Geographic distributions of eastern Bering Sea flatfish: Effects of environmental variability and population abundance

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Objectives

1) Describe the Eastern Bering Sea System and recent trends in environmental variability and flatfish distributions

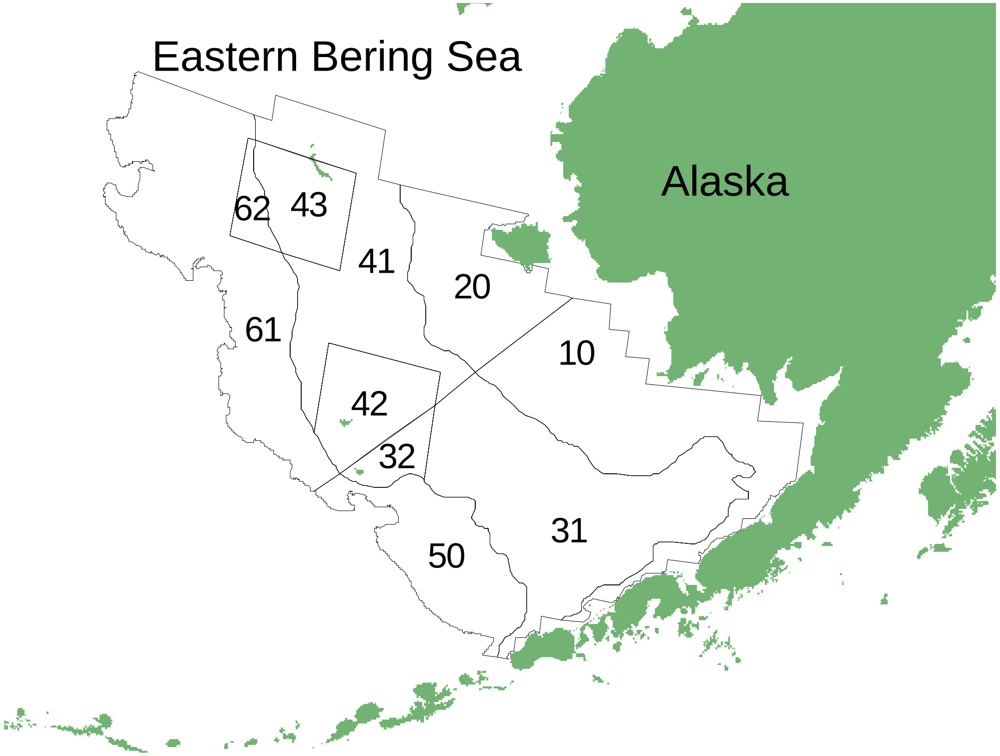
2) Describe statistical models relating changes in flatfish distributions to environmental variability and changes in abundance.

3) Describe how Alaska flatfish stock assessments have addressed the effect of environmental variability on survey data.

Study area

Highly productive system – Primary productivity ranges from 200 to 800 g C m^{-2}

Sea ice plays a major role in primary and secondary productivity, particularly in the formation of the "cold pool"



Methods

Eastern Bering Sea trawl data used for analysis, 1982-2004

1) Consistent gear and sampling design since 1982
2) Summer survey, stations location on a 20 nm x 20 nm grid

Estimation of mean temperature (also depth and sediment size)

1) average in survey area – tows are weighted by their proportion of survey area
2) average occupied by a species – tows are weighted by their proportion of survey area and relative CPUE

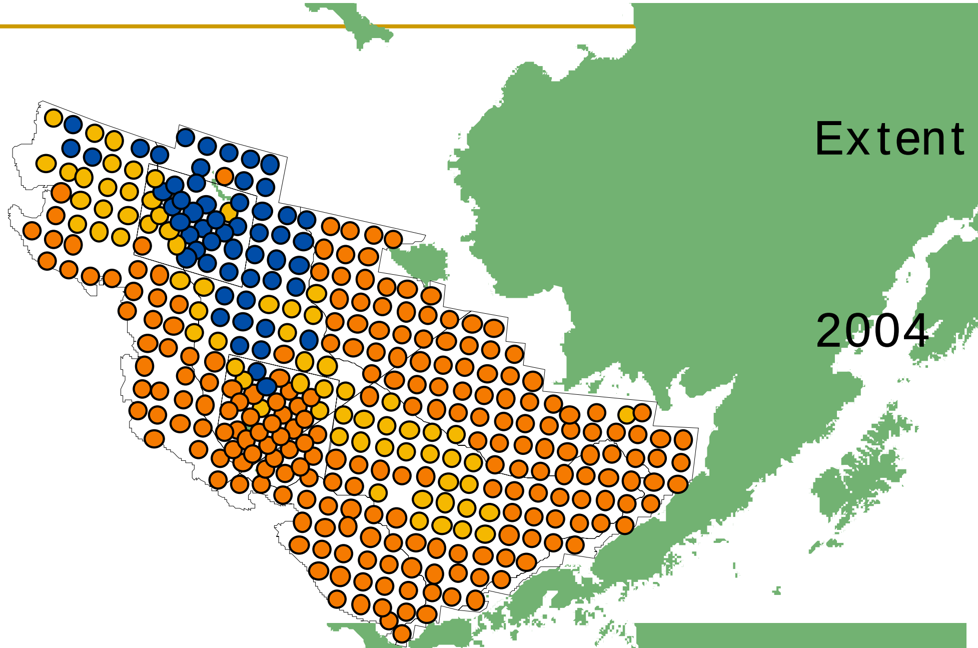
Compute centroids of flatfish distributions by year

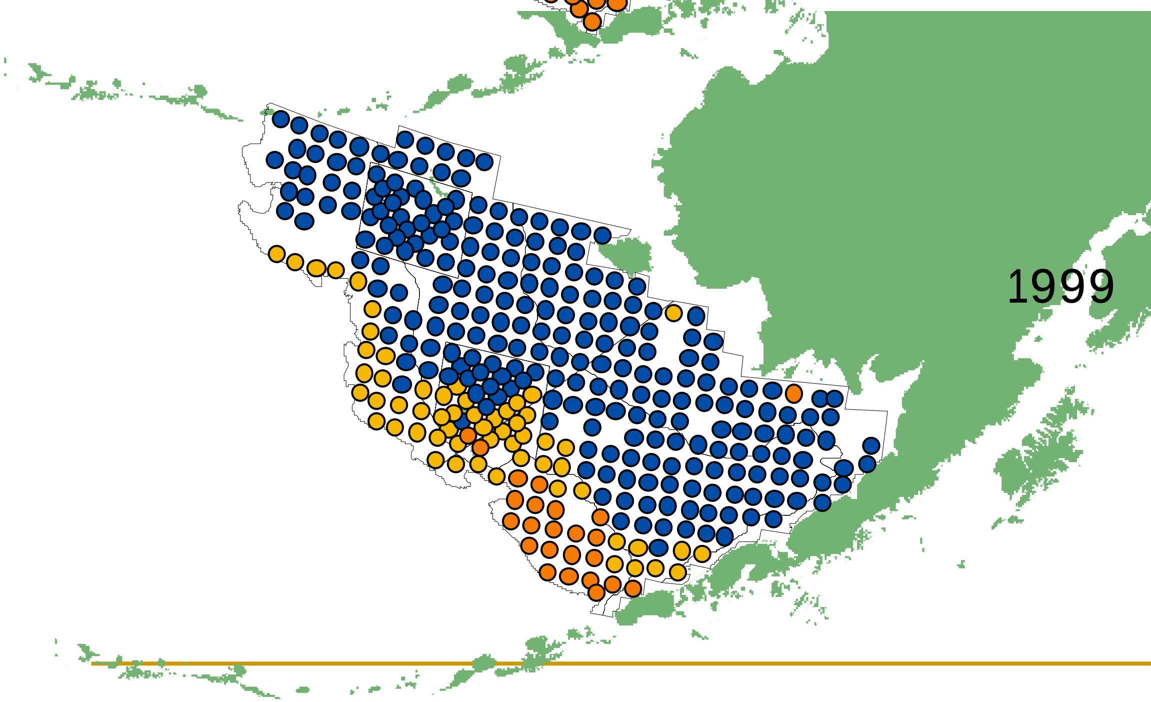
Average latitude and longitude of stations where a species is found, weighted by catch per unit effort (CPUE)

Compute ellipses encompassing 50% of the flatfish distribution

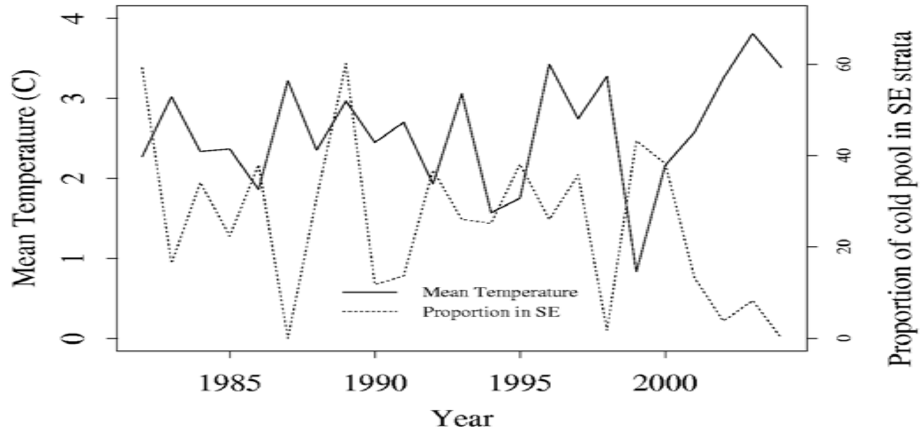
Fit bivariate normal curves to the spatial distributions

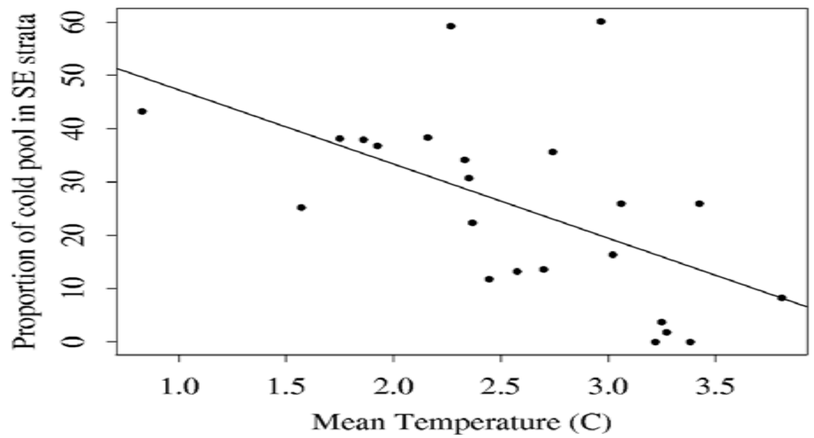
Extent of cold pool on the EBS shelf



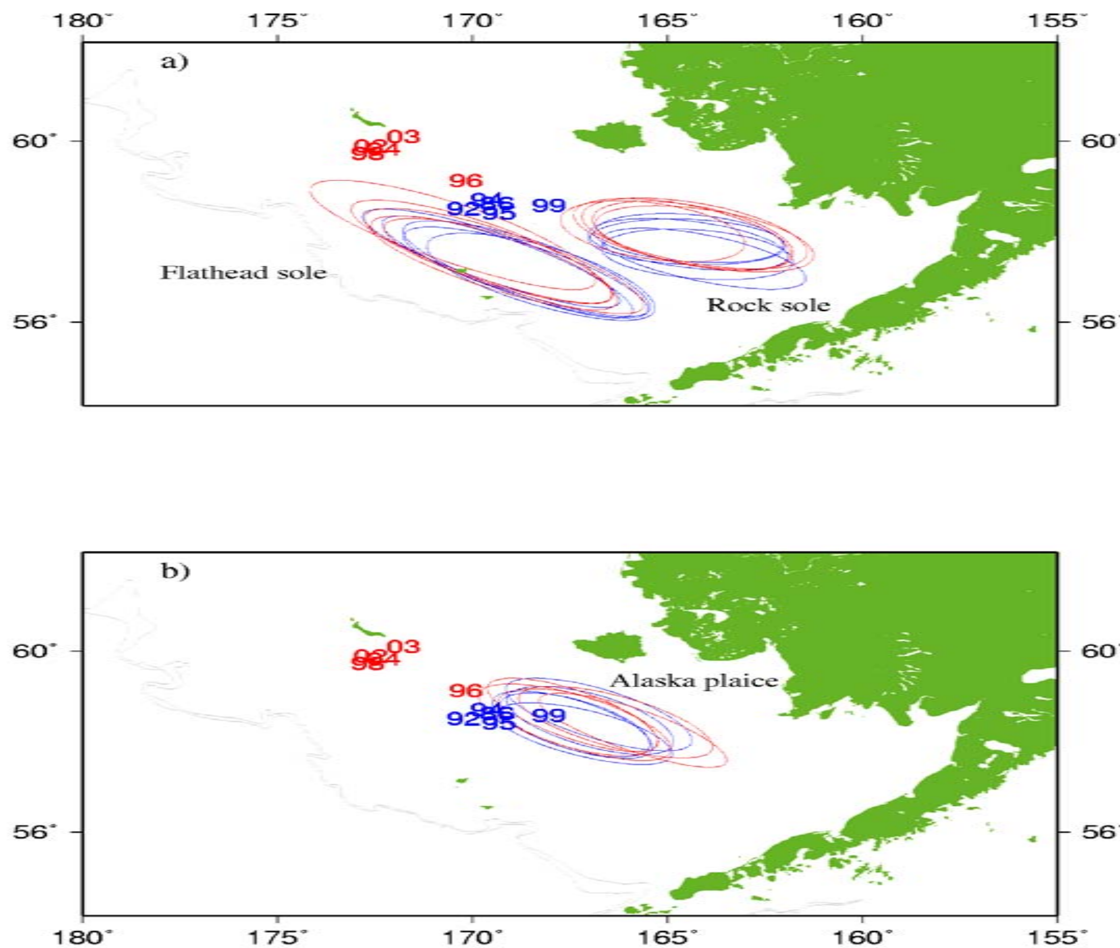


Time series of mean temperature and proportion of cold pool in SE shelf

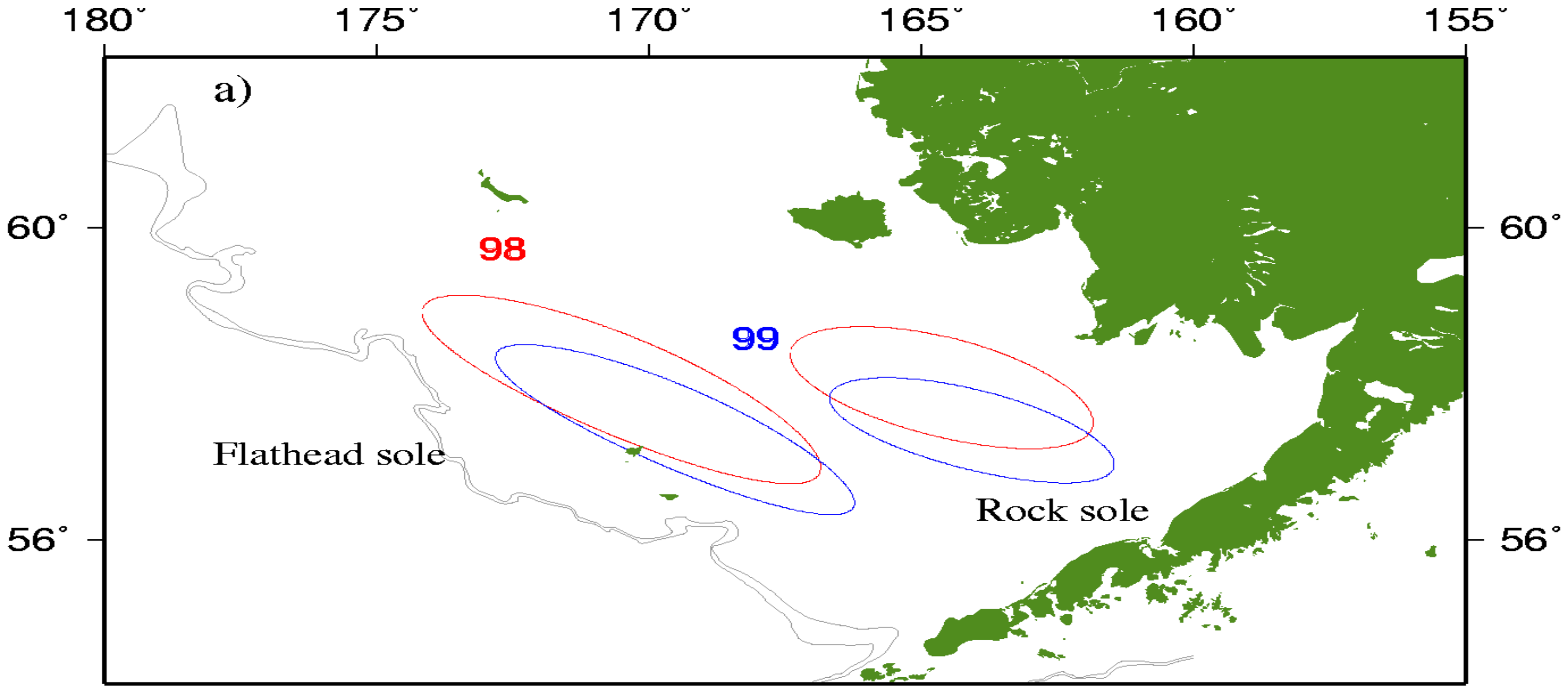




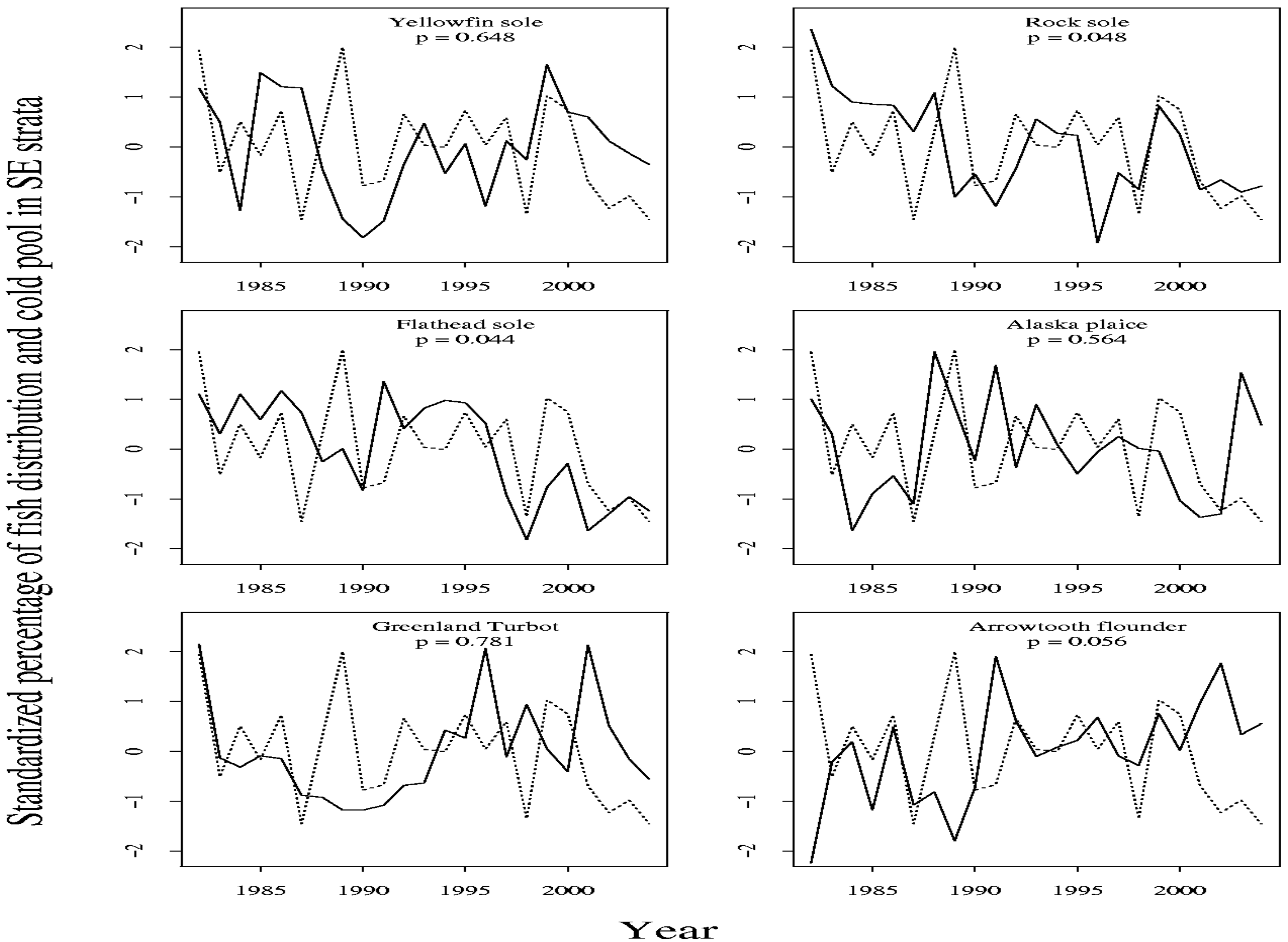
Distribution shifts of flatfish between warm and cold years



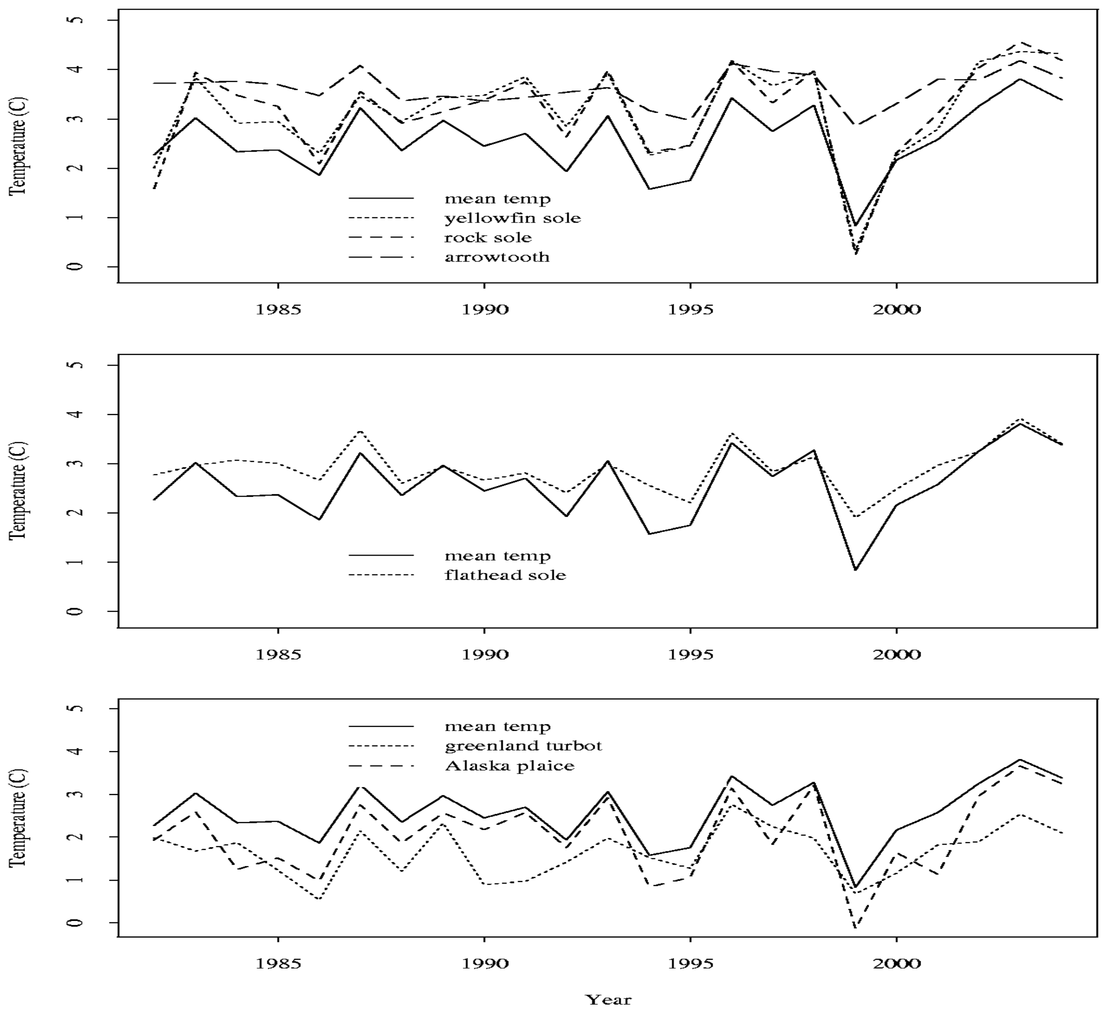
Rock sole and flathead sole distributions – 1998 and 1999



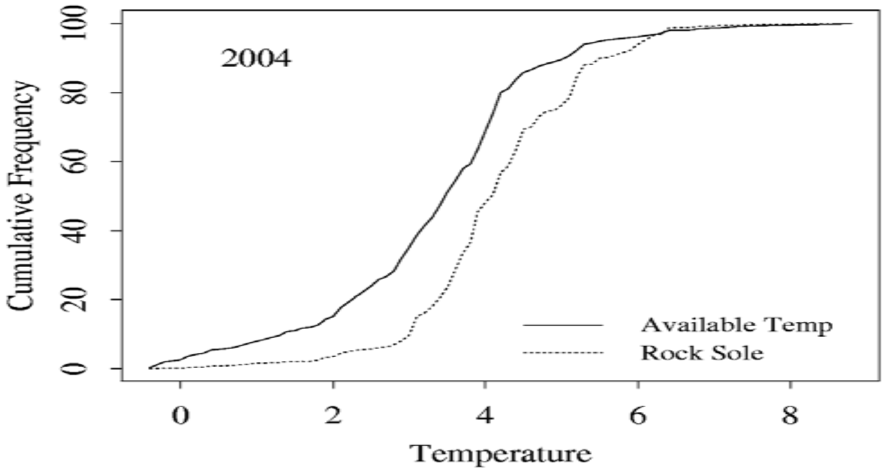
Relationship between fish distributions and cold pool distribution

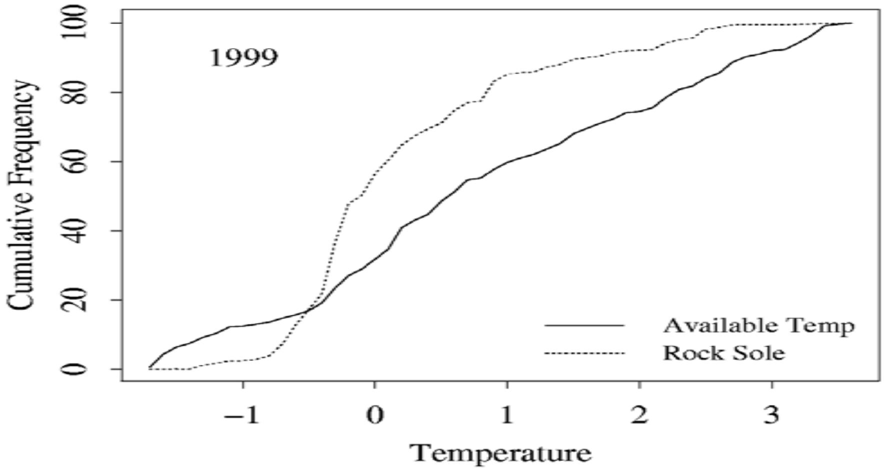


Time Series of Mean Temperature Occupied by Various Flatfish Species



Example CDF plot for Rock Sole and Temperature in 2004 and 1999

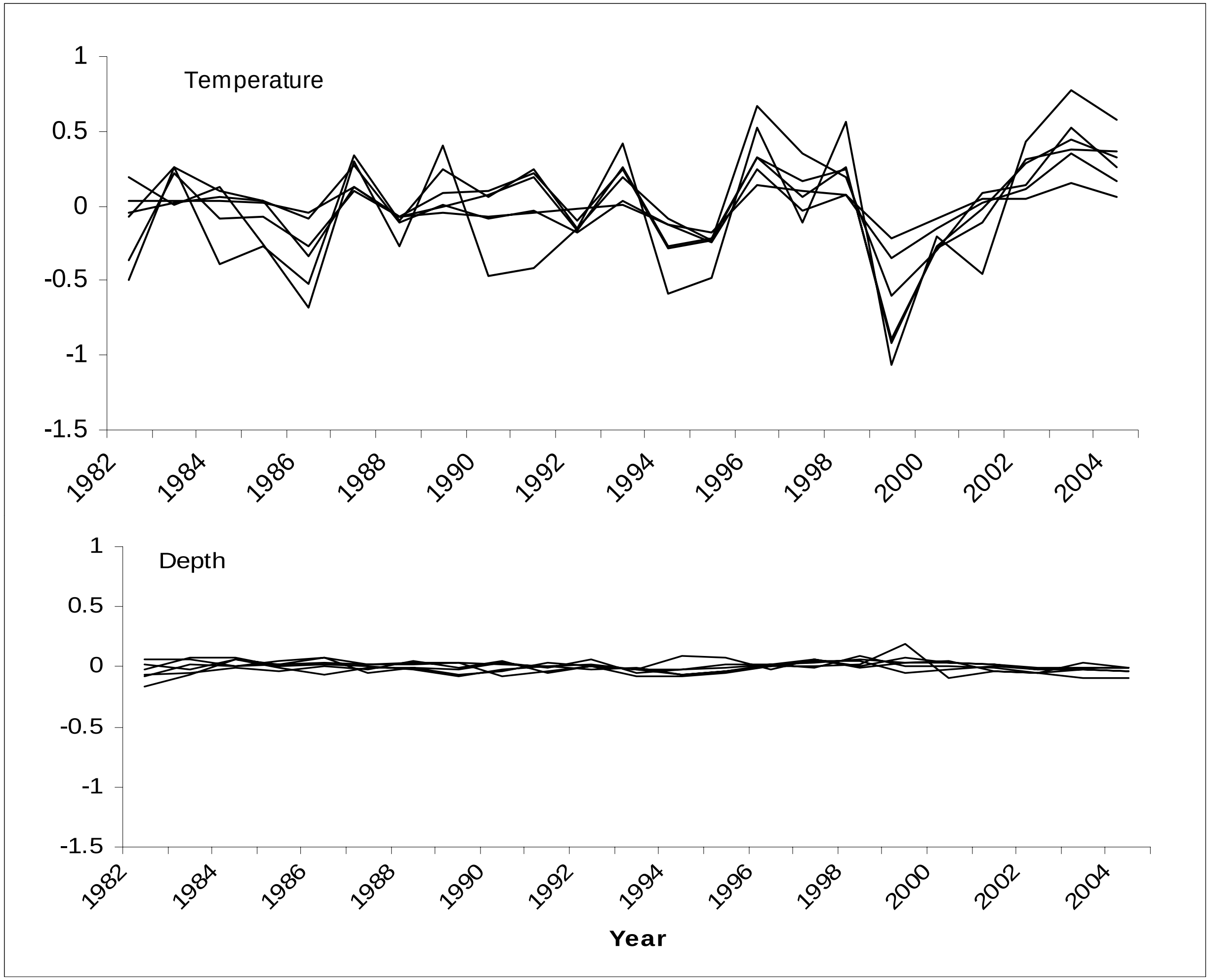




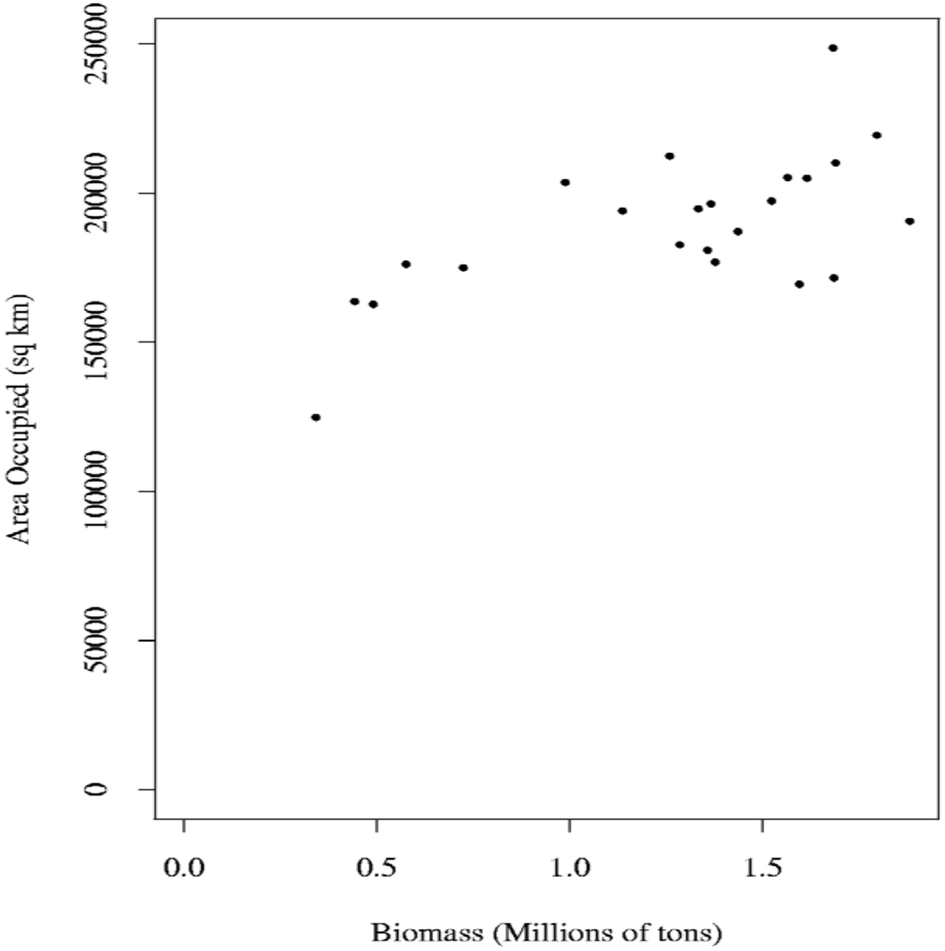
Results of Randomization Tests

Environmental variable	Regime	Year	Yellowfin sole	Rock sole	Flathead sole	Alaska plaice	Greenland turbot	Arrowtooth flounder
Temperature	Cold	1986	0.032	0.000	0.000	0.000	0.000	0.000
		1992	0.000	0.000	0.073	0.283	0.000	0.000
		1994	0.010	0.001	0.000	0.000	0.004	0.000
		1995	0.014	0.000	0.000	0.000	0.000	0.000
		1999	0.000	0.000	0.000	0.000	0.120	0.000
	Warm	1996	0.000	0.000	0.003	0.028	0.000	0.000
		1998	0.000	0.000	0.507	0.031	0.000	0.000
		2002	0.000	0.000	0.632	0.043	0.000	0.000
		2003	0.000	0.000	0.012	0.858	0.000	0.000
		2004	0.000	0.000	0.017	0.449	0.000	0.000

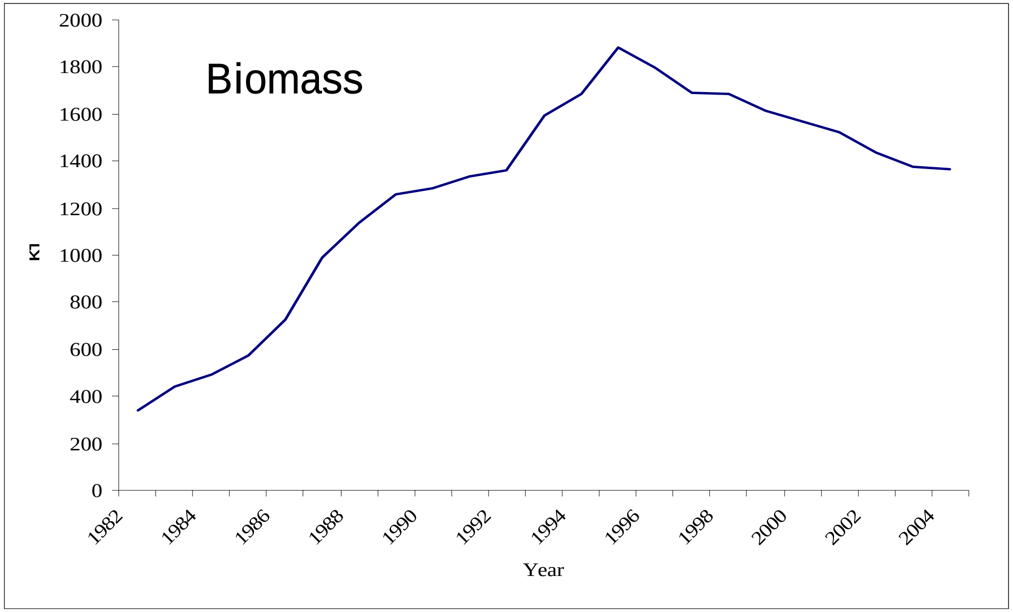
Depth-Temperature trade-offs are minimized on the EBS shelf



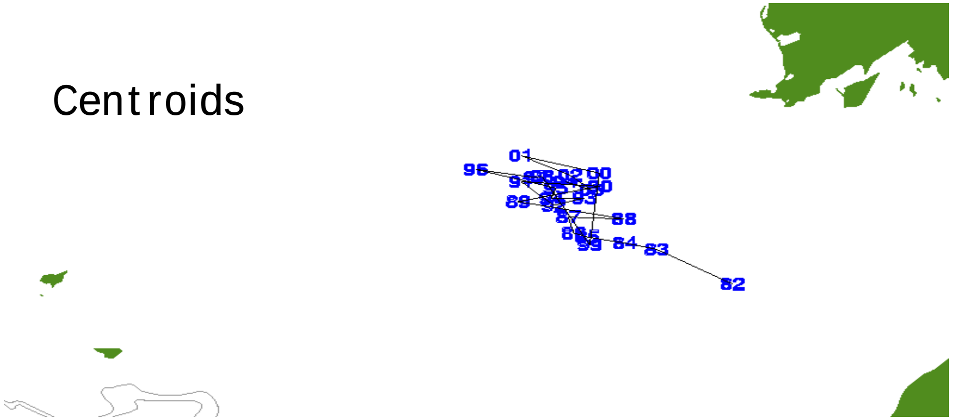
Density-Dependence Habitat Selection – a potentially confounding process



Rock sole have moved north as they have expanded their range



Centroids



Statistical Test for DDHS

$$y_{h,t} = \alpha_h B_t^{\beta_h}$$

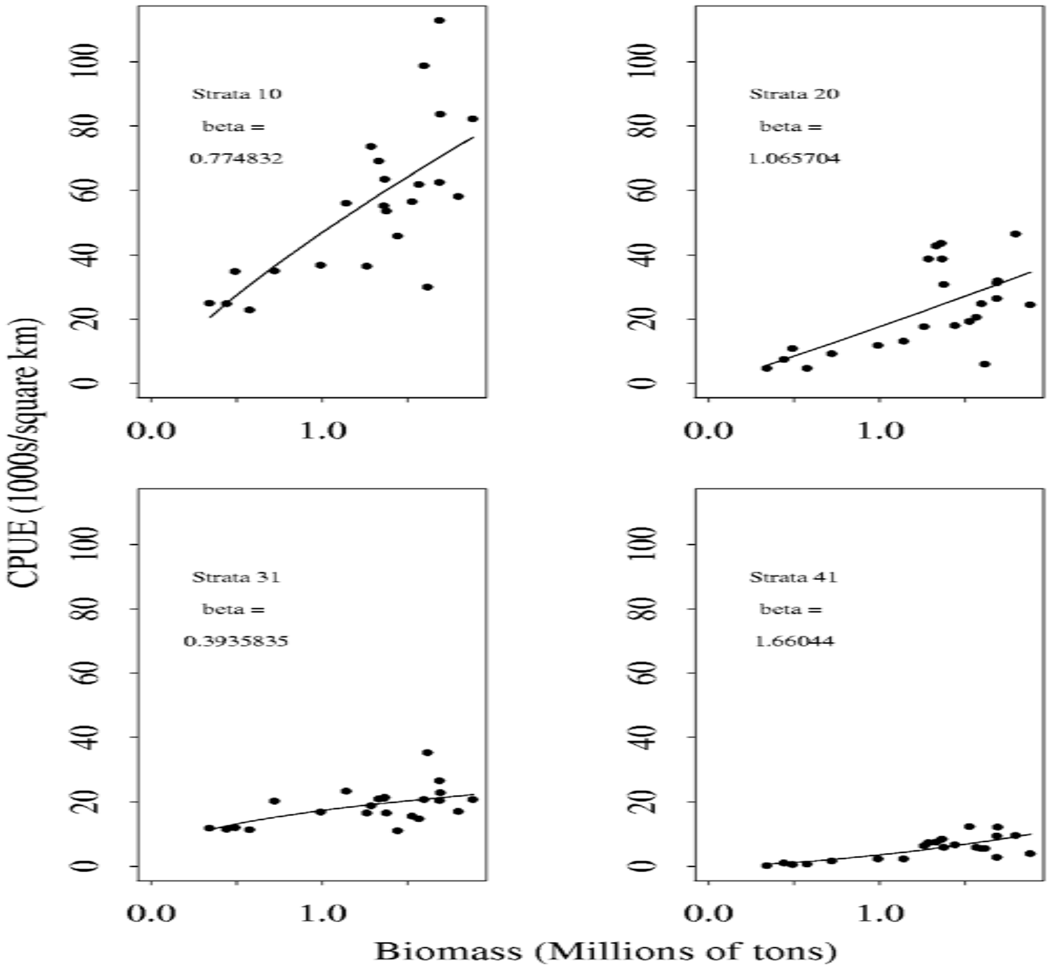
h = stratum
y = survey cpue within statum h
B = total biomass (across all strata)

Density dependent habitat selection

1) β < 1 in optimal habitats (stability in local CPUE with changes in population size)
2) β > 1 in marginal habitats (expansion during times of population increase)

A GLM was used to test for differences in β between strata

Density Dependent Habitat Selection –Rock Sole



Multiple Regression Model Relating Rock Sole Distribution to Biomass and Location of Cold Pool

Model:

Proportion of rock sole in SE = $\beta_0 + \beta_1$*biomass + β_2*proportion of cold pool in SE

Term	Estimate	t value	Pr(>|t|)
Intercept	83.7239	25.3546	0
biomass	8.03E-06	-3.8593	0.001
Proportion of CP in SE	0.1132	2.0619	0.0525
R-squared	0.526		
p-value	0.00057		

What are the resource management implications of shifting populations?

1) The catchability and availability of our surveys are affected

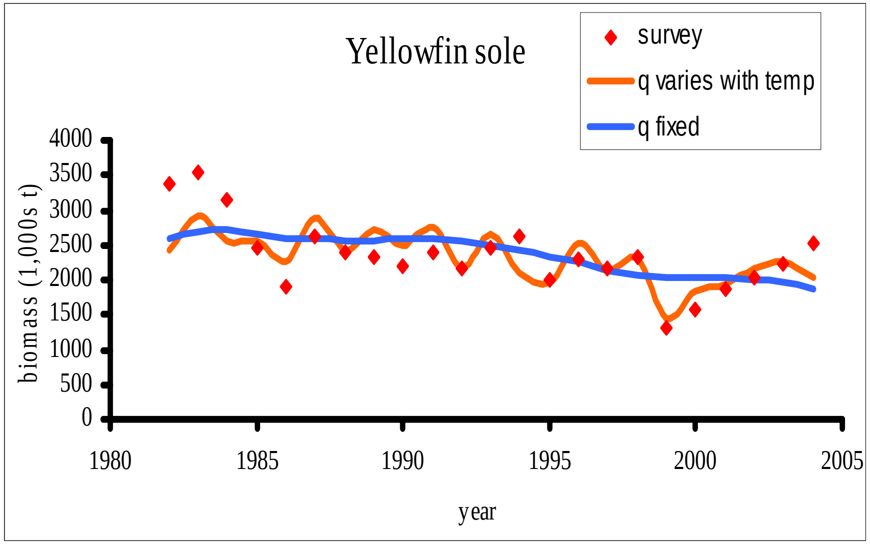
Catchability – refers to fish that are available to be captured by the gear but are not selected (i.e. changes in behavior)

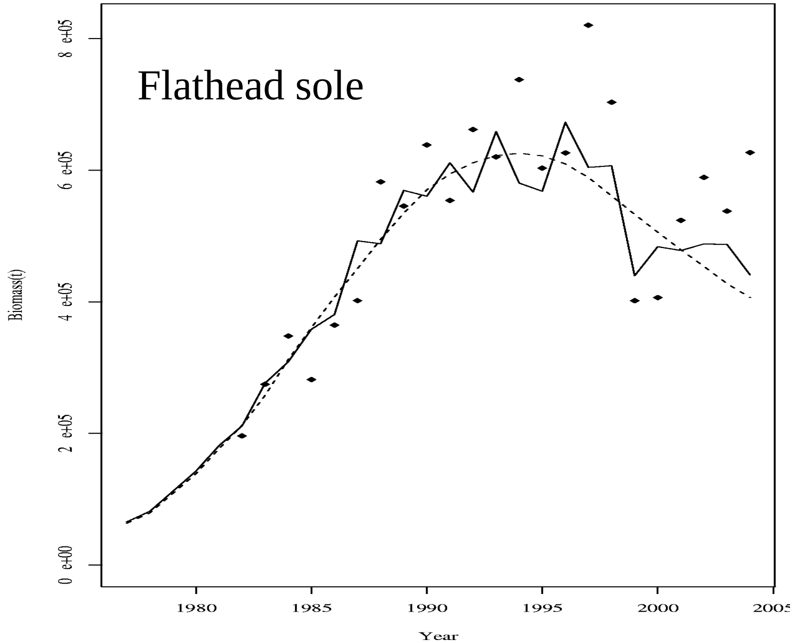
Availability – refers to the extent to which fish are available to the survey gear (i.e. changes in distribution)

Both things are encompassed in the the catchability parameter *q*

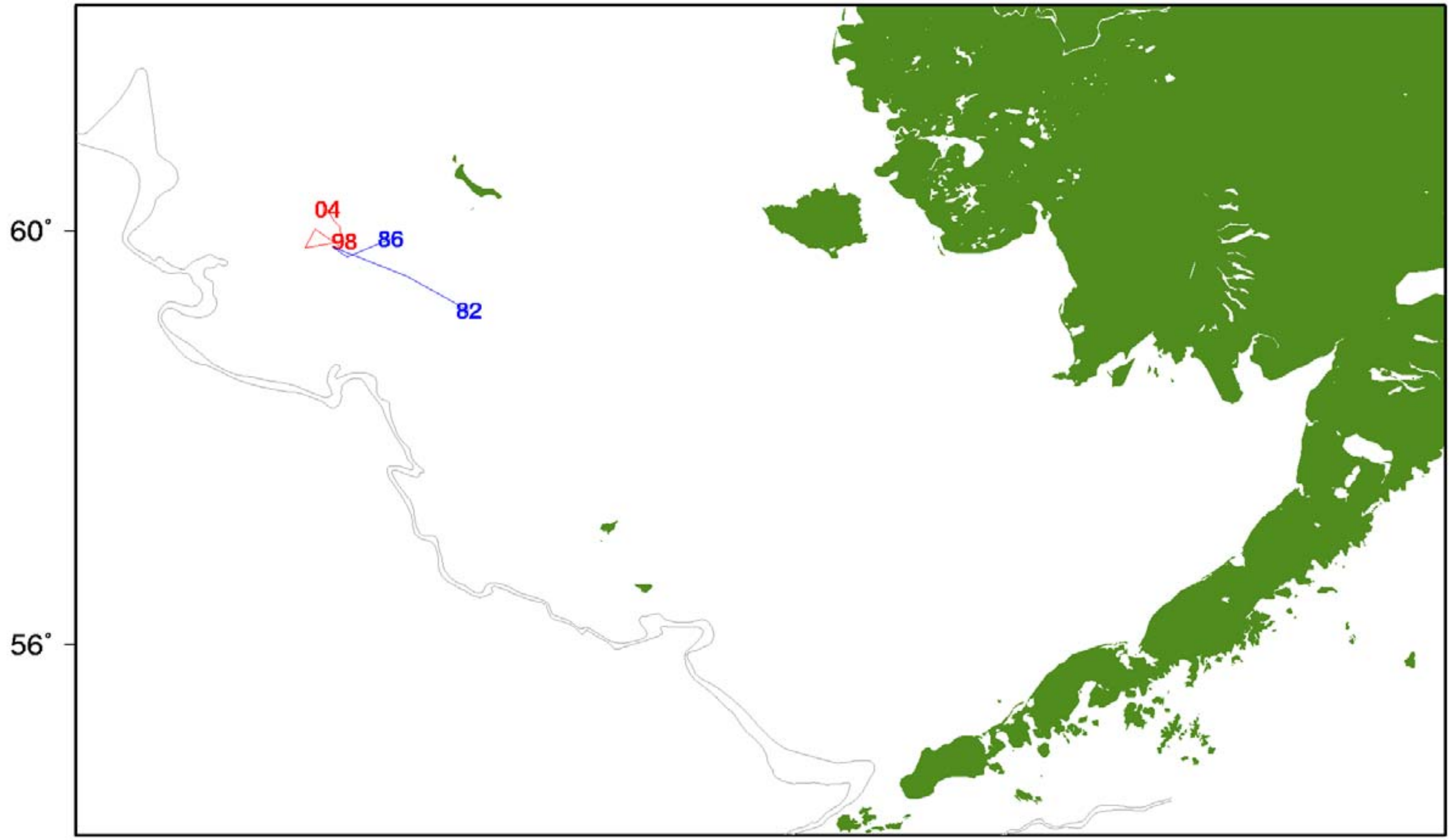
$$\hat{B} = q\sum_{a} s_a N_a W_a \qquad q = e^{(\alpha + \beta T)}$$

Examples of estimating temperature-dependent catchability





Greenland Turbot – movement may affect availability



Conclusions and items for future work

1) The spatial distributions of rock sole and flathead sole appear related to temperature, although for rock sole this effect may reflect movement associated with density-dependent habitat selection

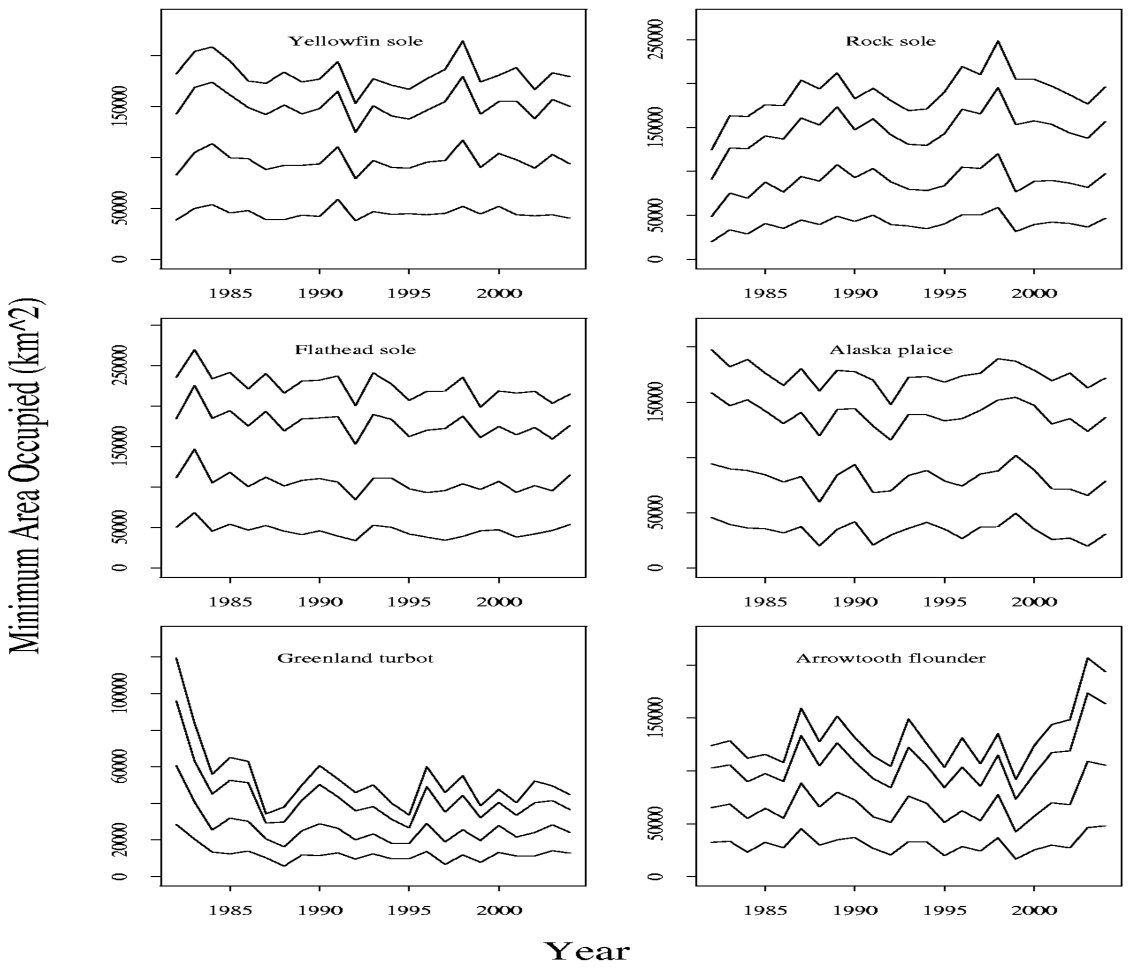
2) Several flatfish species on the EBS shelf showed dramatic movements in 1999, which was an unusually cold year in the midst of an overall warming trend

3) Because broad regions of the EBS shelf have similar depth characteristics, flatfish are able to maintain preferred depth while adjusting distributions.

4) We are able to adjust survey catchability estimates to account for temperature anomalies, but mechanisms remain elusive– do the responses reflect the physiological effect of cold temperature or some other process?

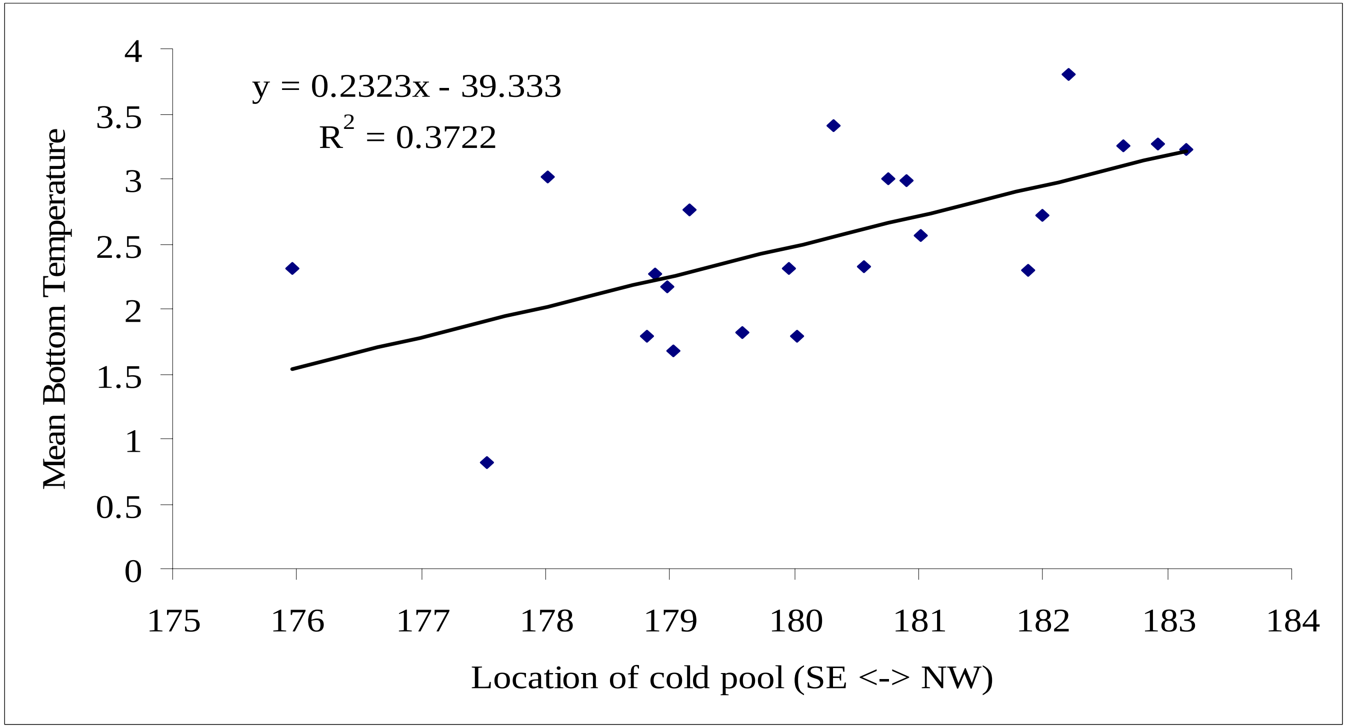
5) Habitat models for flatfish have generally not considered the effect of environmental variability, but these factors may be important (particularly in years corresponding to unusual events)

Minimum Area Occupied by various Flatfish Species

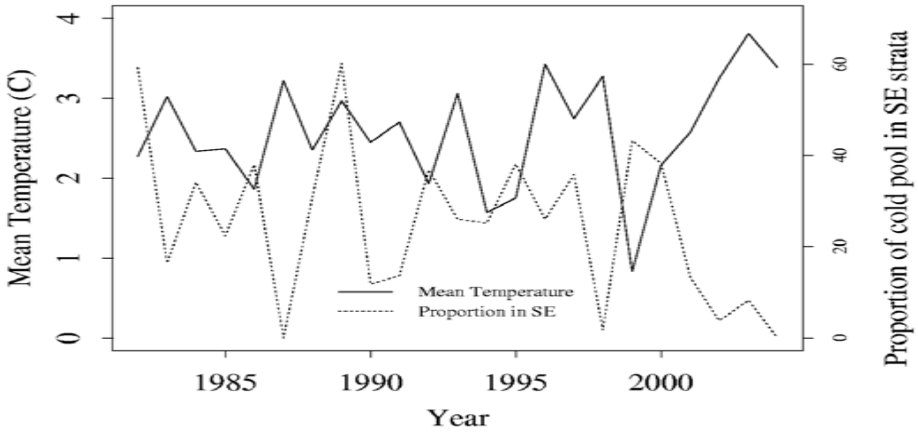


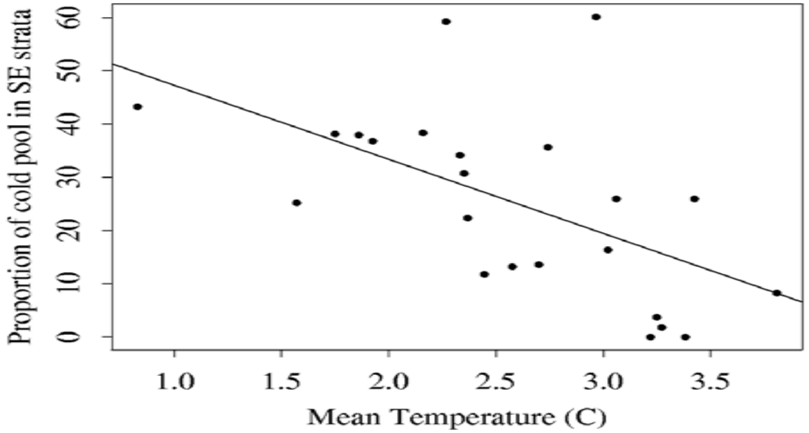
Time Series of Environmental Data

Cold pool location – relative location along a southeast to northwest axis



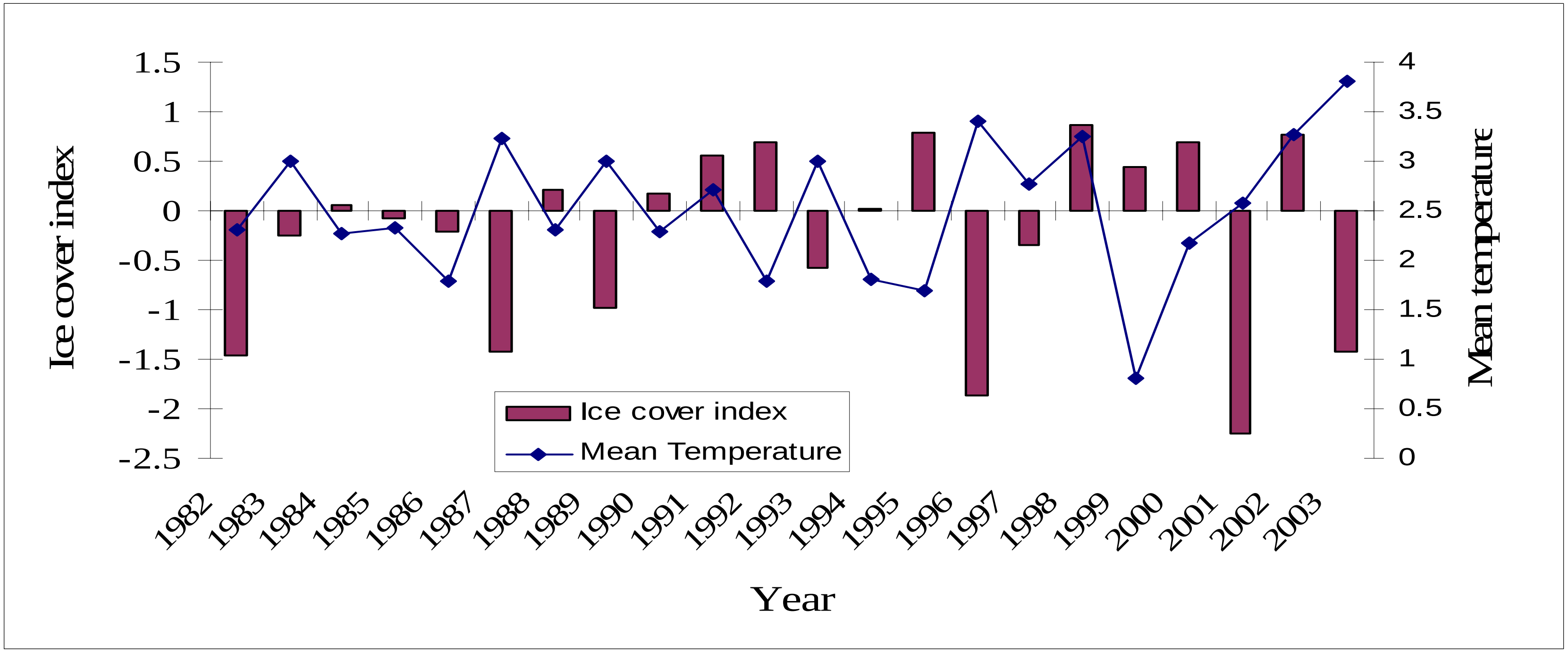
Time series of mean temperature and proportion of cold pool in SE shelf



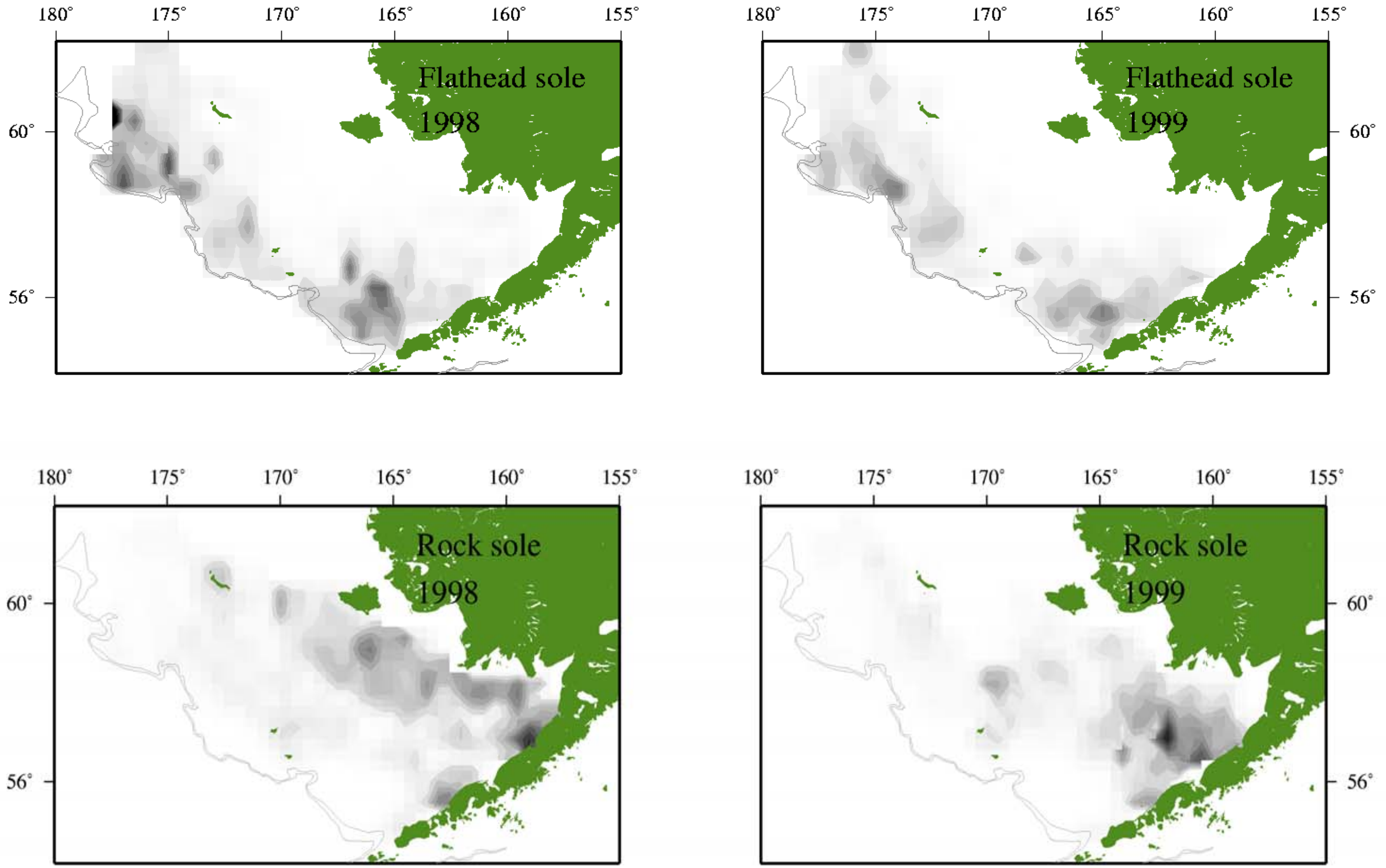


Time Series of Environmental Data

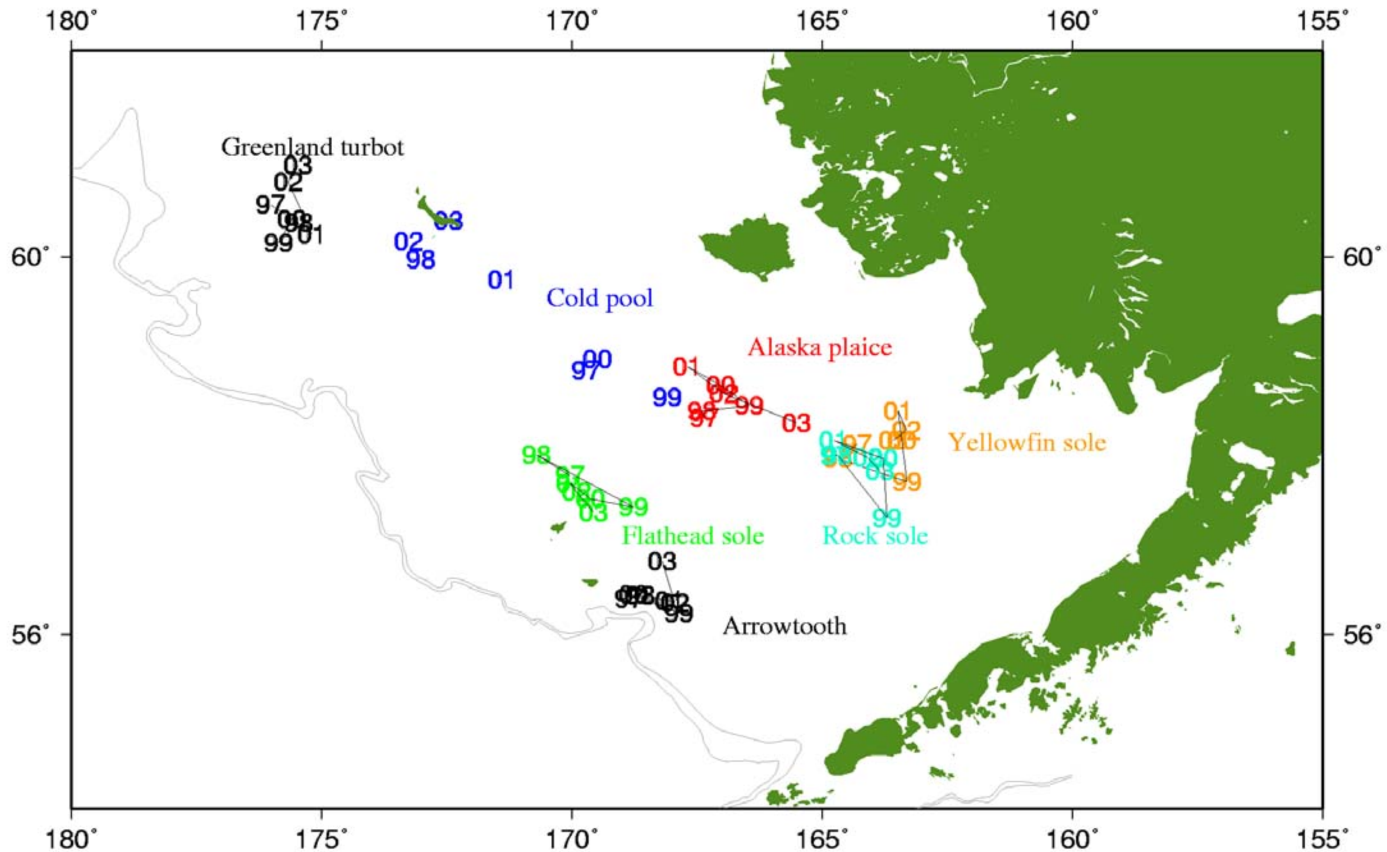
Ice cover index – a measure of the quantity of sea ice
Mean bottom temperature – from bottom trawl survey



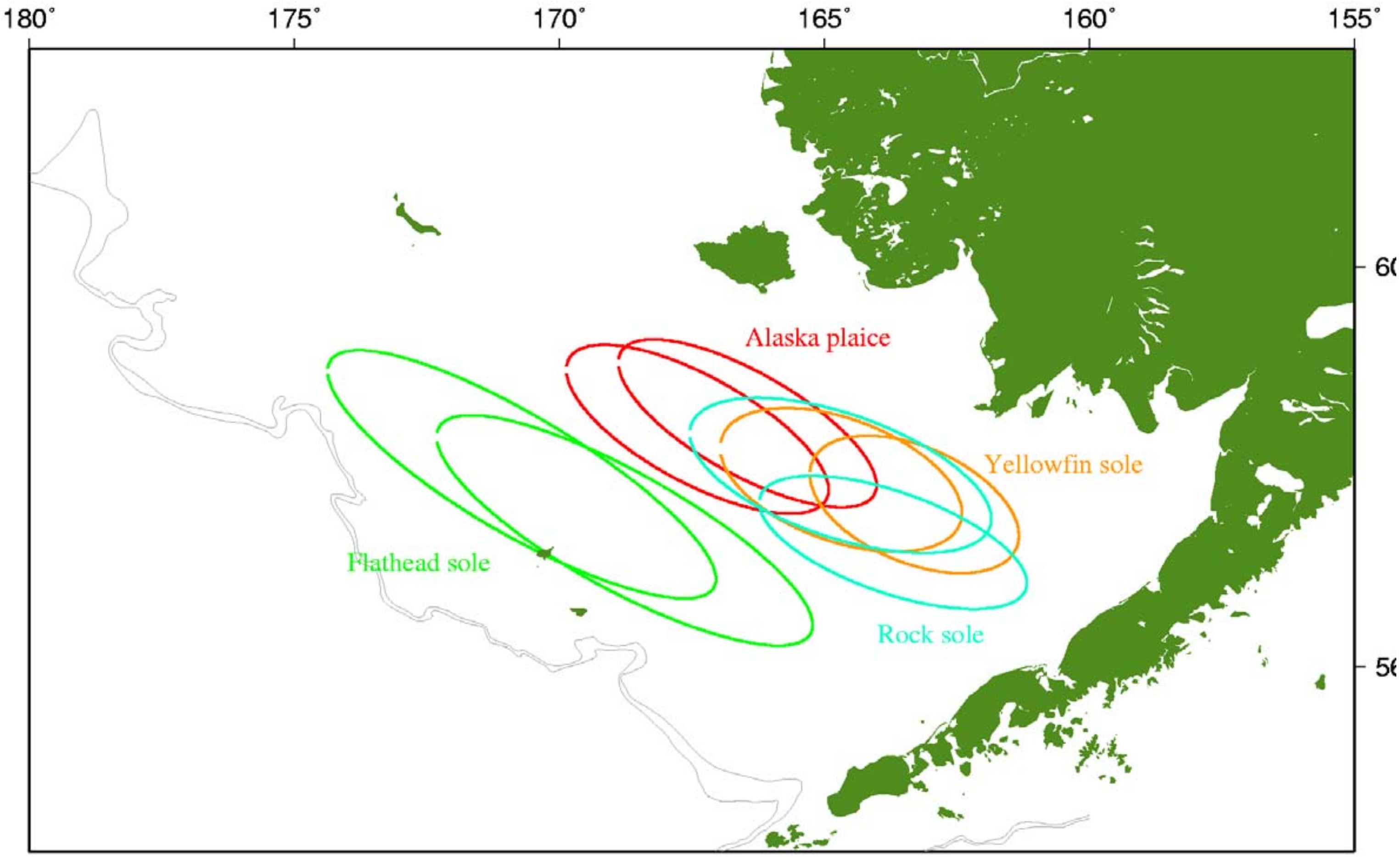
Contour plots of distributions, 1998-1999



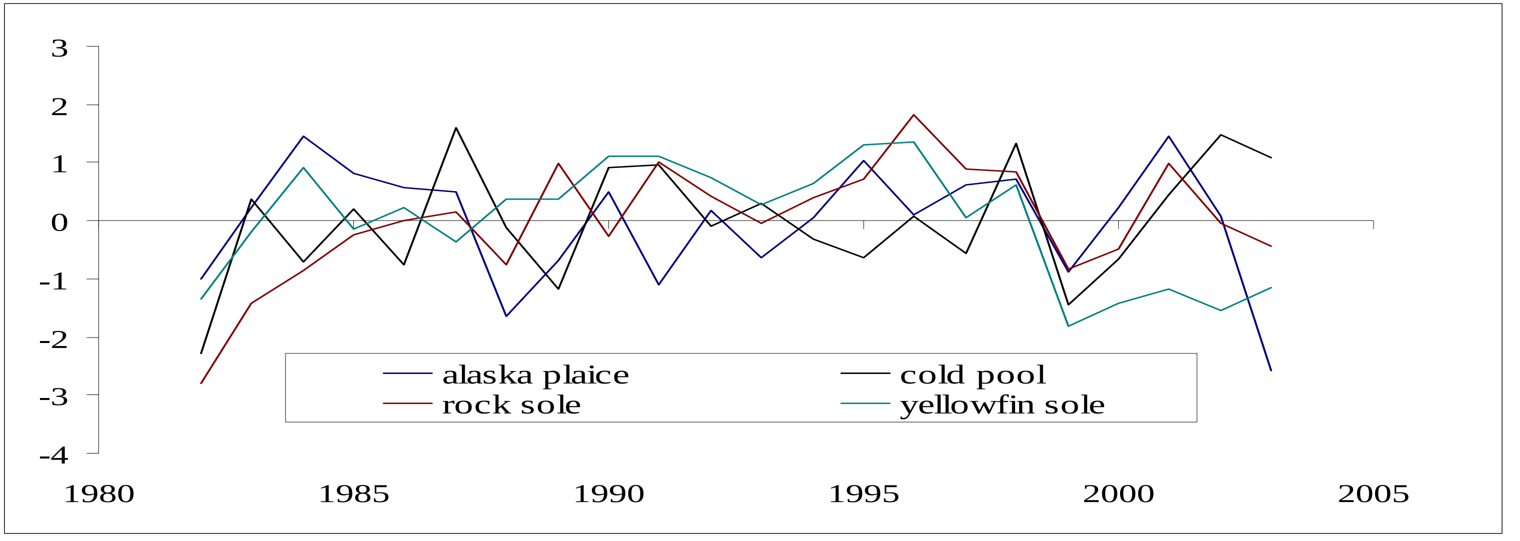
Flathead sole and cold pool centroids, 1998-2003

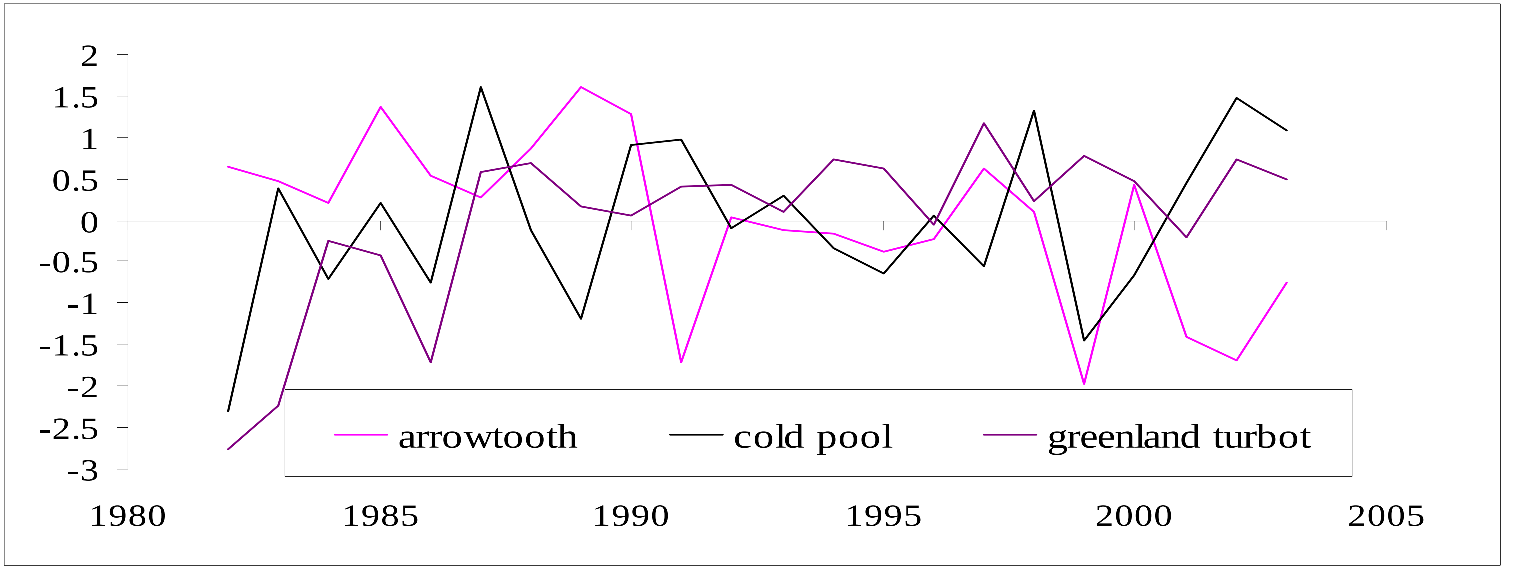


Flathead sole distributions, 1998-1999

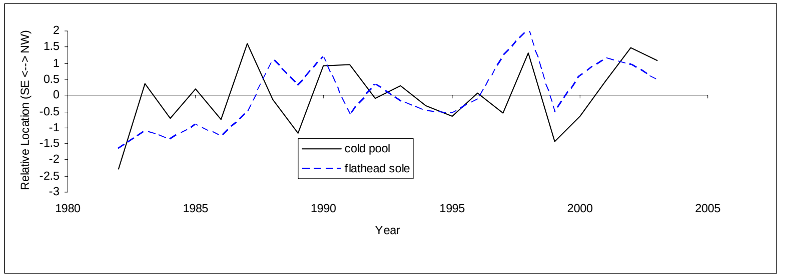


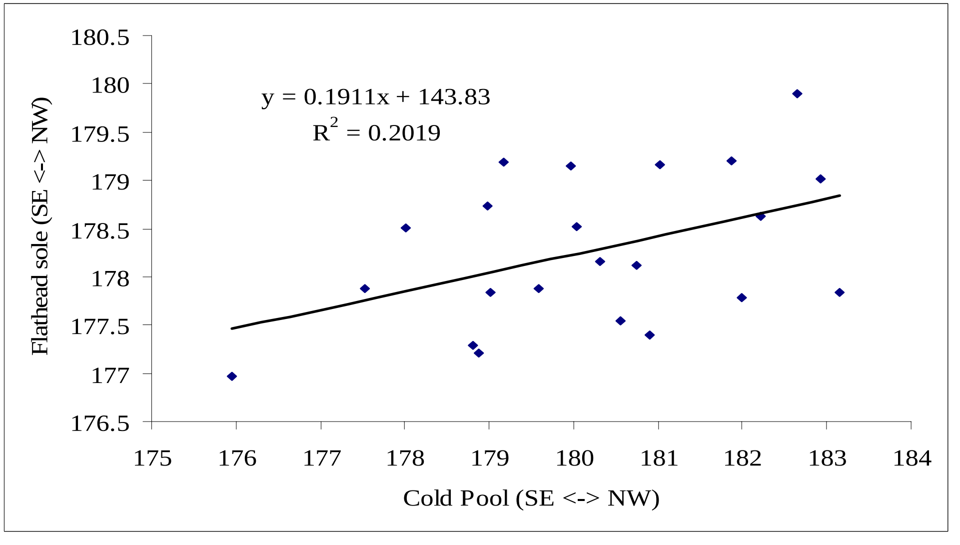
Changes in flatfish distributions in relation to the cold pool





Changes in flathead sole in relation to the cold pool





Other studies relating the cold pool to EBS fish distributions

Wyllie-Echevarria and Wooster (1998)

Artic cod – Generally found in the cold pool in both warm and cool years

Walleye pollock – Seldom found in the cold pool; on the outer shelf during cool years and more widespread during warm years.

Swartzman et al. (1994)

Used Generalized Additive Modeling (GAM) to suggest that the summer spatial distribution of walleye pollock is associated with temperature and depth of the thermocline.

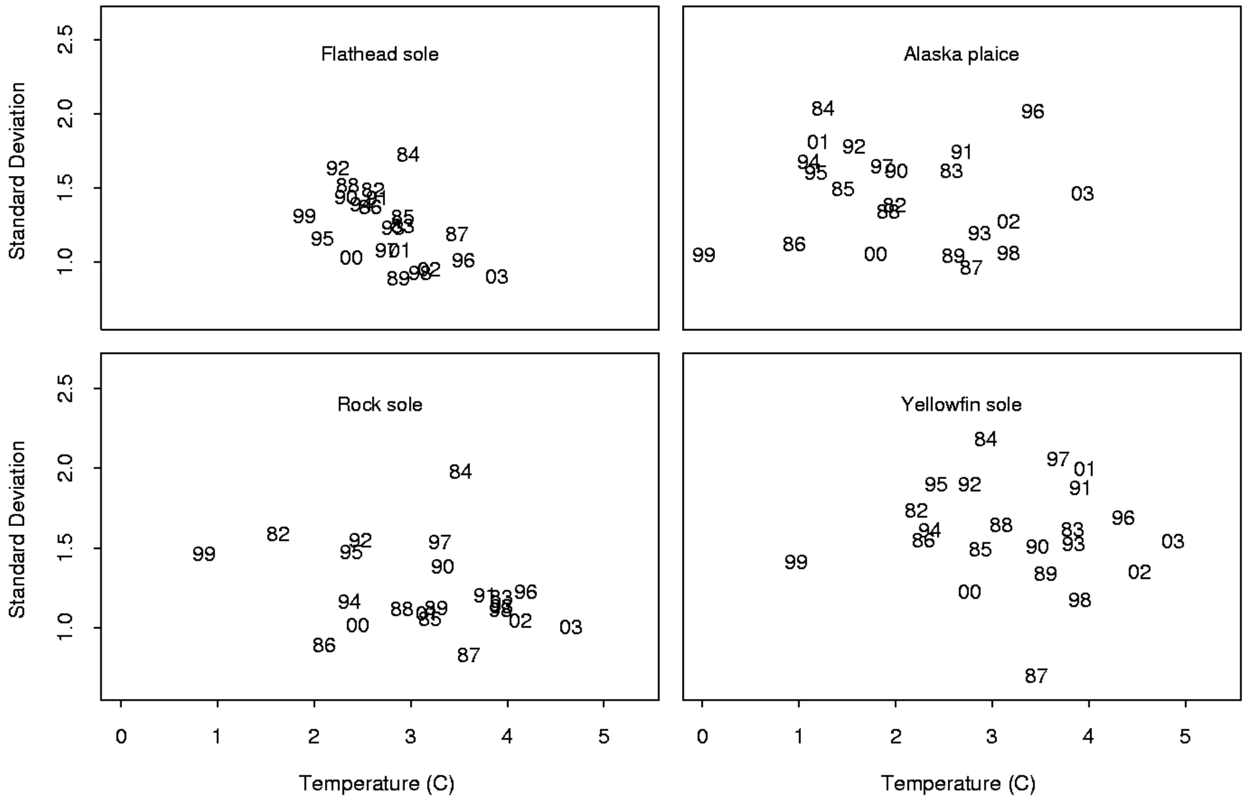
Hypotheses

1) The diet of flathead sole has a larger proportion of fish than some other small flatfish – they could be responding to prey distributions

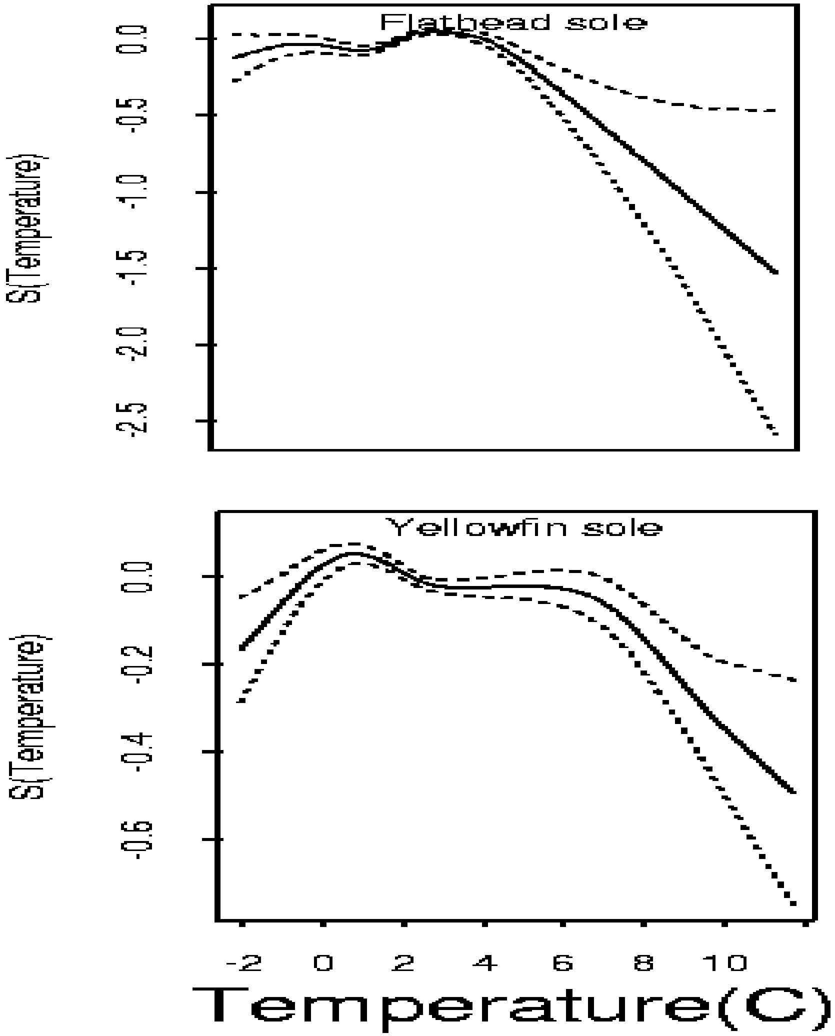
2) The optimal temperature constraints for flathead sole may be more restricting than for other small flatfish

Mean temperature and standard deviation for flatfish species

Alaska plaice – presence of antifreeze peptide proteins that prevents the formation of ice crystals (Knight et al. 1991)



Habitat use of flatfish is likely mediated by environmental variability, but perhaps the signal is more subtle than observed in pelagic species

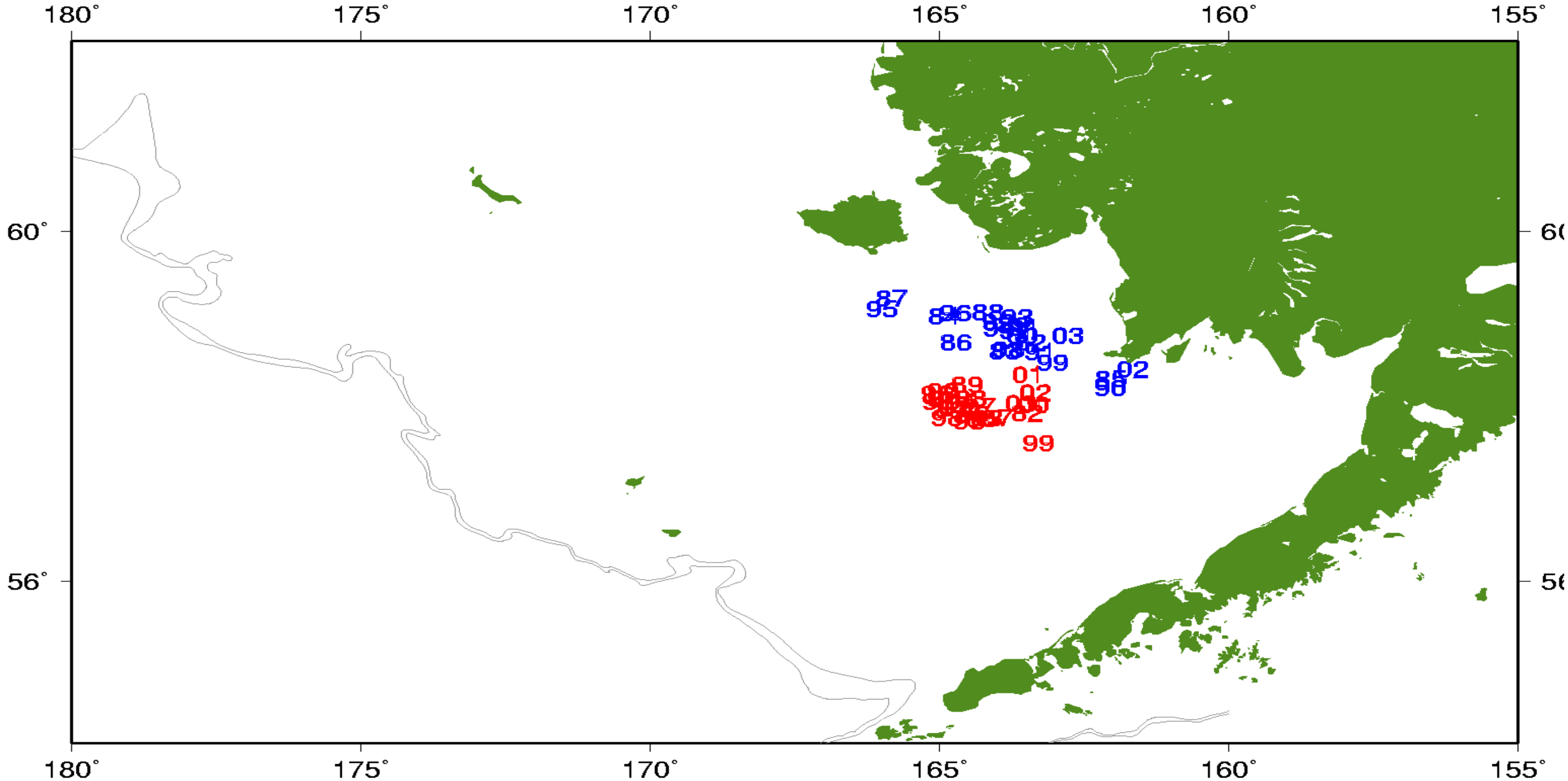


GAM model of habitat use

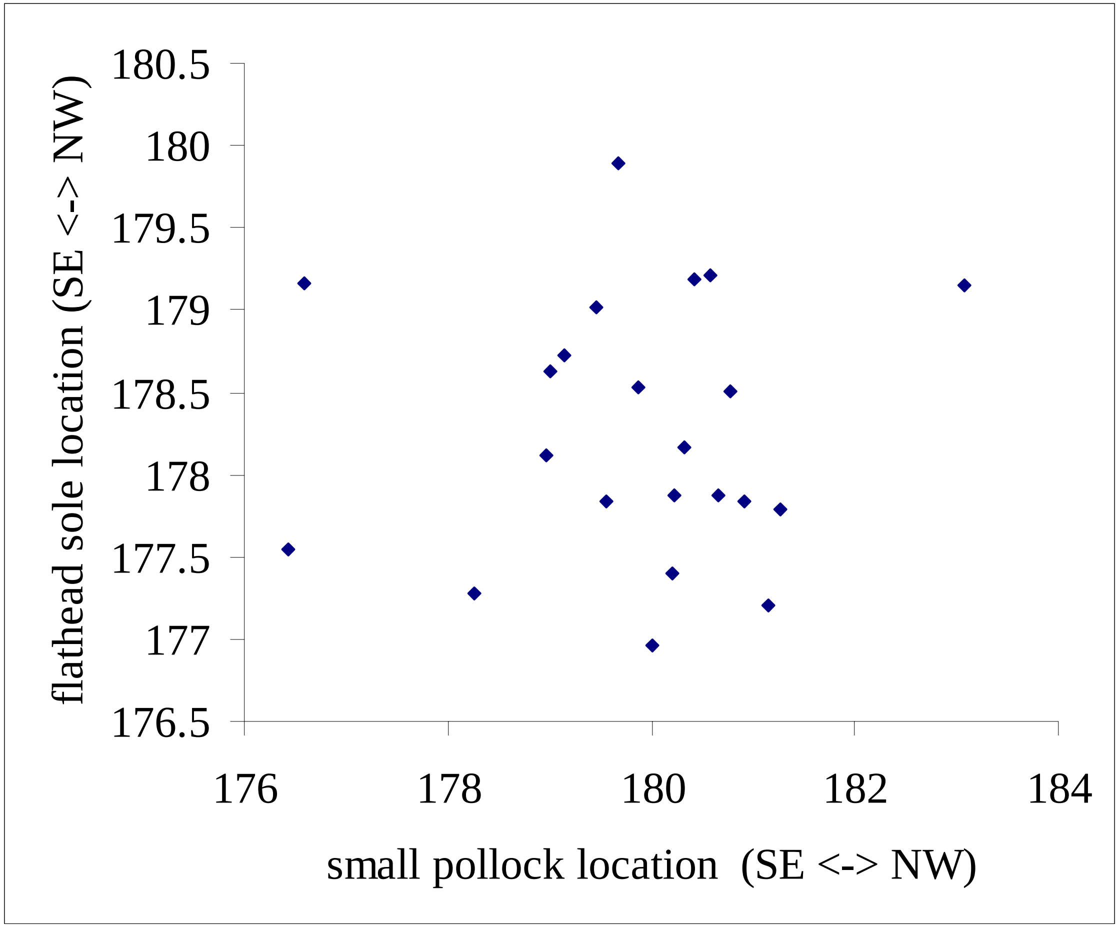
$$\ln\{E(CPUE)\}$$
$$= year + S(T) + S(D)$$
$$+ S(Sed) + S(Lat)$$
$$+ S(Long)$$

Ontogenetic shifts in spatial distribution may be part of the story

Yellowfin sole centroids by size (breakpoint is 12 cm)



Relation between flathead sole location and juvenile walleye pollock (<20 cm) locations



Randomization test to assess significance of associations between fish and environmental distributions

1) Compute cumulative frequency distributions of the proportion of the survey habitat (f(x)), and proportion of the fish distribution (g(x)), with temperatures ≤ x.

2) Use the maximum difference between f(x) and g(x) as a test statistic indicating the extent to which fish distributions differ from the available habitats

3) Compute the distribution of the test statistic from 2000 randomizations of the pairings of the catch and the environmental factor x;

4) Use the distribution from (3) to assess statistical significance of the observed test statistic.