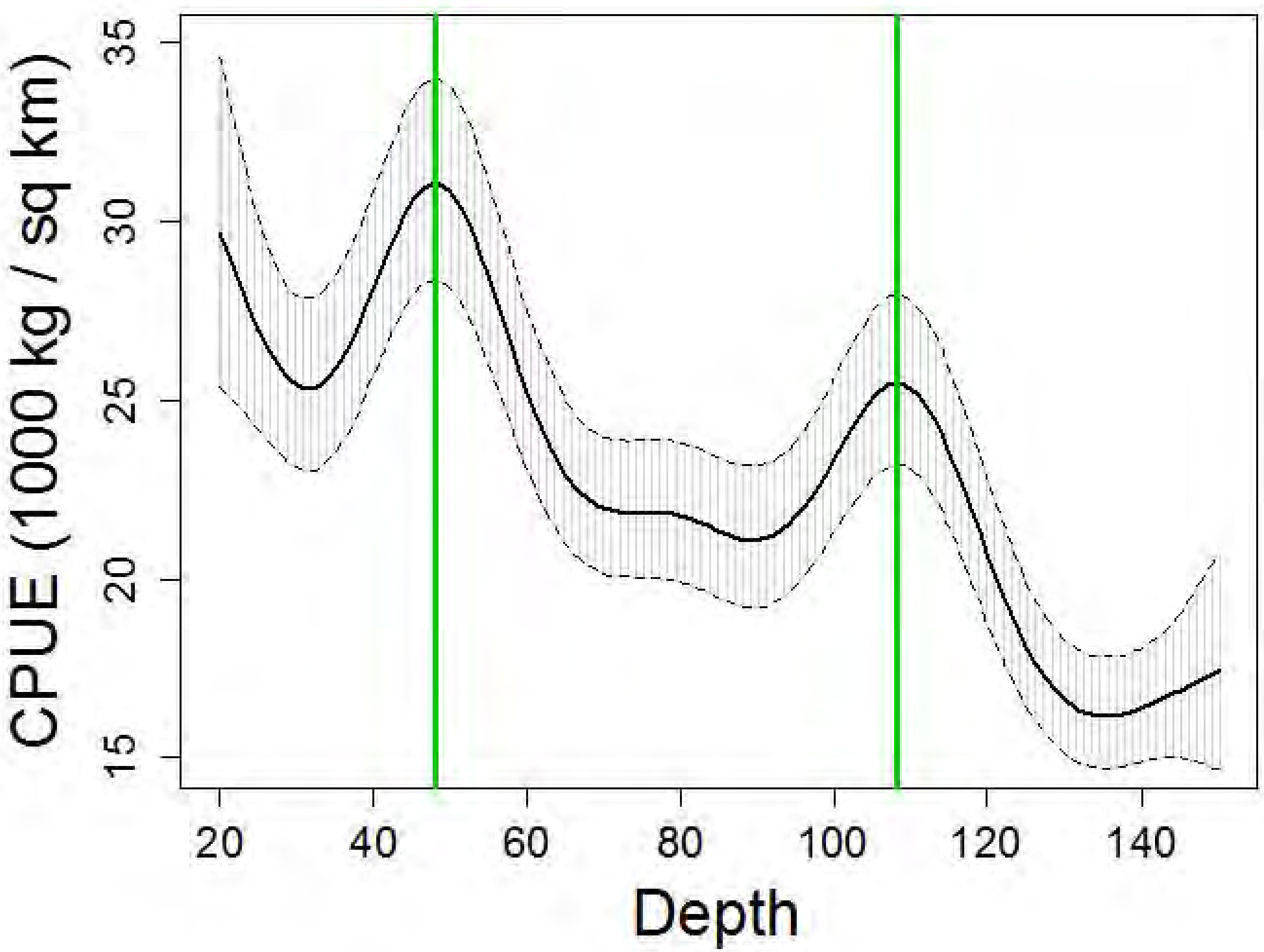
Cold years: 2007-2012



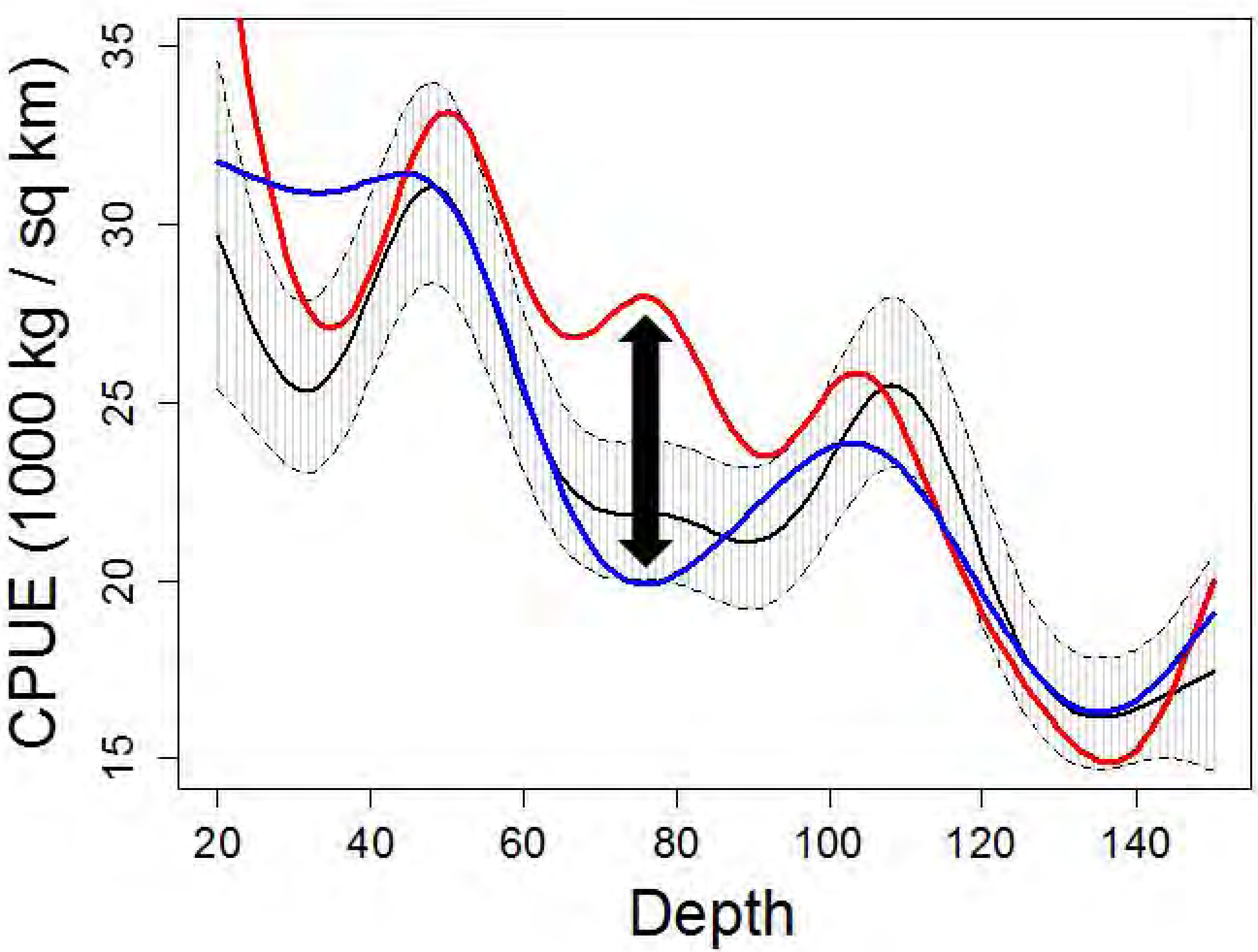
Warm years: 2001-2005



Total density (catch-per-unit effort or CPUE) is linked to oceanographic features



Total CPUE: warm vs. cold years



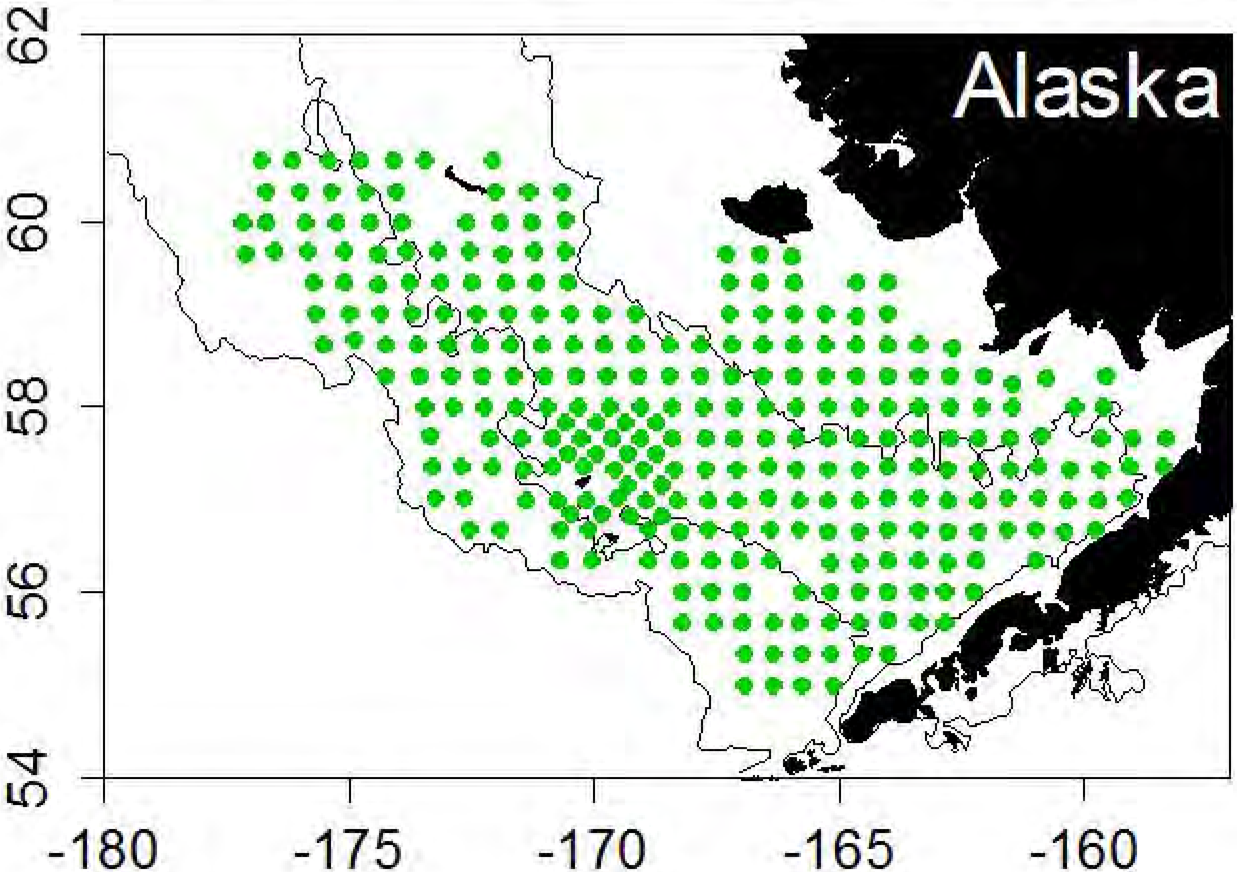
Measures of distribution

- Center of gravity
- Ellipses (defined by center of gravity and inertia)
- However, true distribution and distributional changes much more complex
  - Coastlines
  - Islands
  - Topographic features

- → Alternative measure of distribution:
  - First mode from a PCA / EOF analysis based on time series of abundance at a grid of survey stations

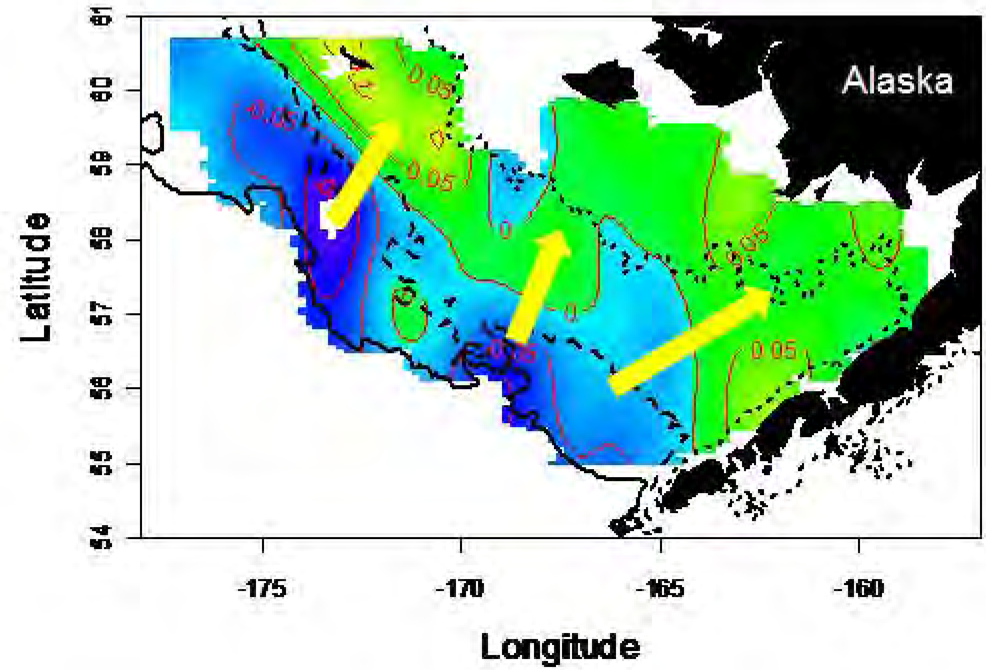
Survey grid

- Stations sampled in all years, 1982-2012
- Catch-per-unit-effort (CPUE) anomalies by station & year



Example: Total biomass (CPUE)

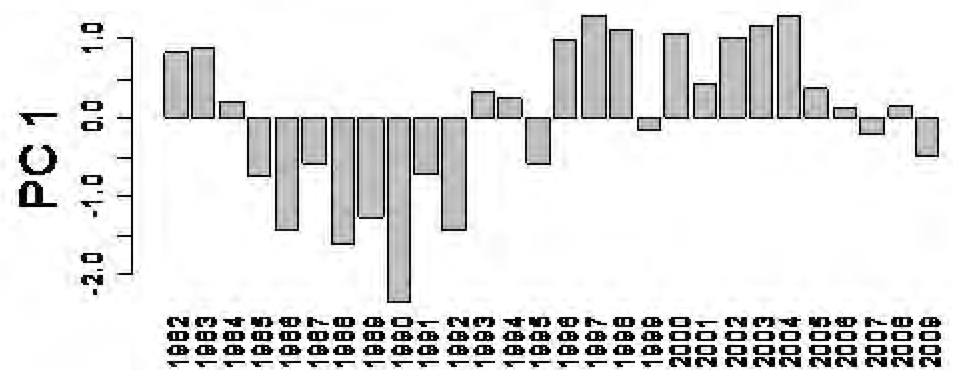
Spatial pattern
(first mode from PCA of total CPUE)
~ 12% of total variance



Time trend

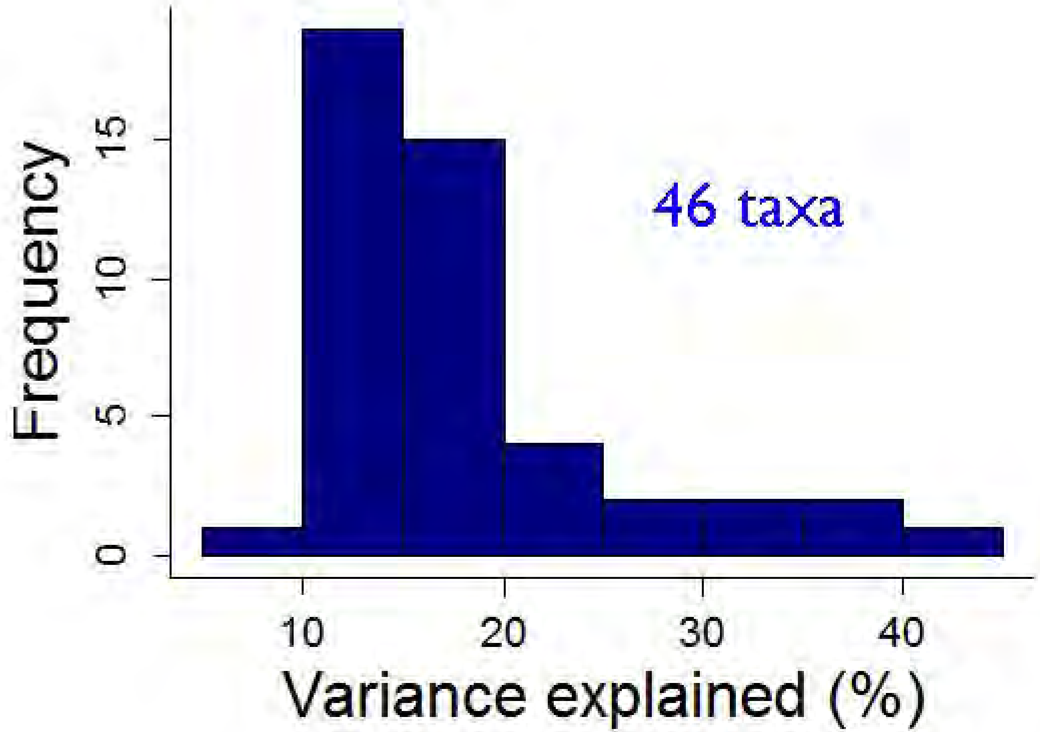
Correlated with mean annual bottom temperature:

r = 0.42 (p = 0.026)



First mode of variability for each species

- Save first mode (PC1) from a PCA of CPUE series (1982-2012) at 285 stations
- Proportion of total variability in CPUE accounted for by the first mode:



Modeling variability in spatial distribution

- PC1 as response variable
  - Advantages
    - Reflects actual changes in <u>pattern</u> of distribution
    - Sensitive to all forms of distributional shifts, except proportional change at each location
  - Disadvantages
    - Less intuitive than center of distribution
    - Interpretation is species-specific because spatial patterns differ!
- Potential drivers examined
  - Temperature (current or previous year)
  - Advection (multiple lags: effect on earlier life stages)
  - Total biomass (density-dependent response, no lag)
  - Fishery removals (multiple lags up to 3 years earlier)
  - (Mean date of sampling to account for seasonal changes)

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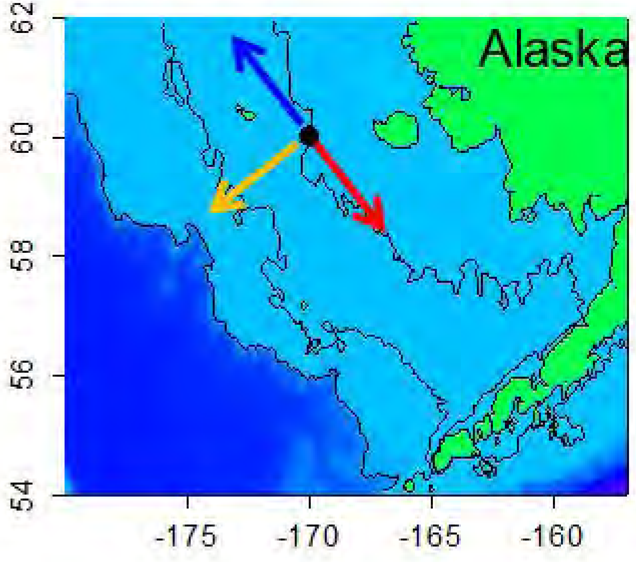
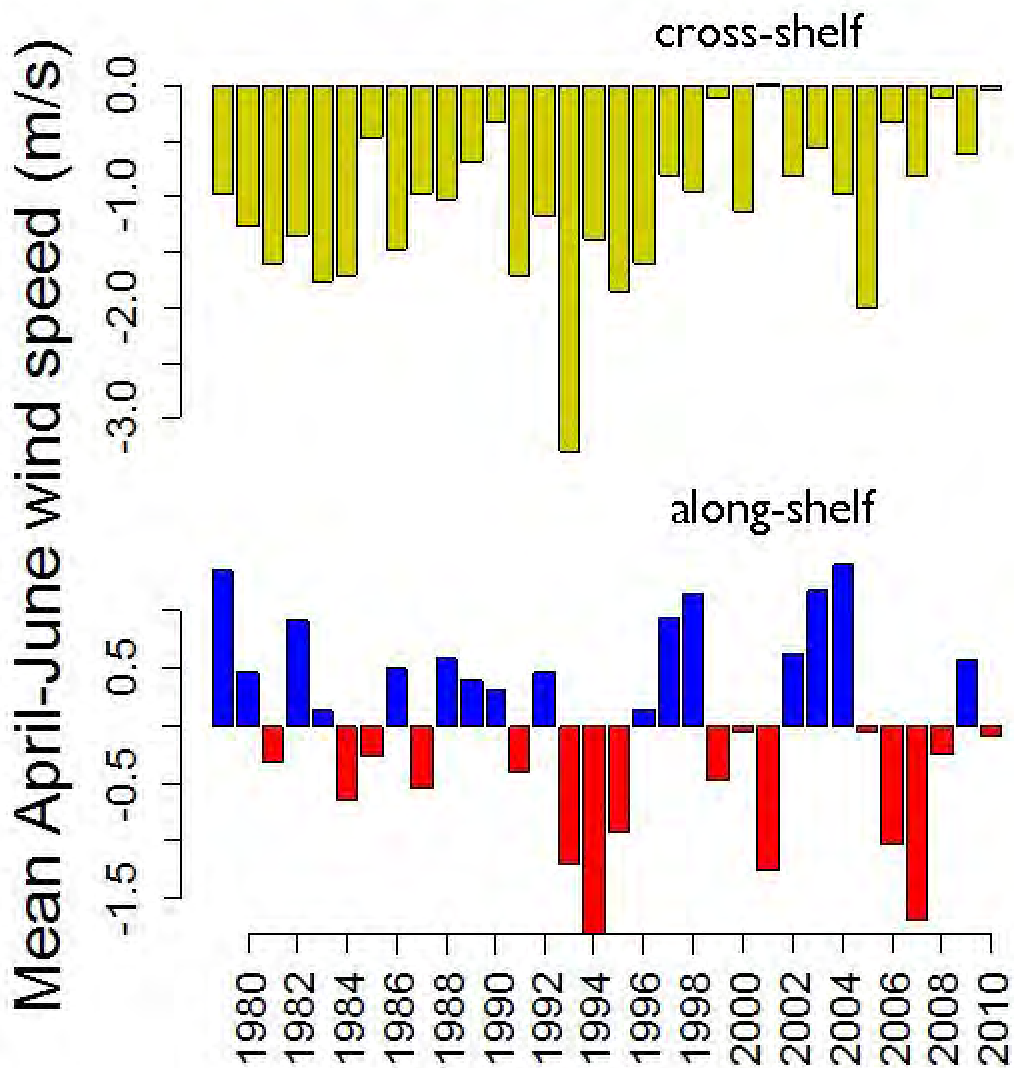
Cross-shelf and along-shelf winds during spring / early summer (April – June)



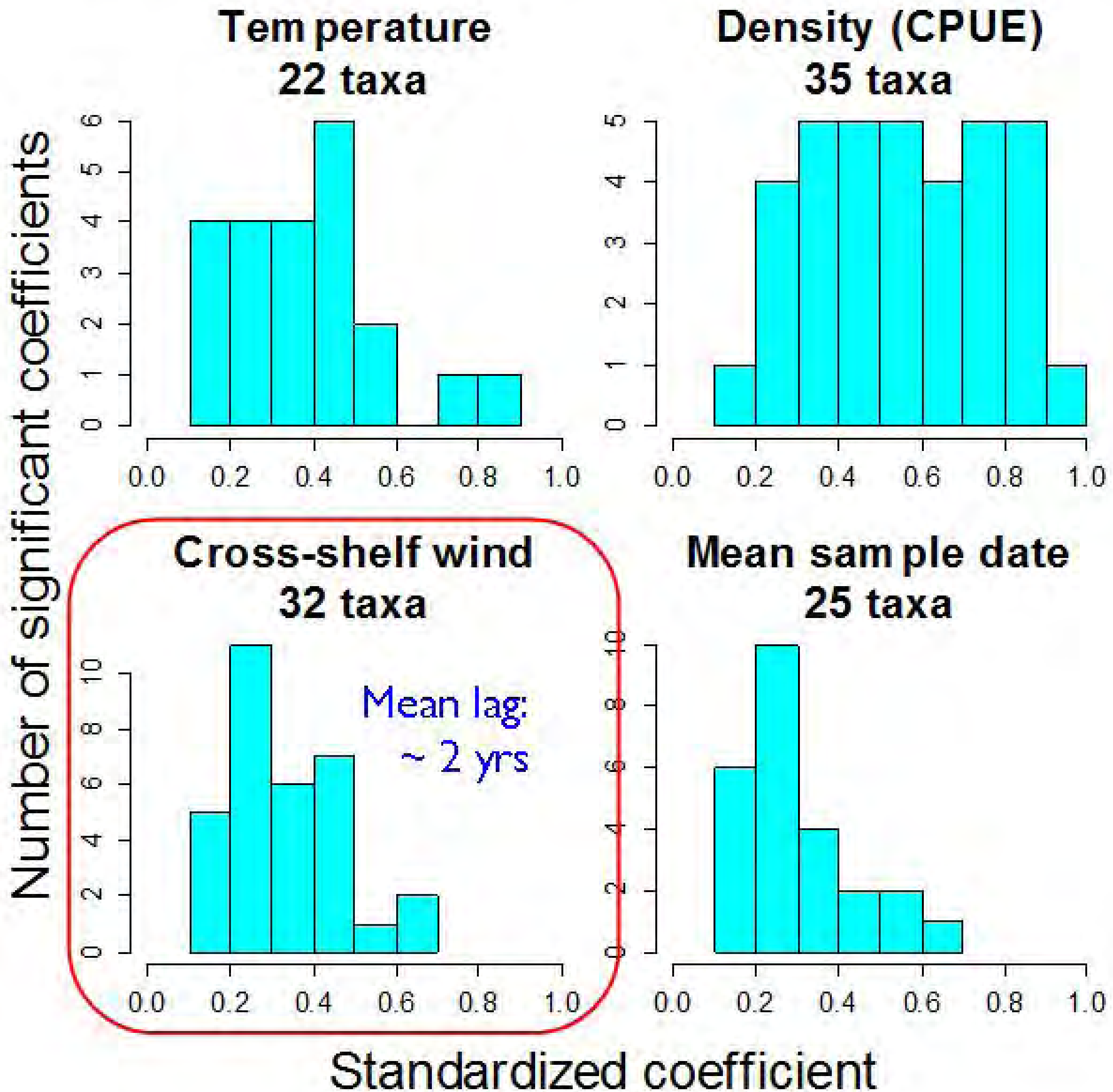


Multiple regression by taxon

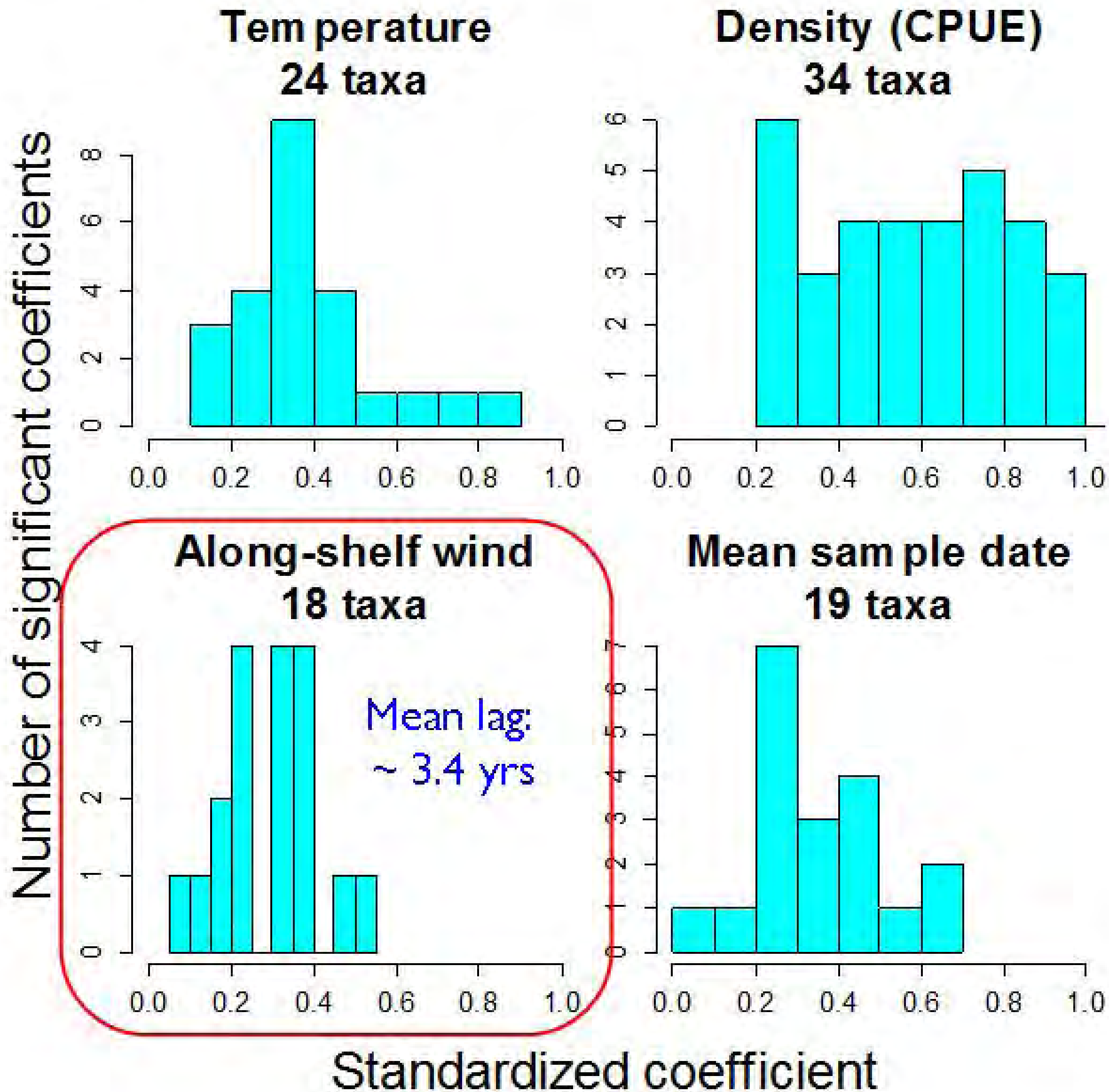
$$PC1 = \alpha + \beta_1 \text{(temp)} + \beta_2 \text{(density)} + \beta_3 \text{(winds)} + \beta_4 \text{(catch)} + \beta_5 \text{(date)} + \varepsilon$$

- Catch available for 8 commercial taxa only!
- Each variable was standardized to allow comparison of magnitude of coefficients
- Sign of coefficients is arbitrary

Estimated effects on spatial distribution

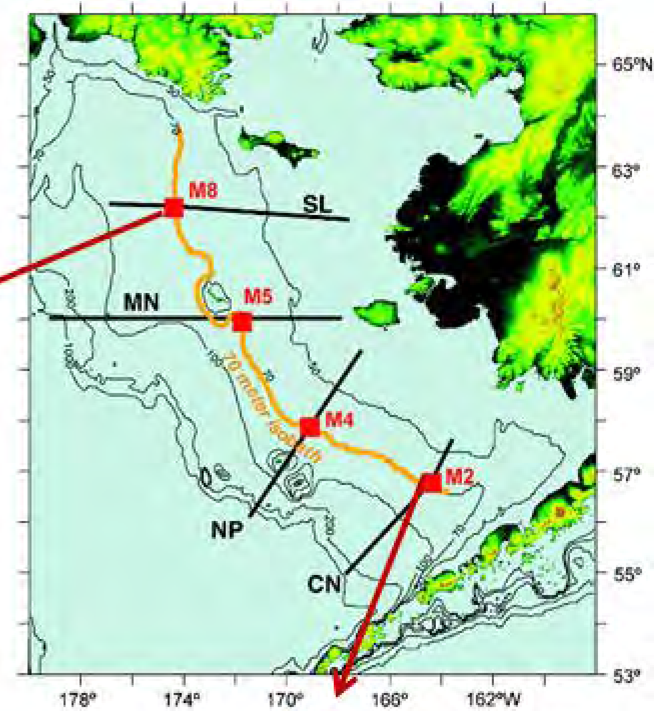


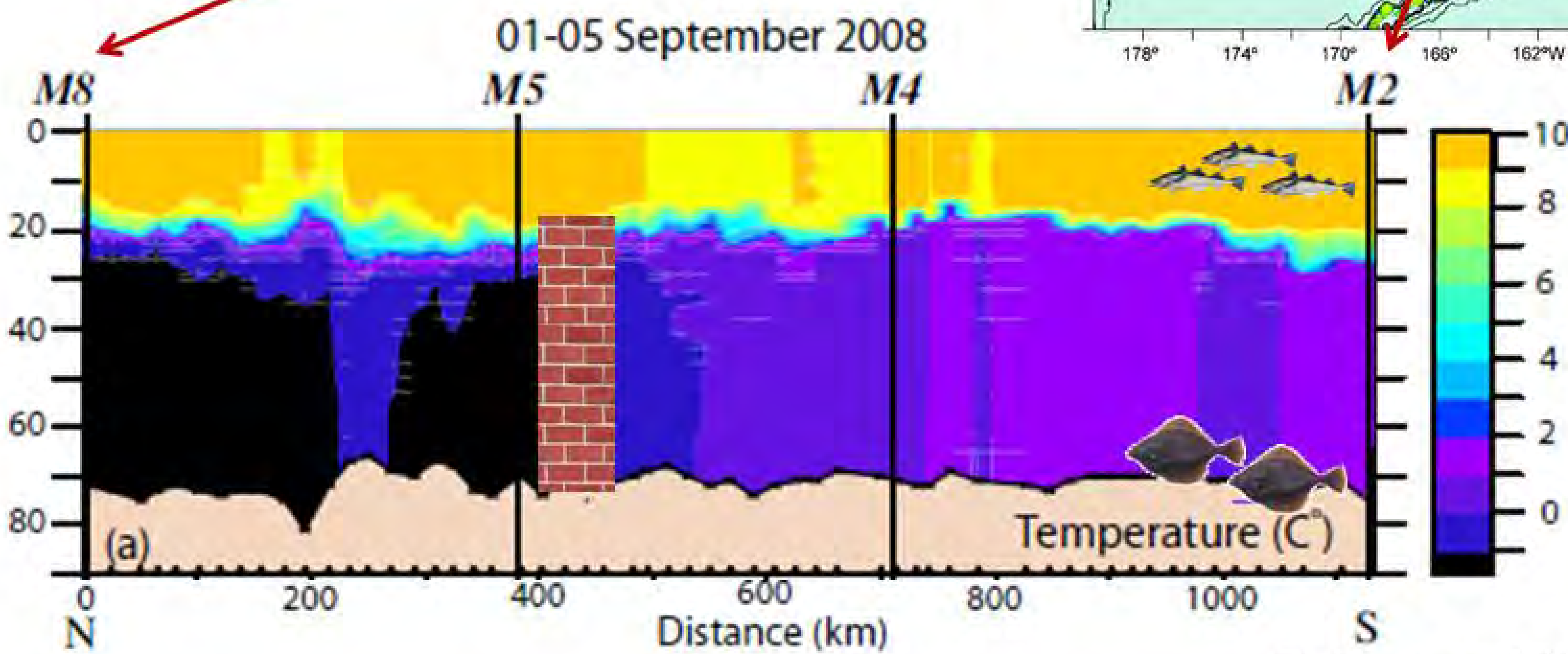
Weaker effect of along-shelf winds



Will subarctic fishes expand into northern Bering Sea through active migration or advection as the Bering Sea continues to warm?

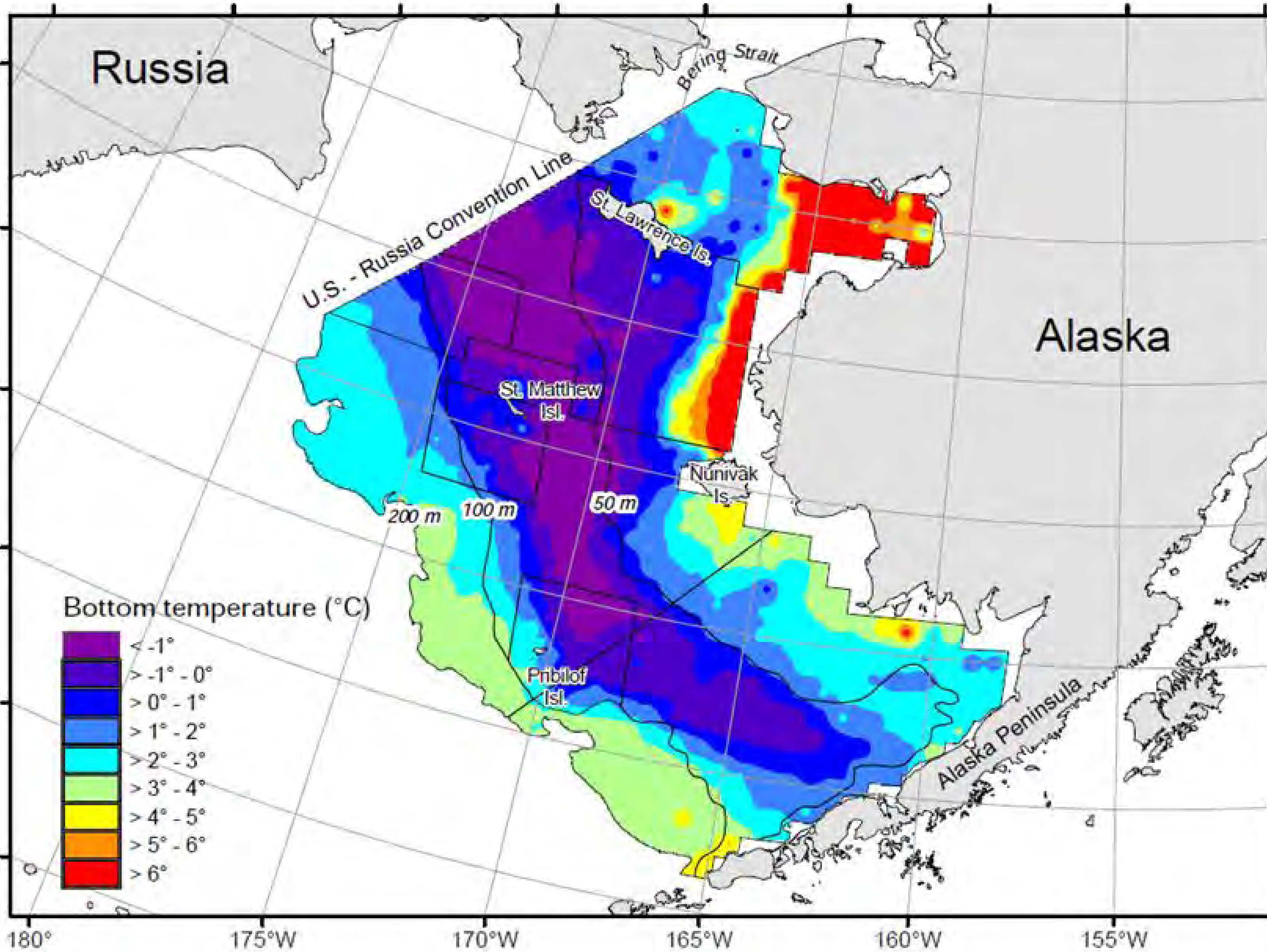
North-South transect: <u>middle</u> shelf (70m)



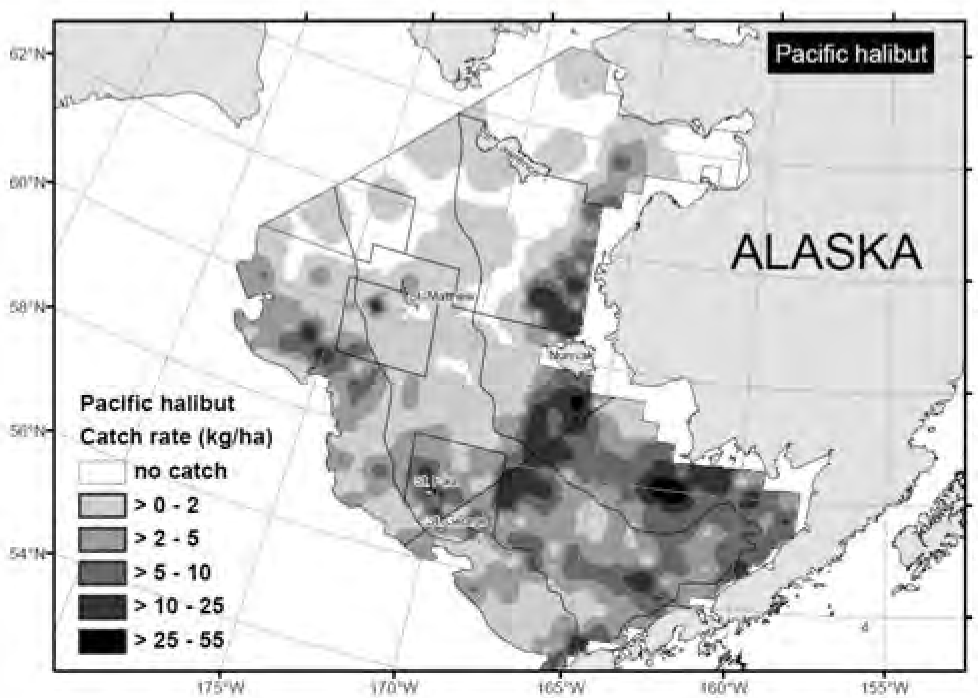


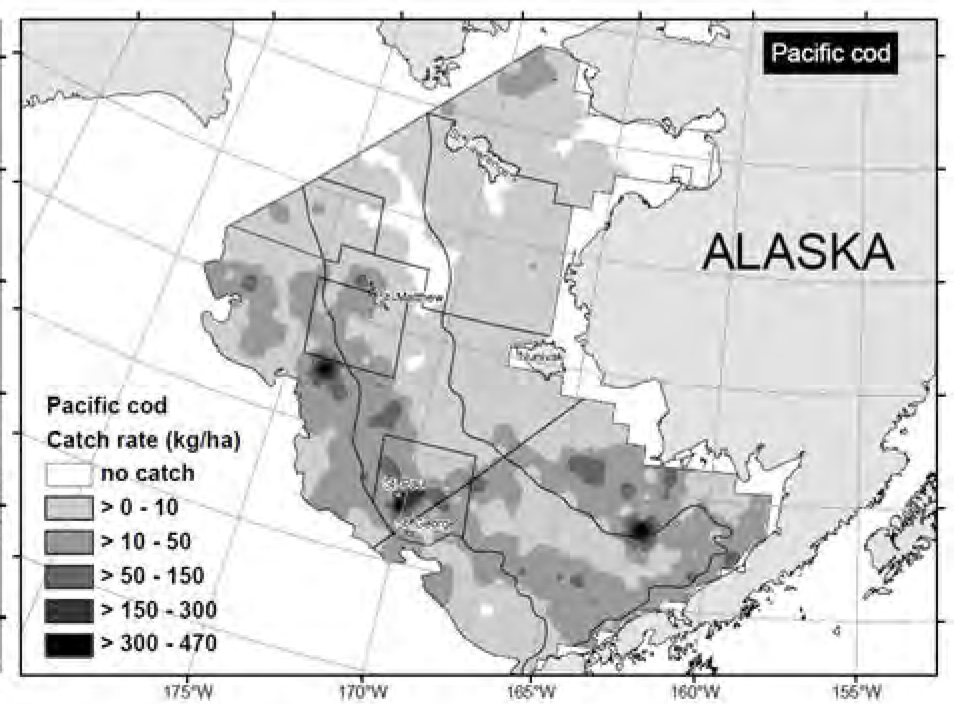
Stabeno et al (2012)

2010 bottom temperatures



Distribution of 2 subarctic species in 2010





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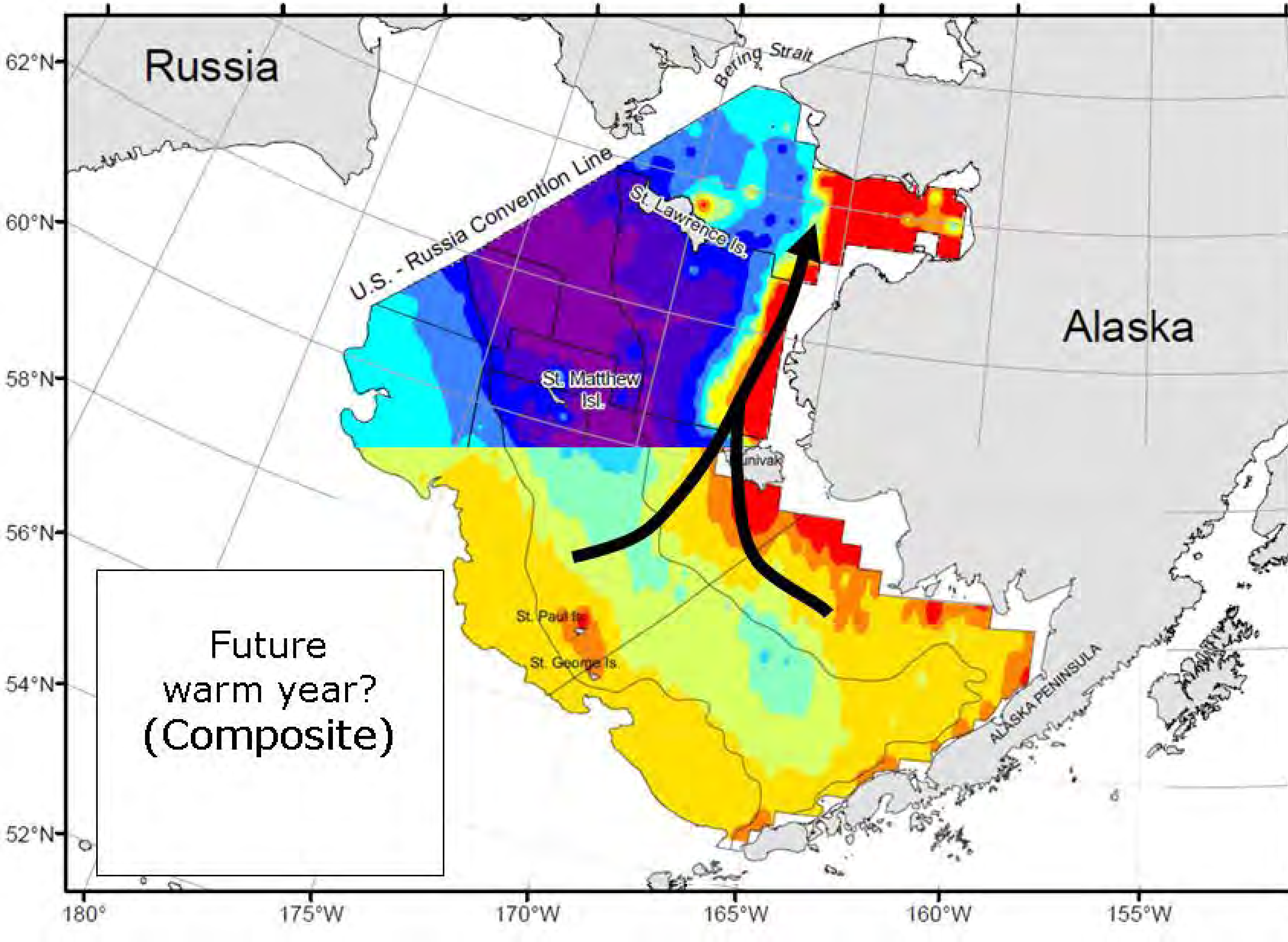
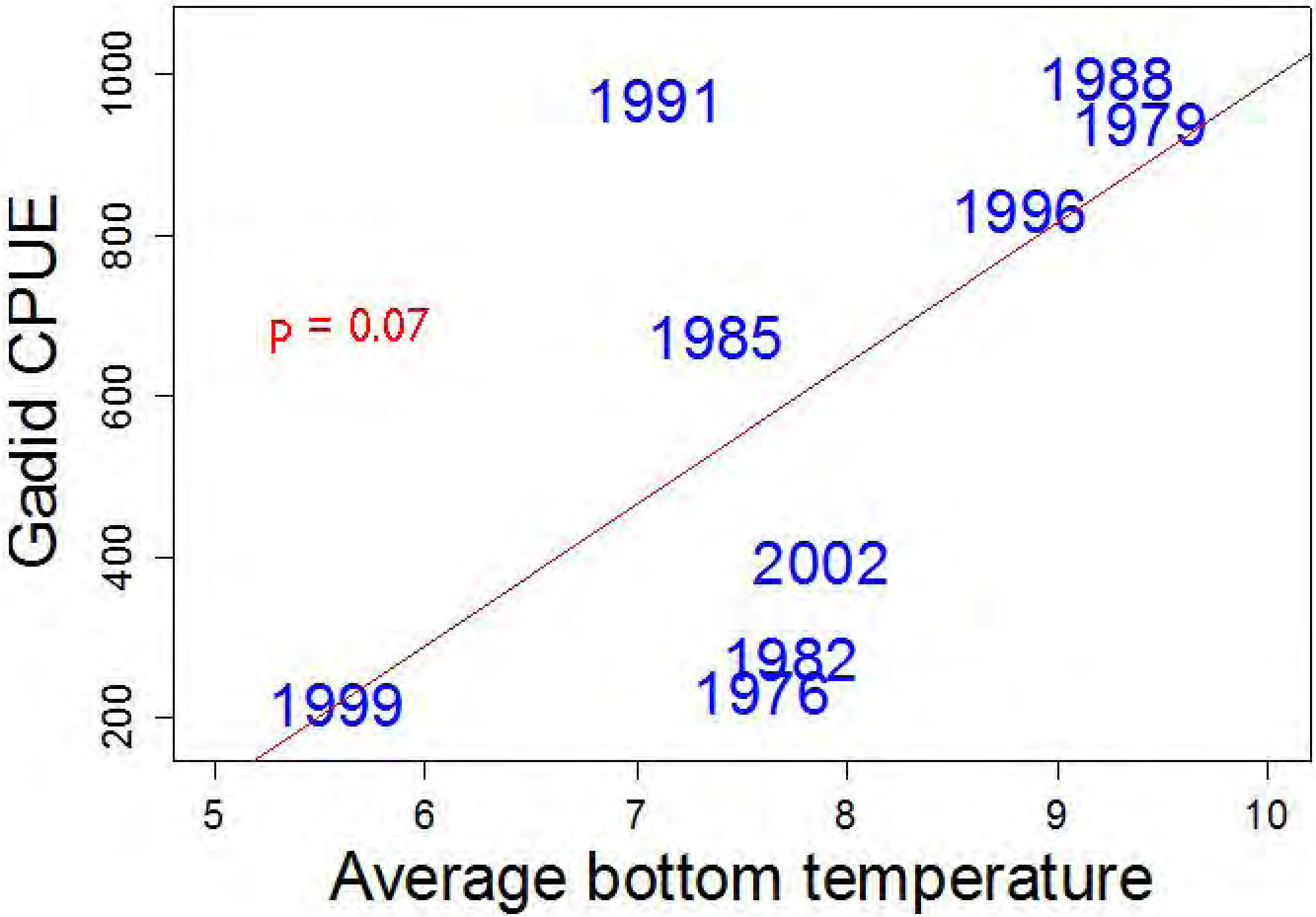


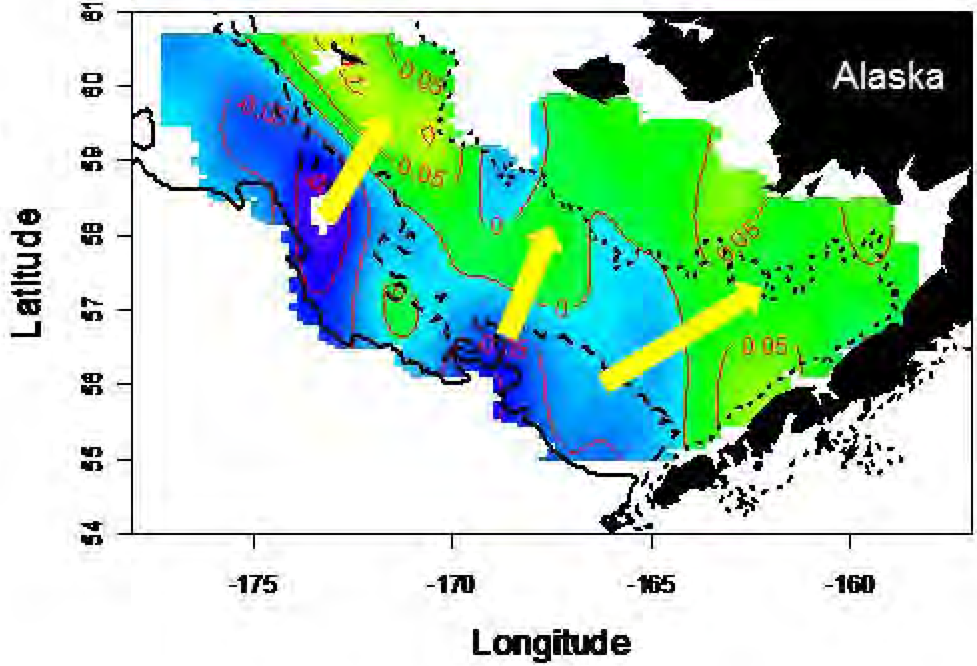
Norton Sound:
Gadid CPUE and temperature, 1979-2002

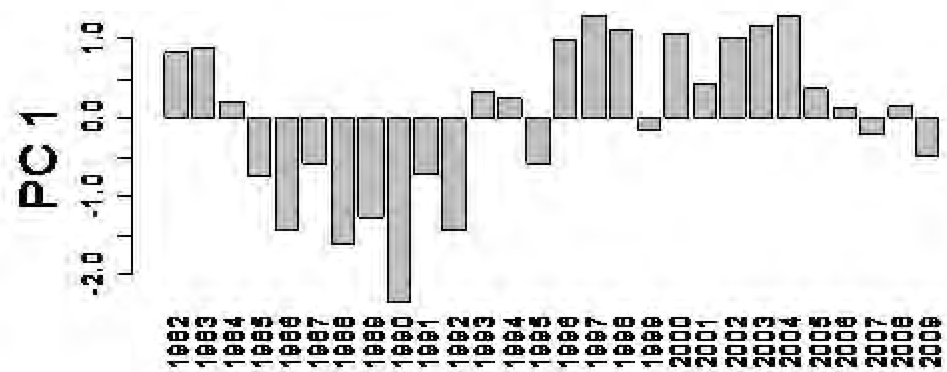


Based on Table 1 from Hamazaki et al (2005)

Increases in shallow and northern part of survey region in warm years

- Provides easier "access" to northern Bering Sea
- Size composition of subarctic species in northern BS most consistent with fish from inner domain





Summary & Conclusions

- Widespread poleward shifts in distribution in response to warming, role of advection not previously quantified
- In addition to density-dependence and temperature, advection appears to play leading role in regulating summer distribution of groundfish on eastern Bering Sea shelf
- Spring-time cross-shelf winds more strongly linked to distribution than along-shelf winds
- Northward spread on middle shelf limited by continuing cold bottom temperatures throughout summer on the northern shelf
- Possible increase in nearshore migration of subarctic species into northern Bering Sea during summer with potentially important impacts on benthic food web