Integrating species environmental thresholds to explore species interactions and parameterize multi-species models

PICES Annual Science Conference 2016 San Diego, USA

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What are the impacts of climate on structuring species distributions and interactions?

Global Ecology & Biogeography (2003) 12, 361–371

RESEARCH REVIEW

Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful?

RICHARD G. PEARSON* and TERENCE P. DAWSON

Environmental Change Institute, School of Geography and the Environment, University of Oxford, 1A Mansfield Road, Oxford OX1 3SZ, U.K. E-mail: richard.pearson@eci.ox.ac.uk

Vol. 303: 111–120, 2000
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MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published October 30

Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf

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www.sciencemag.org SCIENCE VOL 341 13 SEPTEMBER 2013

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Habitat volume and spatial extent influence species distribution and abundance
Climate change is expected to influence the distribution and volume of ocean habitats

Predicting responses to climate change requires understanding habitat associations and environmental tolerances - determinants that influence biogeography

Climate variability and directional climate change

Shifts in species life history, phenology, and recruitment

Shifts in spatial distribution

Shifts in species interactions

Shifts in recruitment and abundance

 

How are individual species distributed and what are the important thresholds?
– Spatial mapping of individual species abundance and variation in abundance
– Identified critical thresholds
– Examined evidence for resource partitioning, competitive exclusion, and predation avoidance (MARSS) and response to environmental forcing (DFA)

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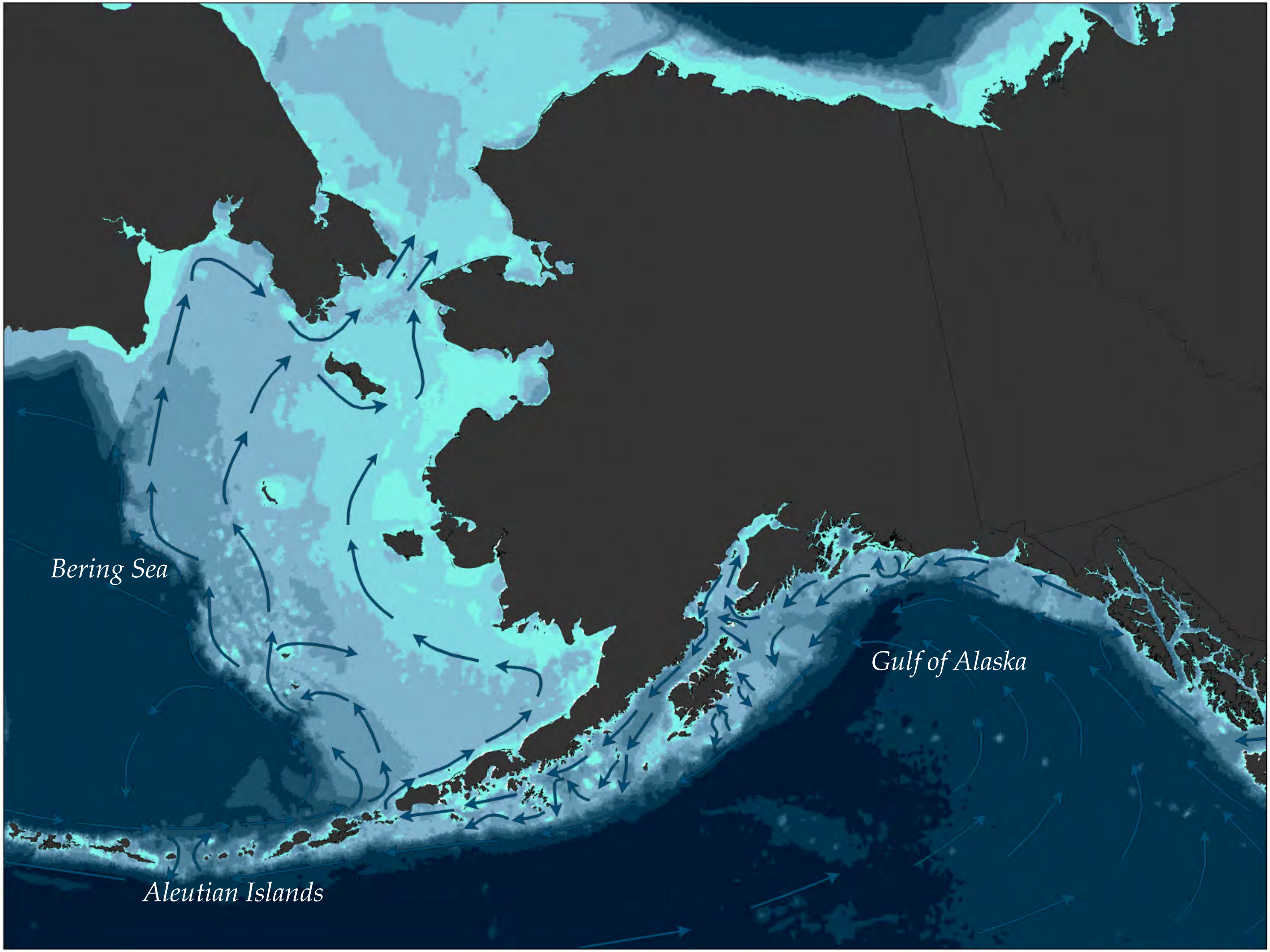
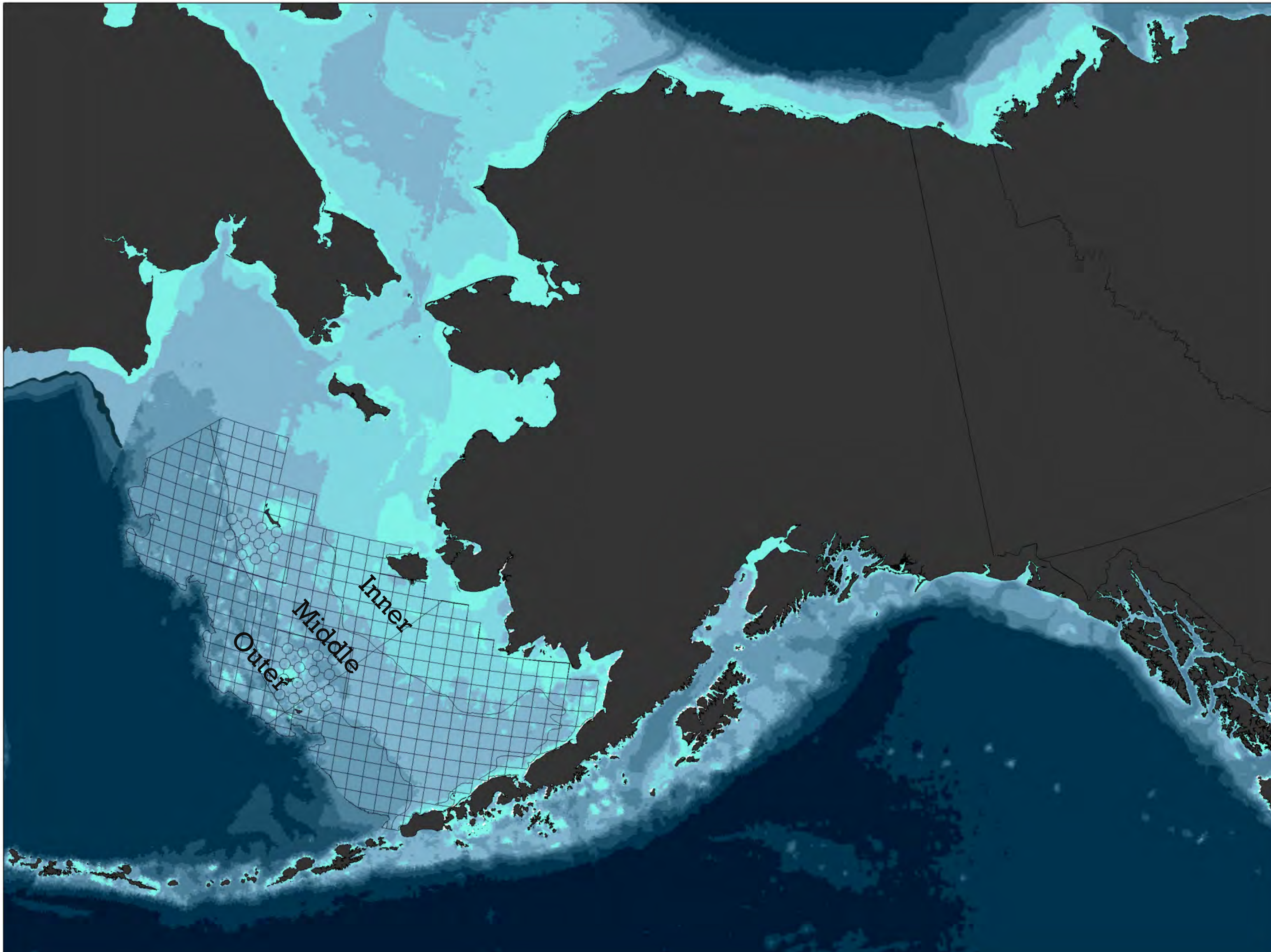
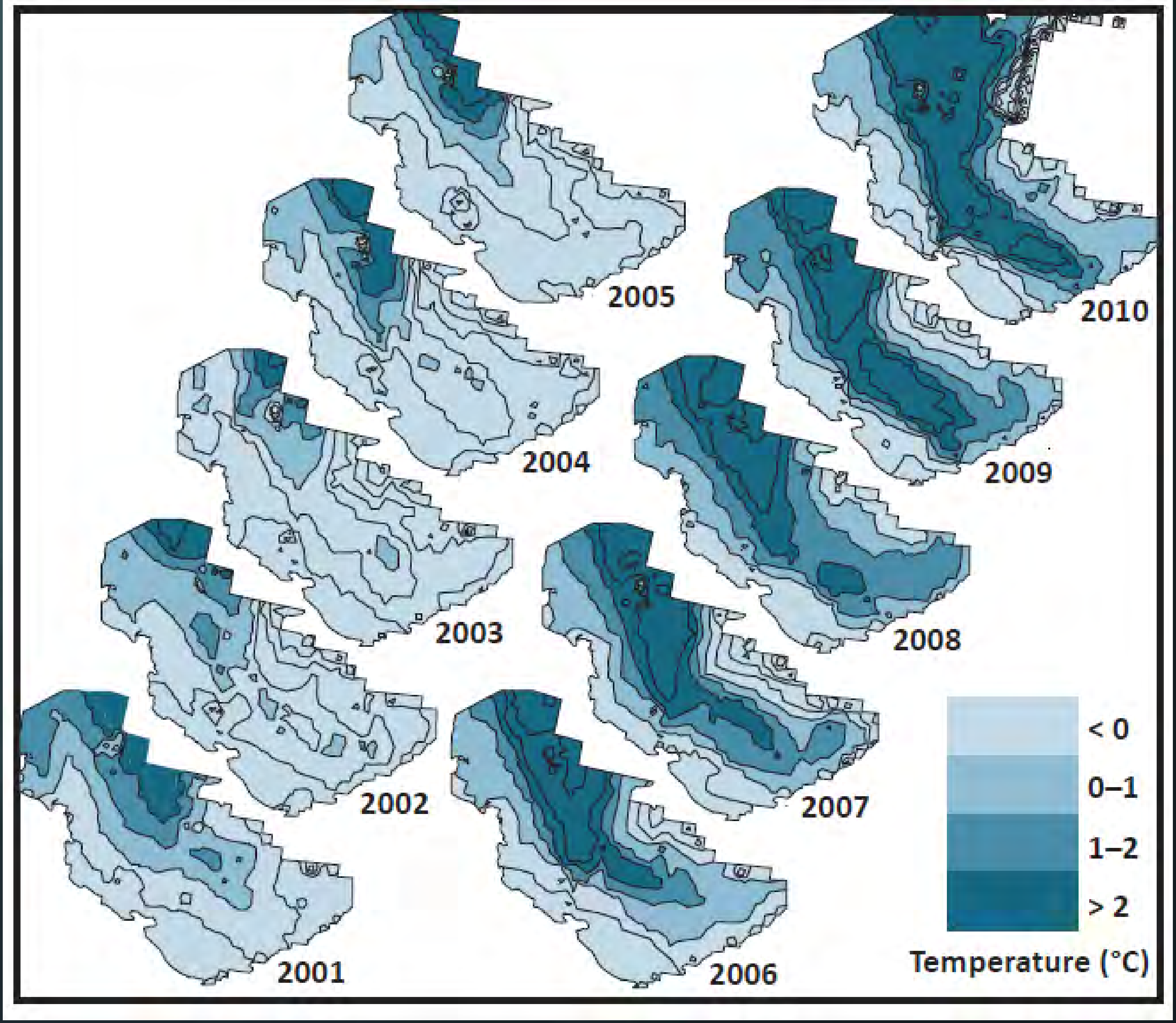
How to integrate that knowledge in models of species dynamics?
– Use environmental correlates to explain residuals in stock-recruitment
– Estimate shifts in habitat volume as means to project forward

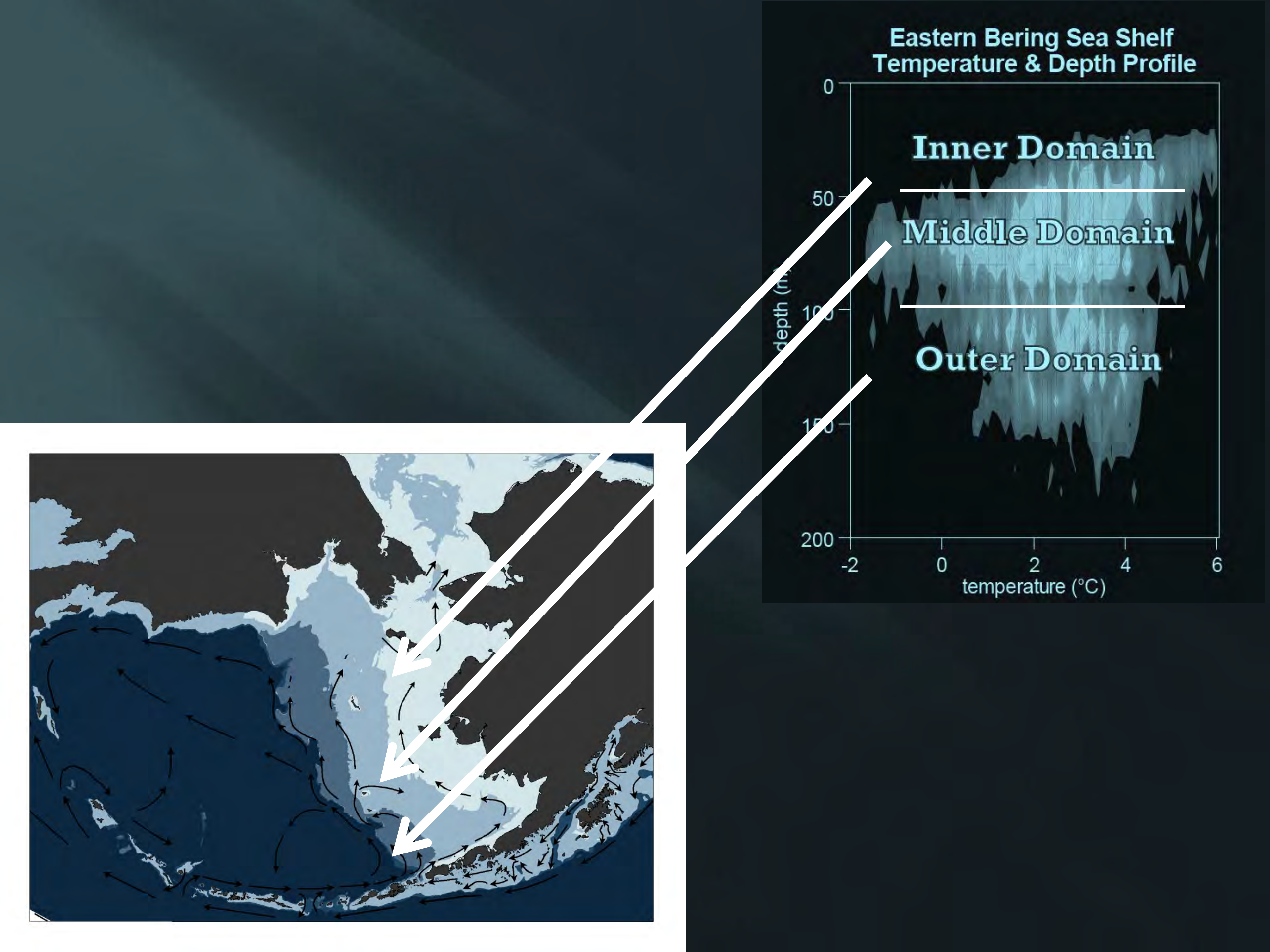

Bering Sea
Gulf of Alaska
Aleutian Islands


Inner
Middle
Outer

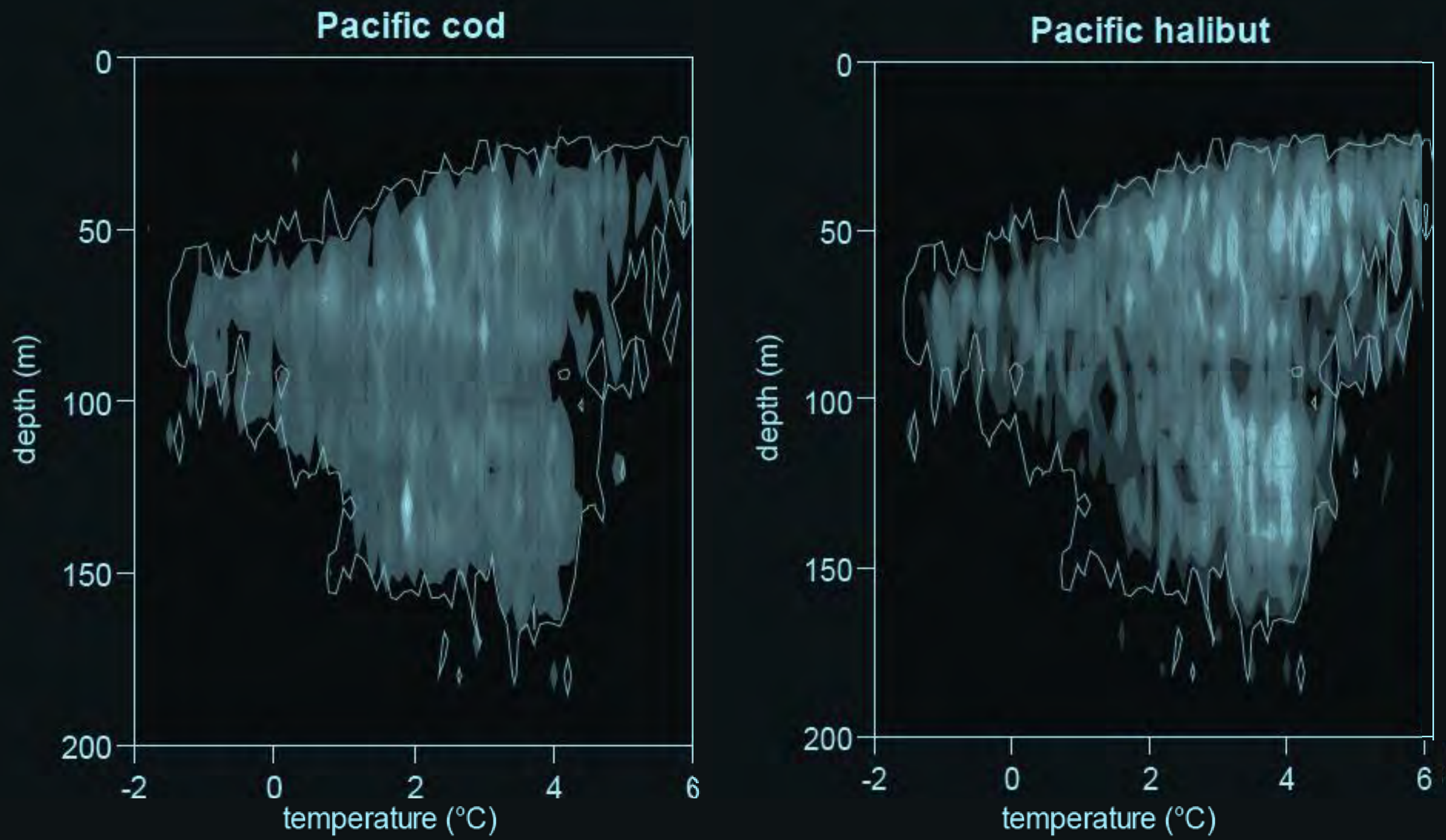


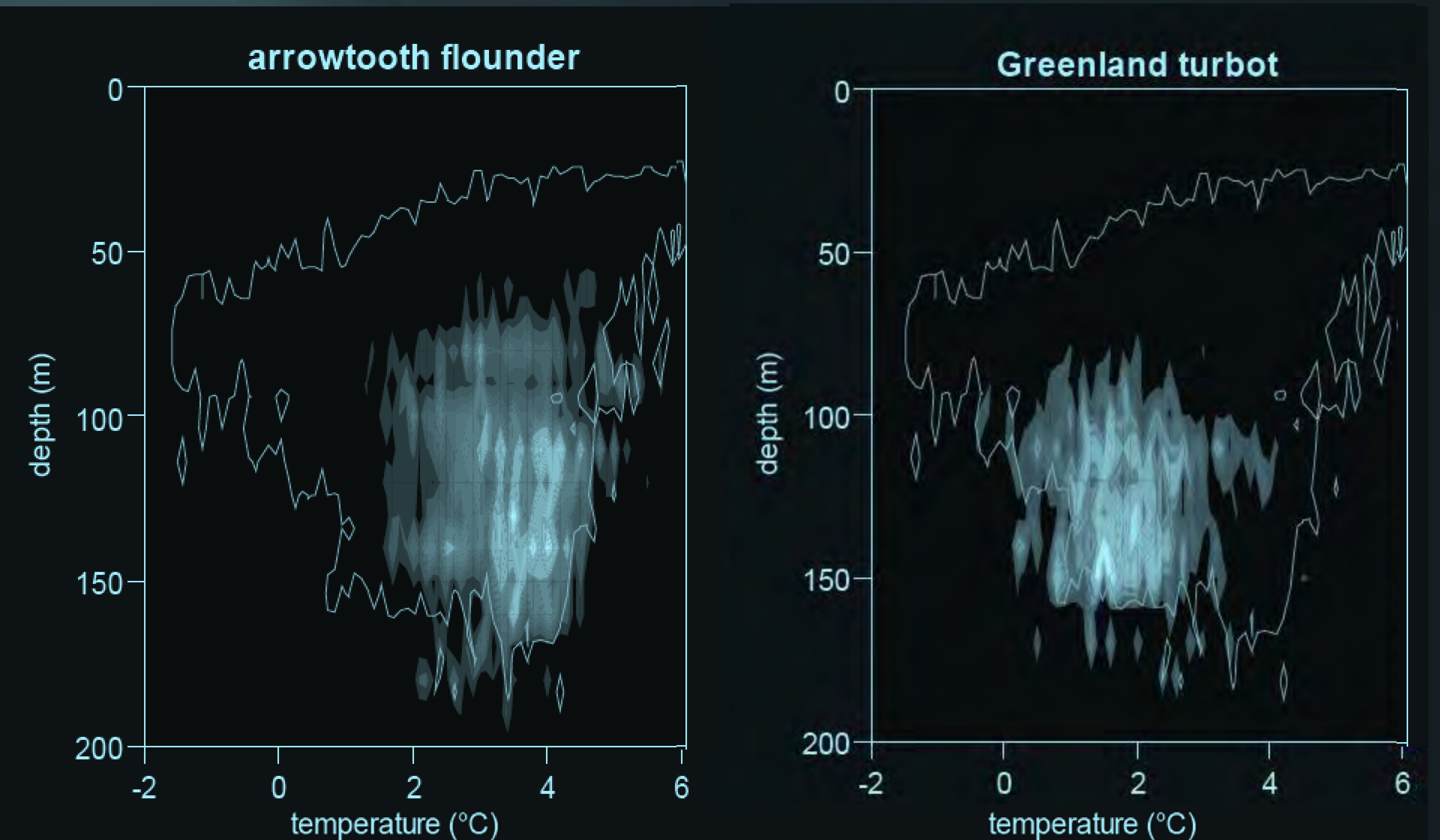
Spatial extent and intensity of the Cold Pool

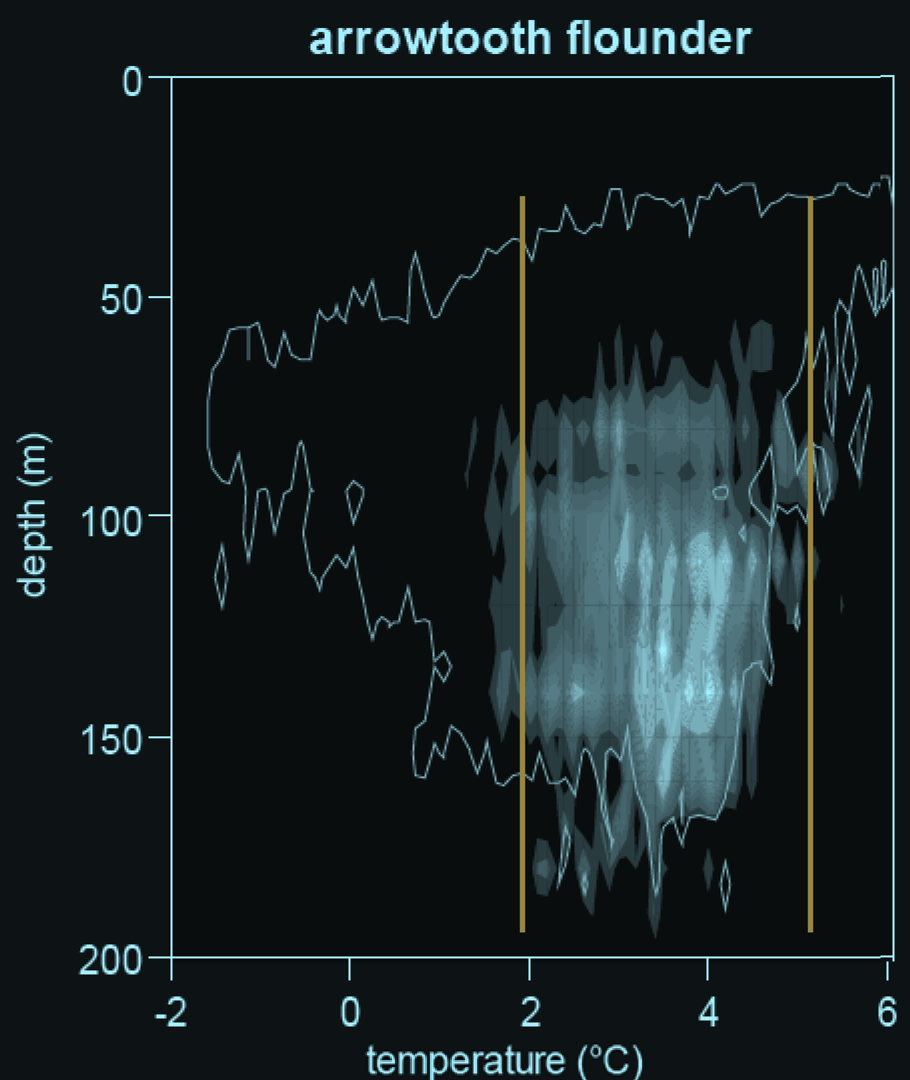
… a residual body of cold water (legacy of sea ice extent)



Eastern Bering Sea Shelf
Temperature & Depth Profile
Inner Domain
Middle Domain
Outer Domain
0
50
200
-2
0
2
4
6
temperature (°C)


Pacific cod
Pacific halibut
depth (m)
0
50
100
150
200
-2
0
2
4
6
temperature (°C)


arrowtooth flounder
Greenland turbot
depth (m)
0
50
100
150
200
-2
0
2
4
6
temperature (°C)



arrowtooth flounder
0
50
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200
depth (m)
-2
0
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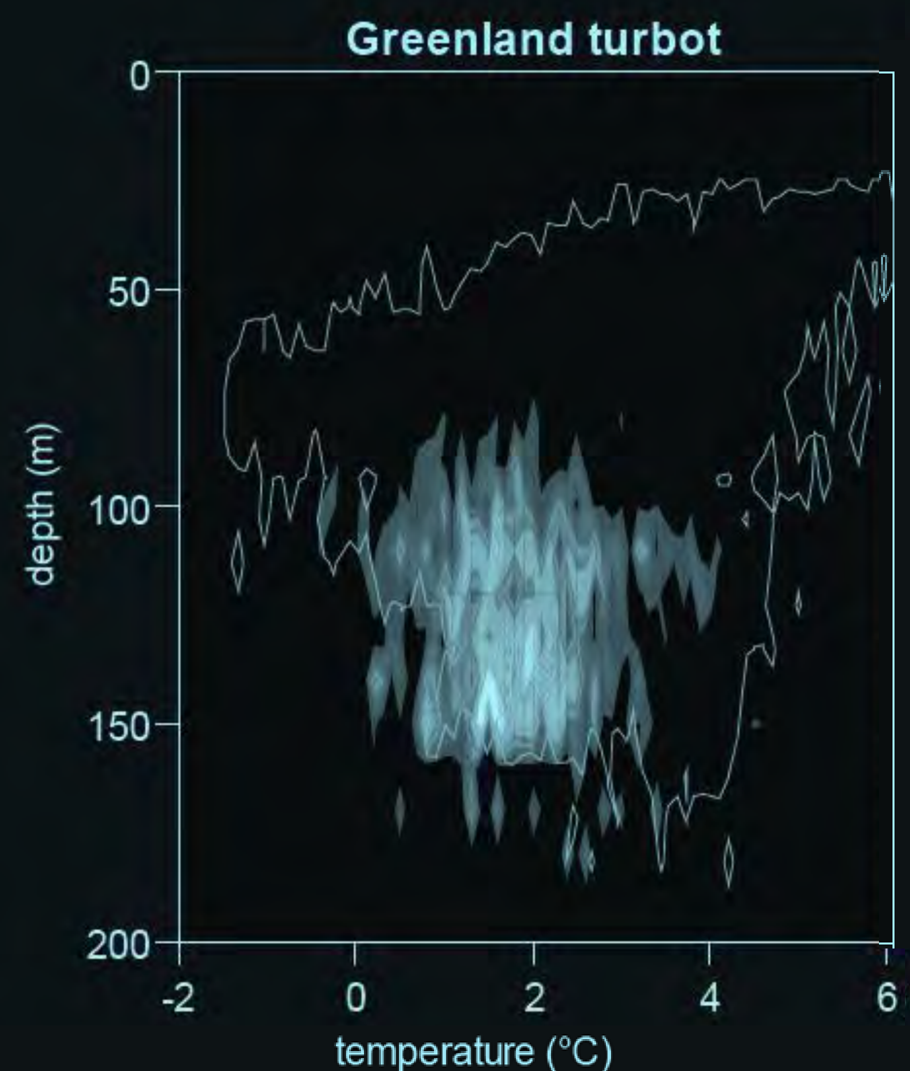
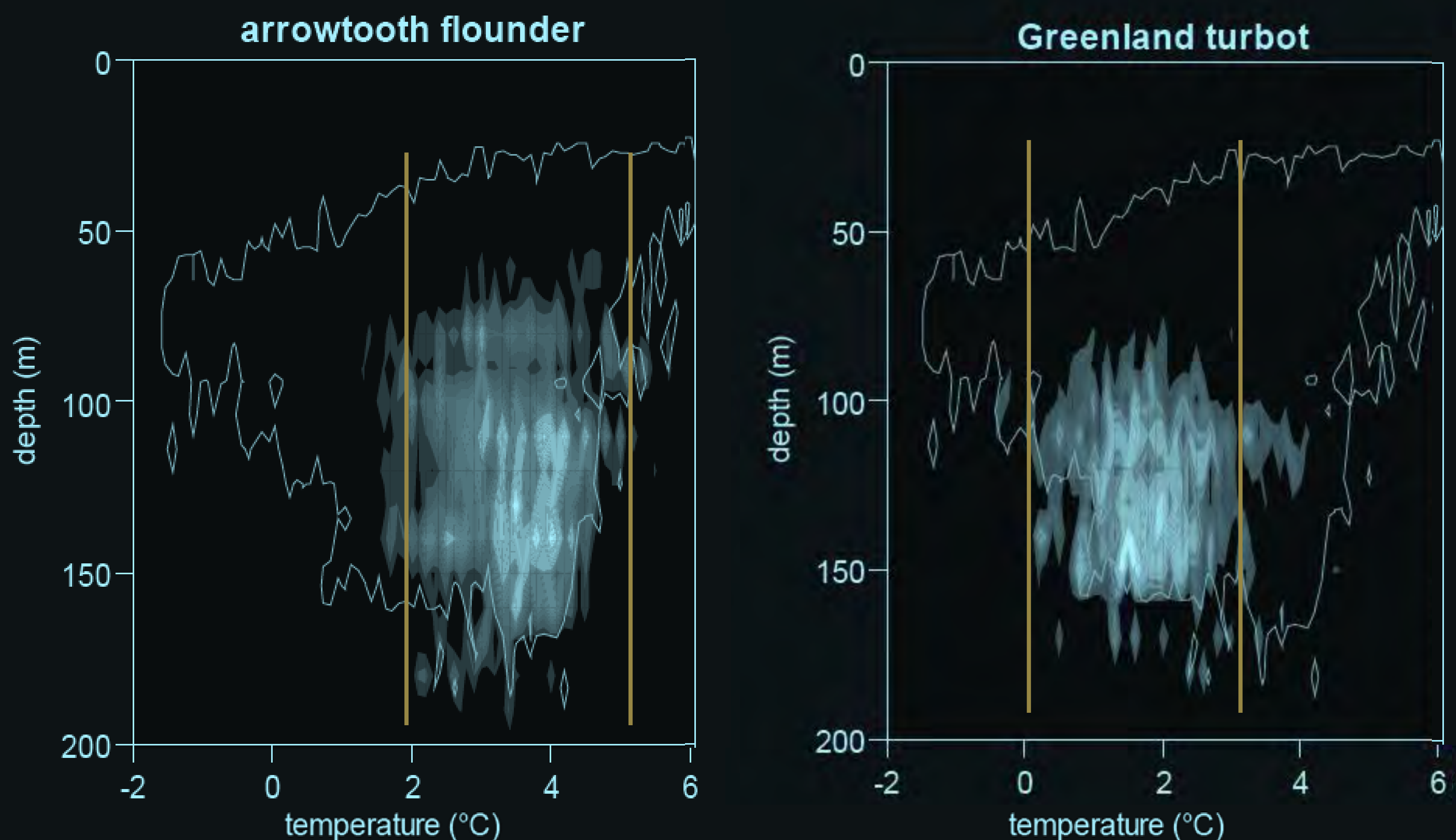
temperature (°C)



Greenland turbot
0
50
100
150
200
depth (m)
-2
0
2
4
6
temperature (°C)



arrowtooth flounder
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0
50
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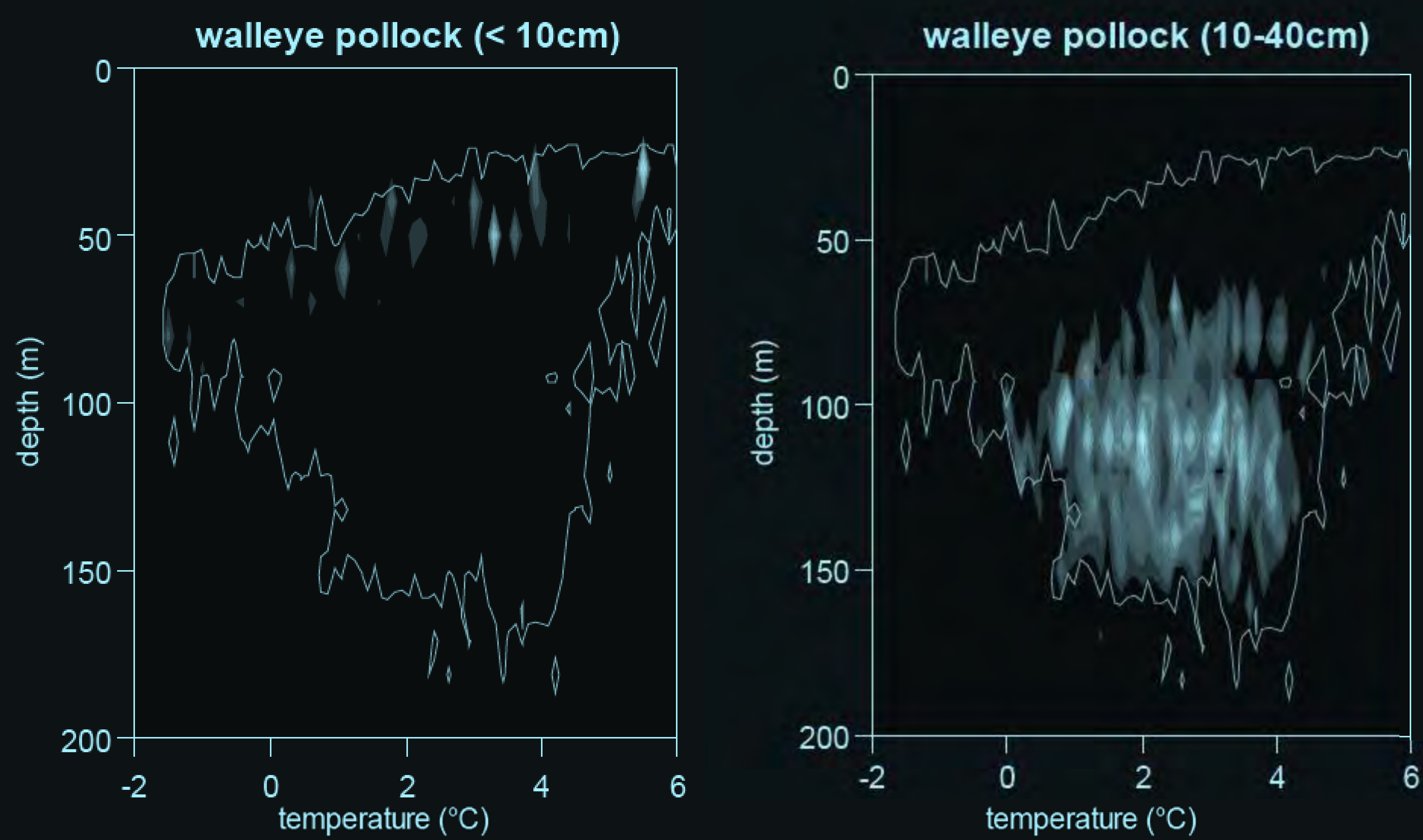
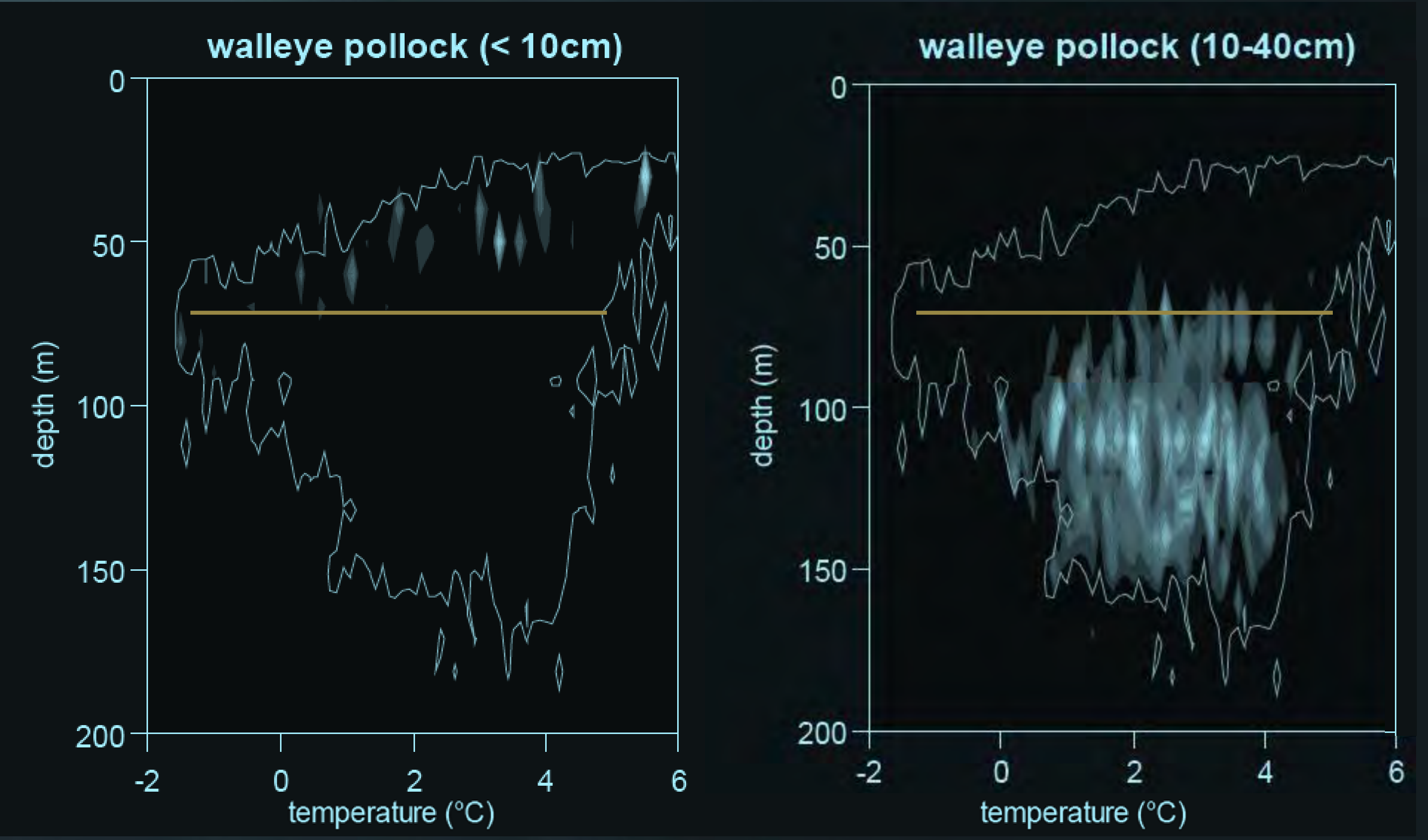
Importance of size, life-stage, predator prey ratios



Importance of size, life-stage, predator prey ratios



Determine method to delineate distinct ecological regions

Premise: Importance of Biogeography

– Ecosystems occur at a hierarchy of scales

- –synthesize physical and biological data
- –identify regional structure
- –delineate meaningful spatial boundaries

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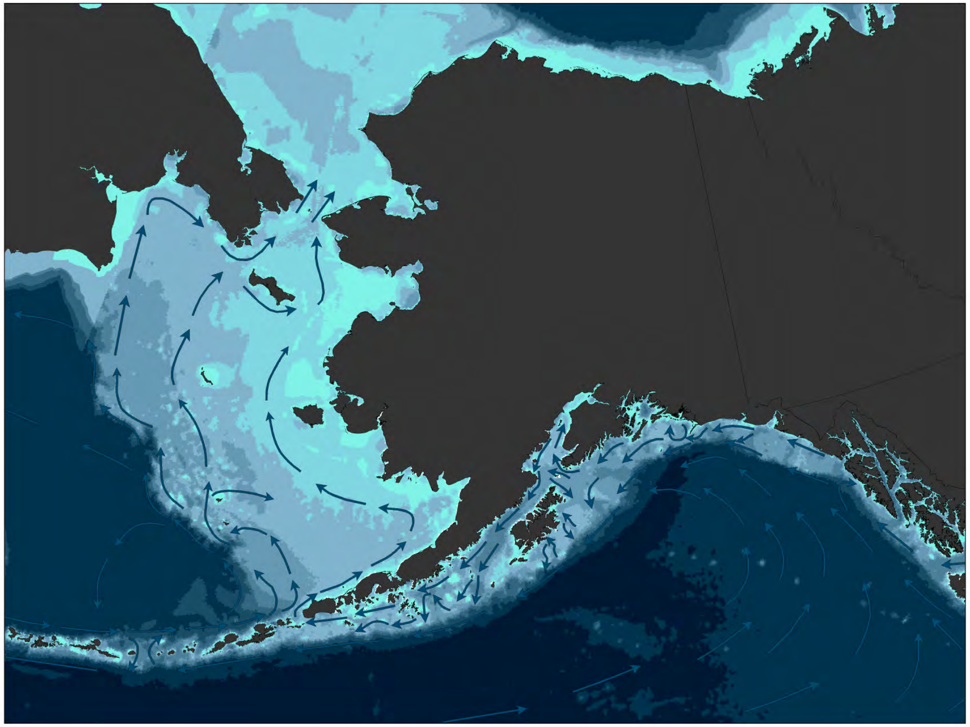
Approach

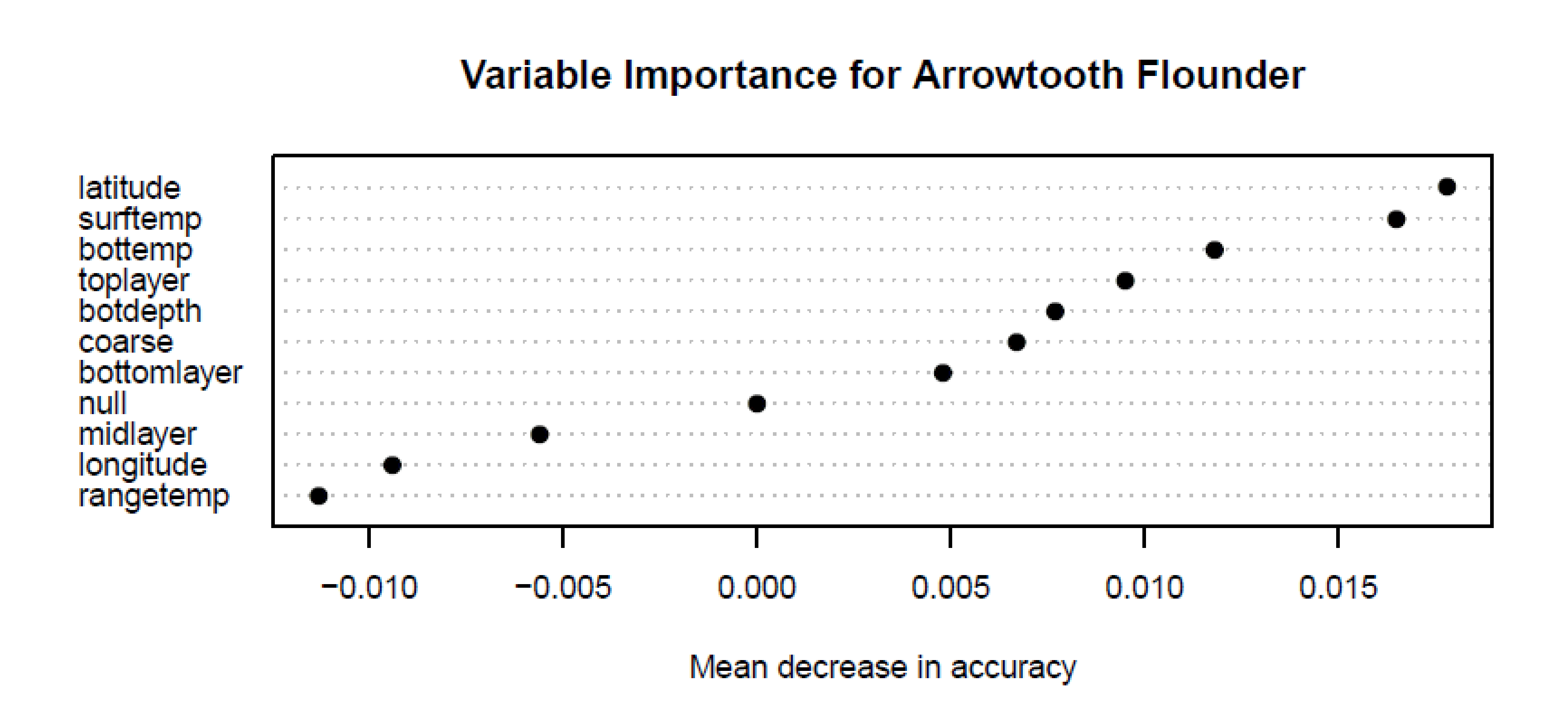
– Identify threshold shifts in community composition

Random forests *–Species responses to physical variables*

Fits multiple regression trees, with bootstrap sample
Applies binary recursive partitioning as a statistical classifier

Quantifies…
- extent to which environmental variables predict distribution patterns (R^2)
- relative importance of a variable

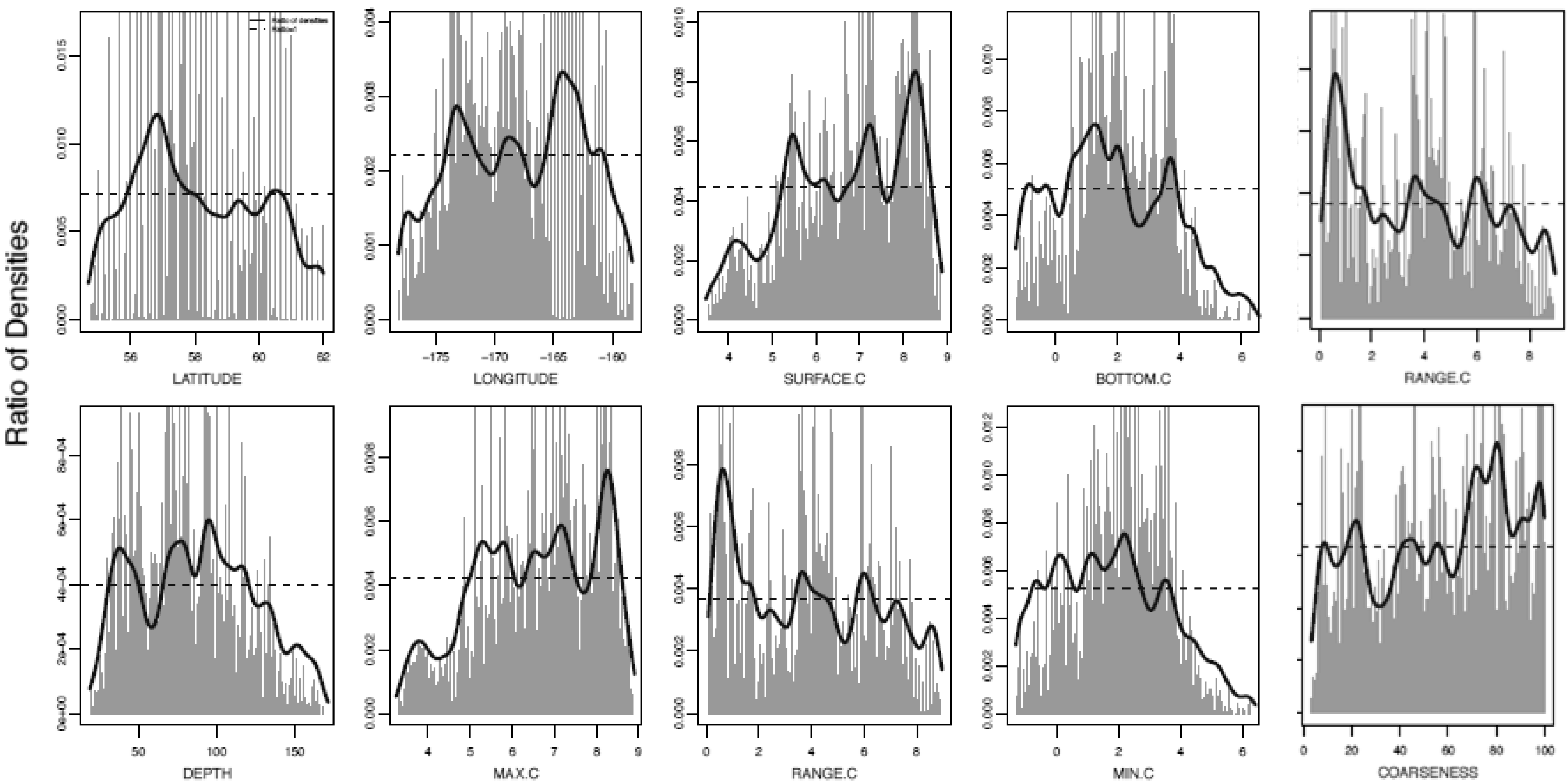




Each tree… an accuracy and error related to observations not in bootstrap sample
Variable importance – increase in prediction error when values randomized

Extended forests *– Community shifts along environmental variable*

Synthesize goodness-of-fit (R^2) and predictor importance of RFs of multiple species
Determine thresholds or breakpoints in community composition



Density of split importance standardized by the density of number of splits at a value

Extended forests *– Community shifts along environmental variable*

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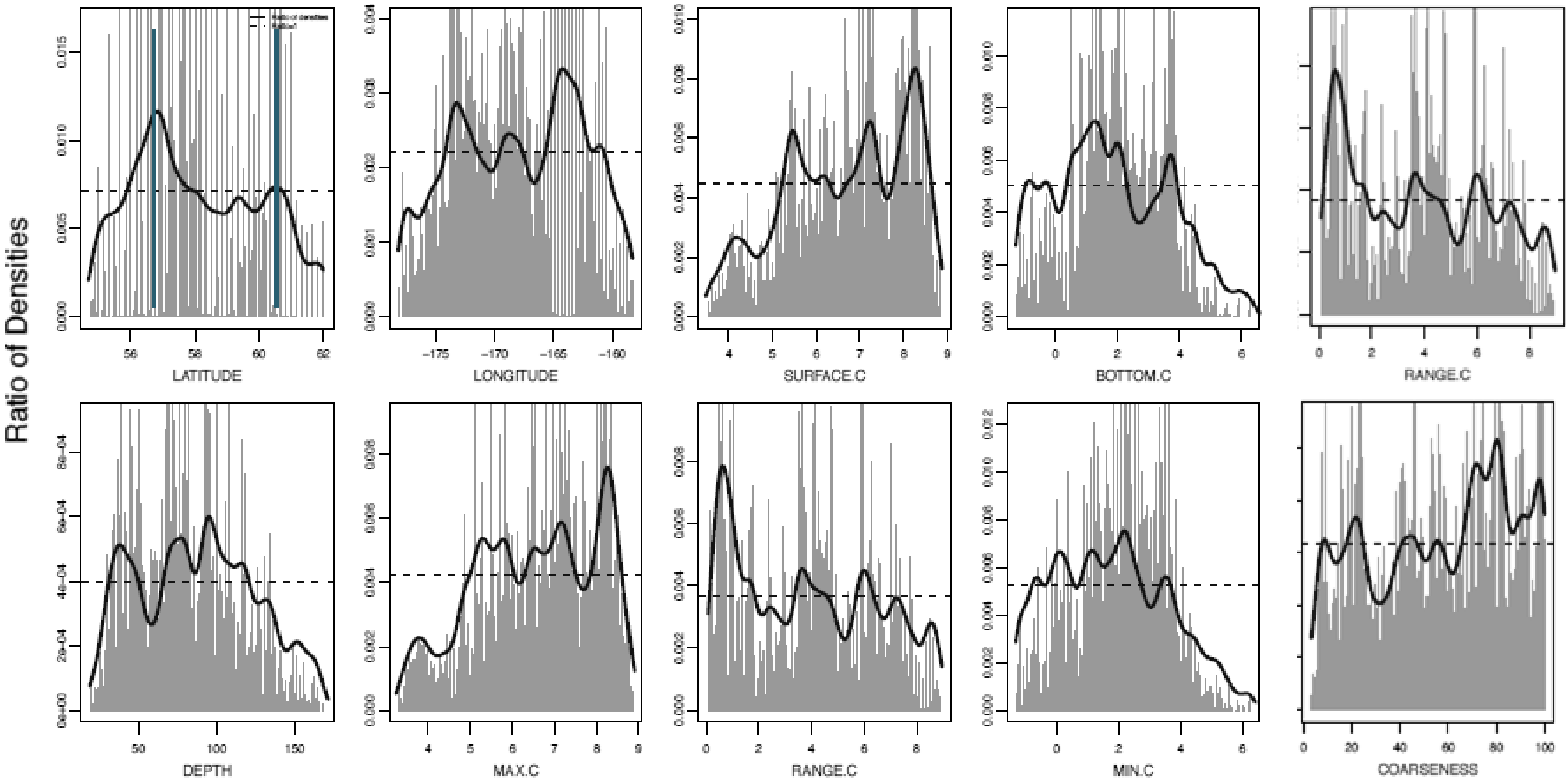

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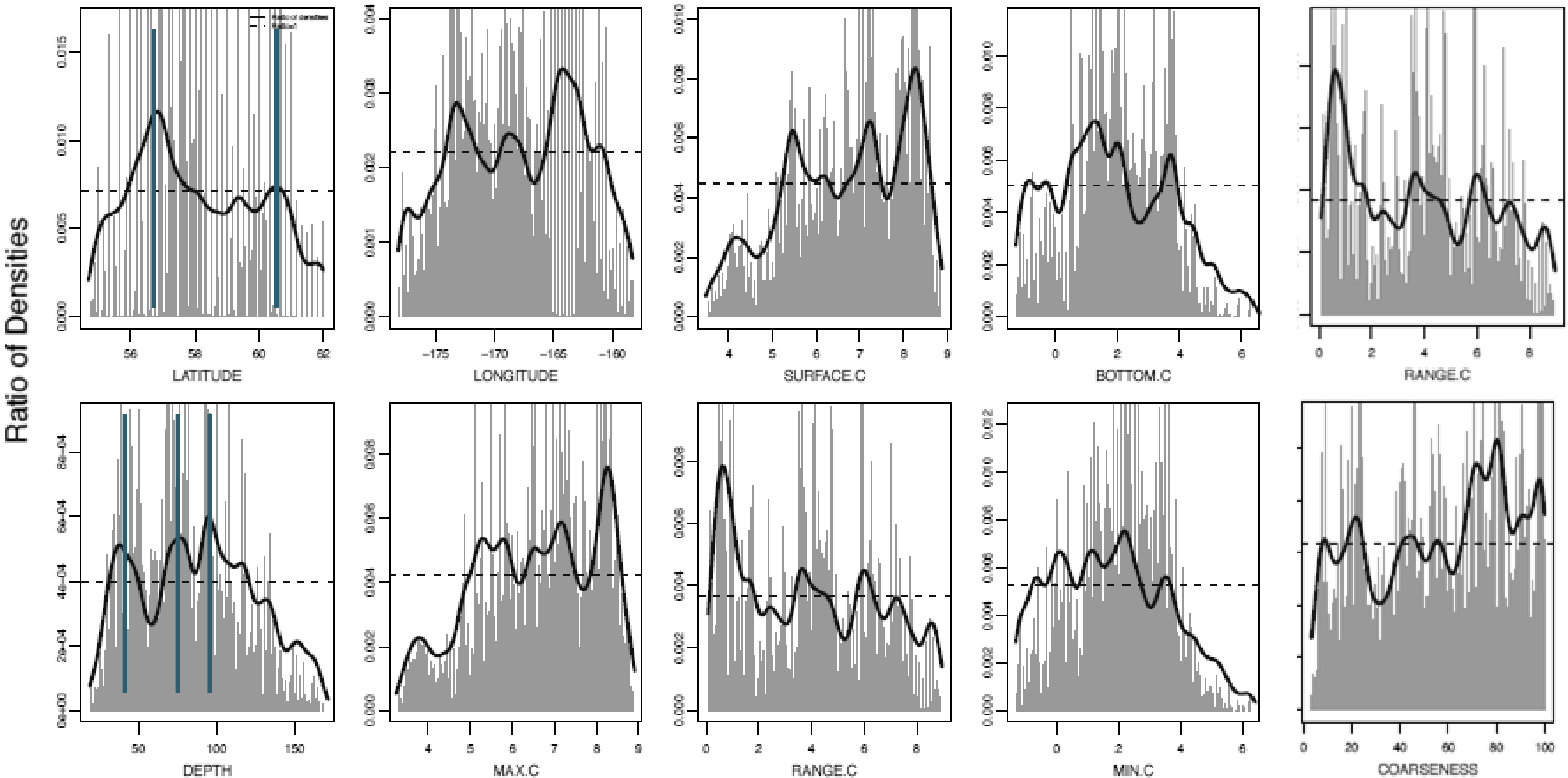

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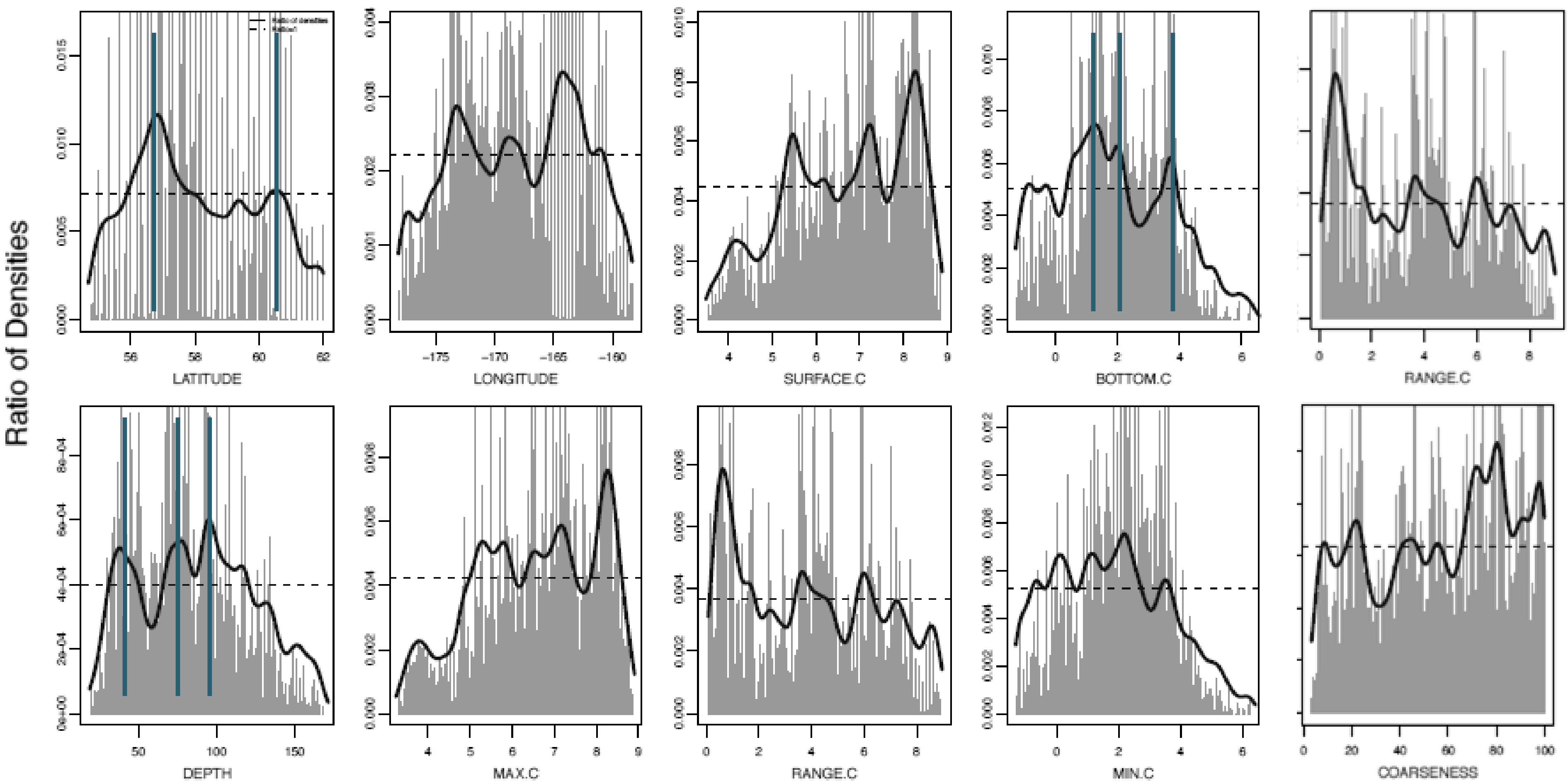

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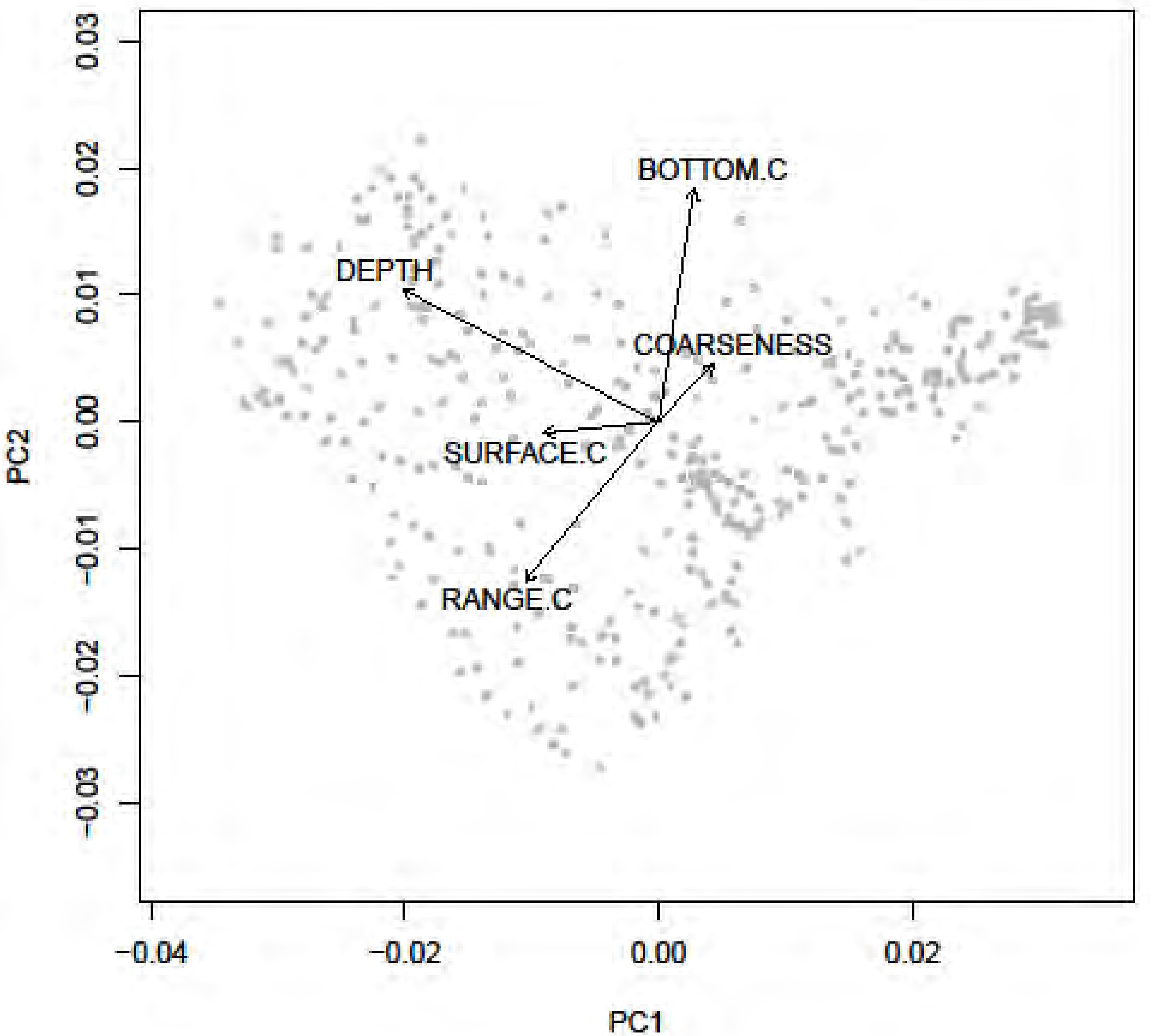
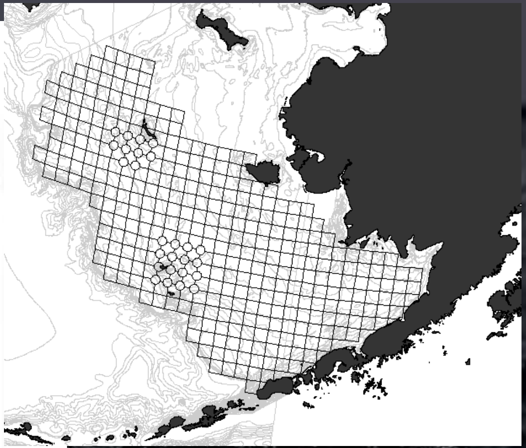
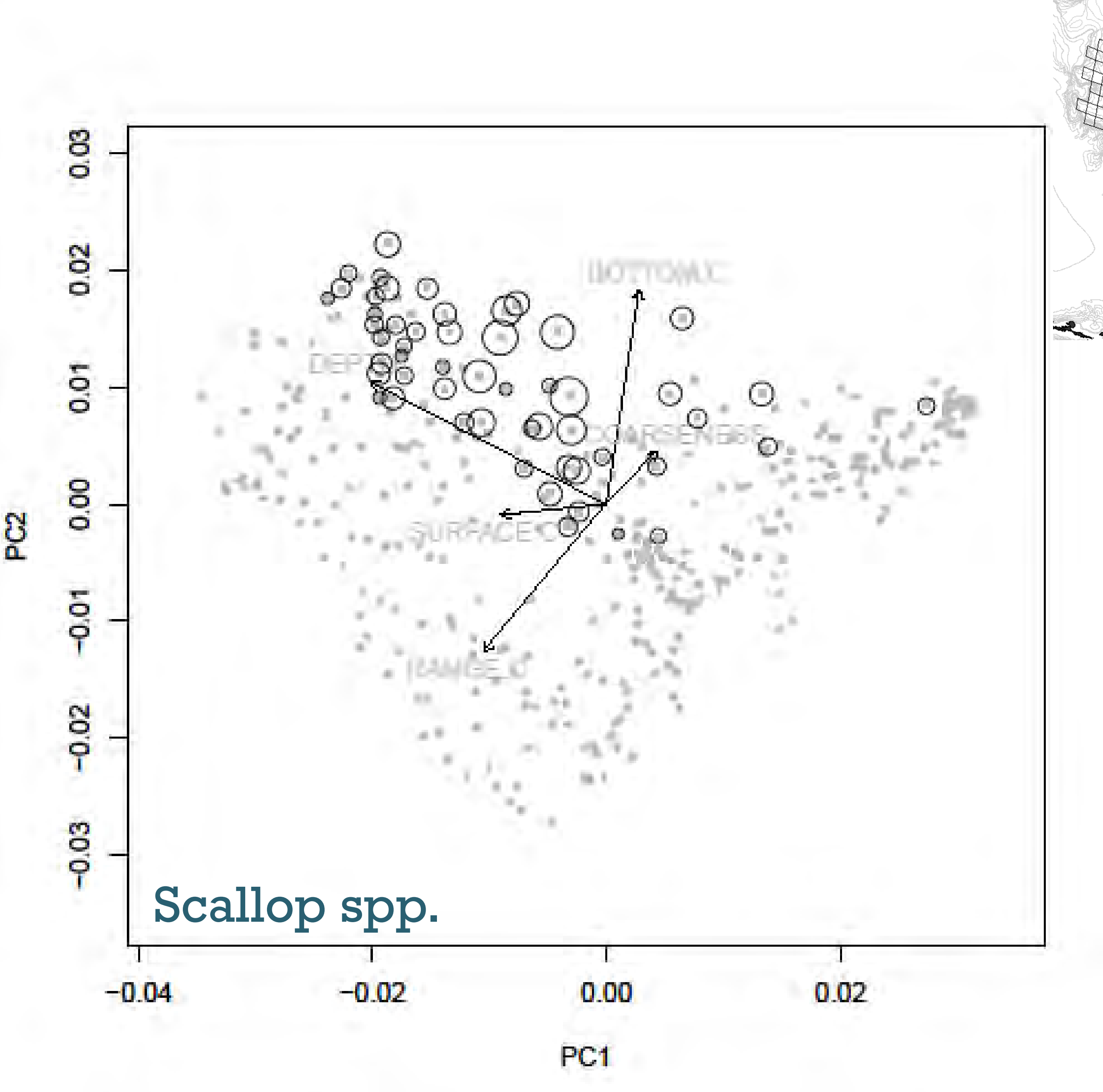
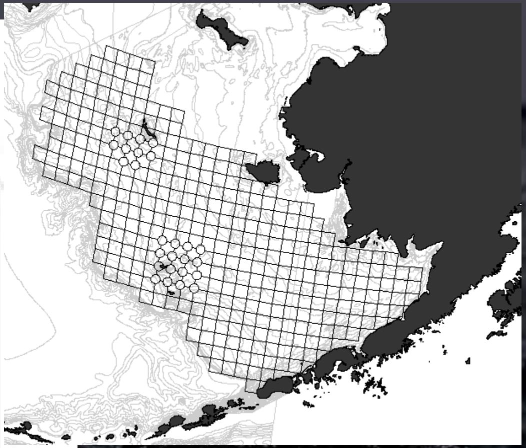




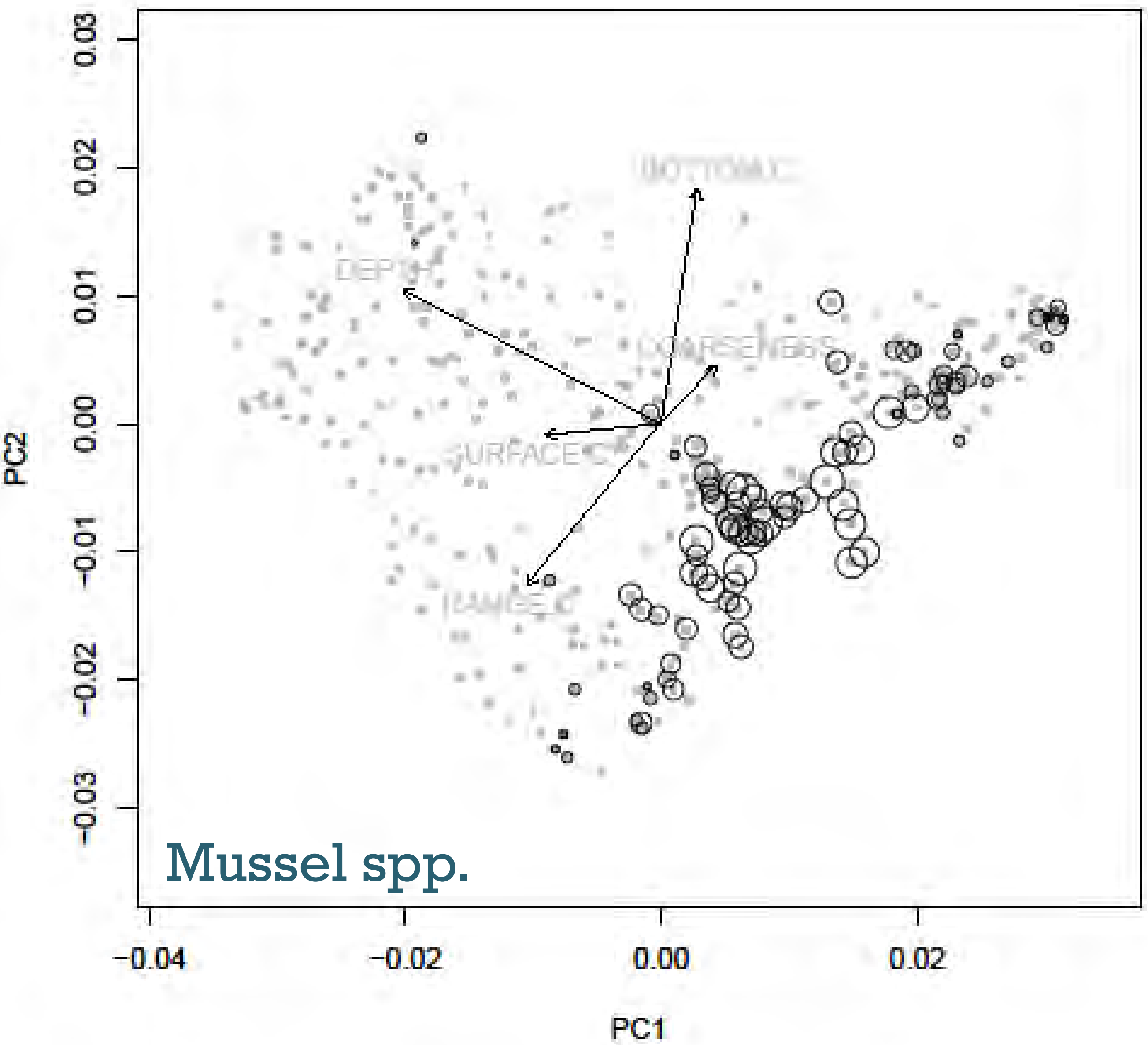
Use ordination to determine how stations distribute on environmental gradients

Coordinate position represents inferred biological composition associated with environmental predictors.

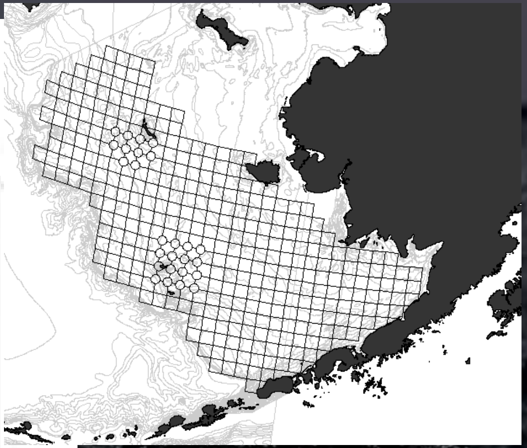




Overlay weighted distribution of species at each station



Mussel spp.



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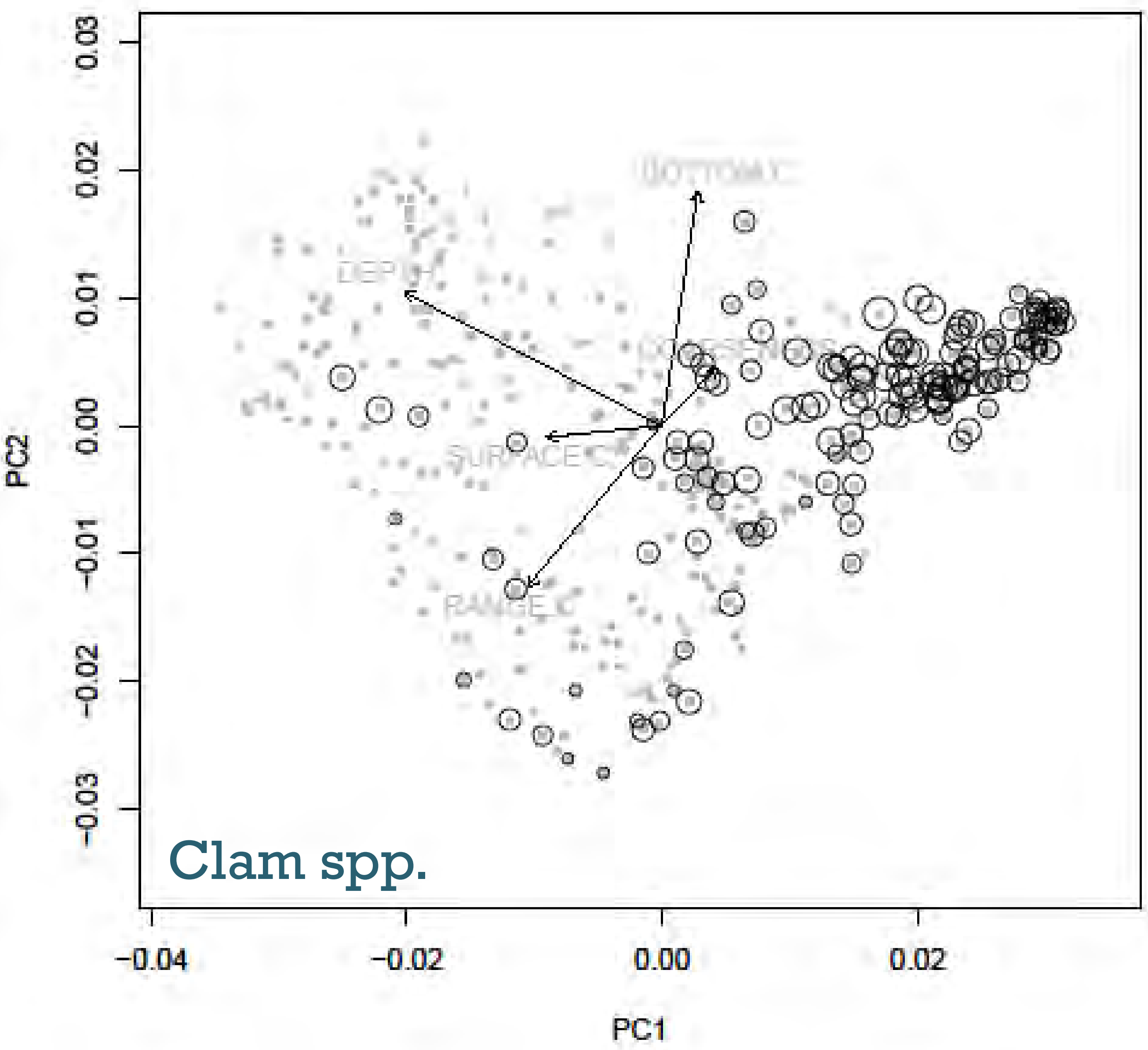
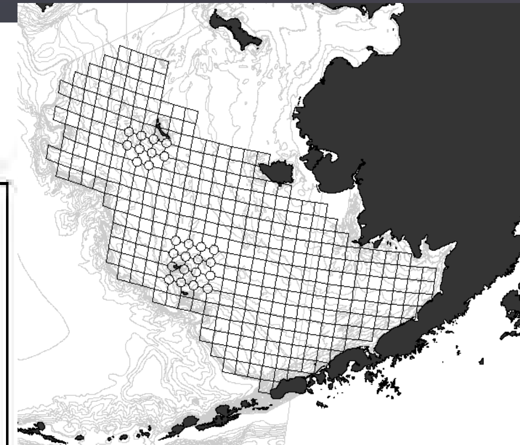
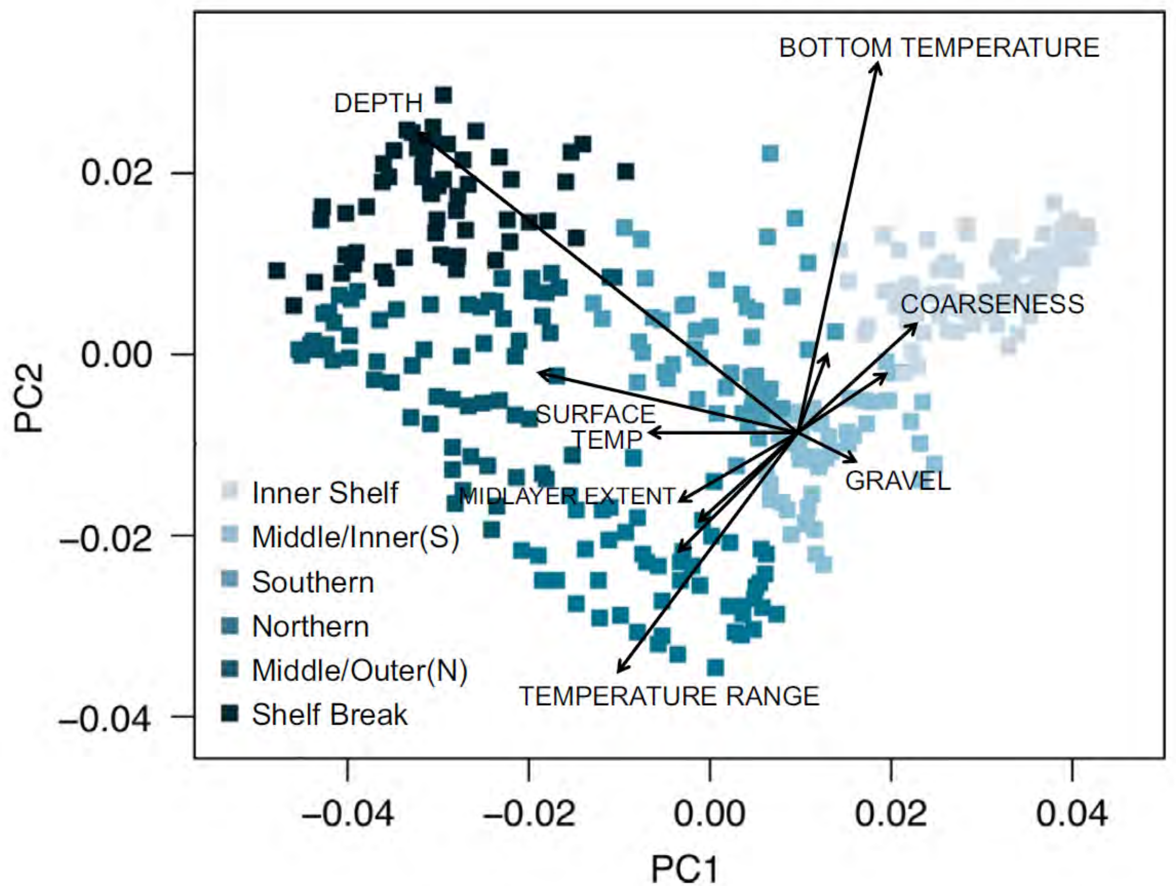




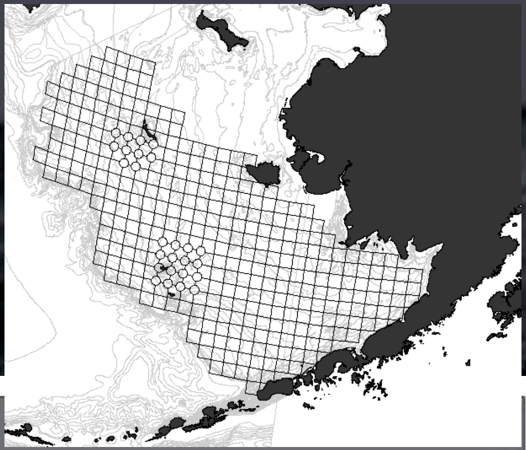
Overlay weighted distribution of species at each station

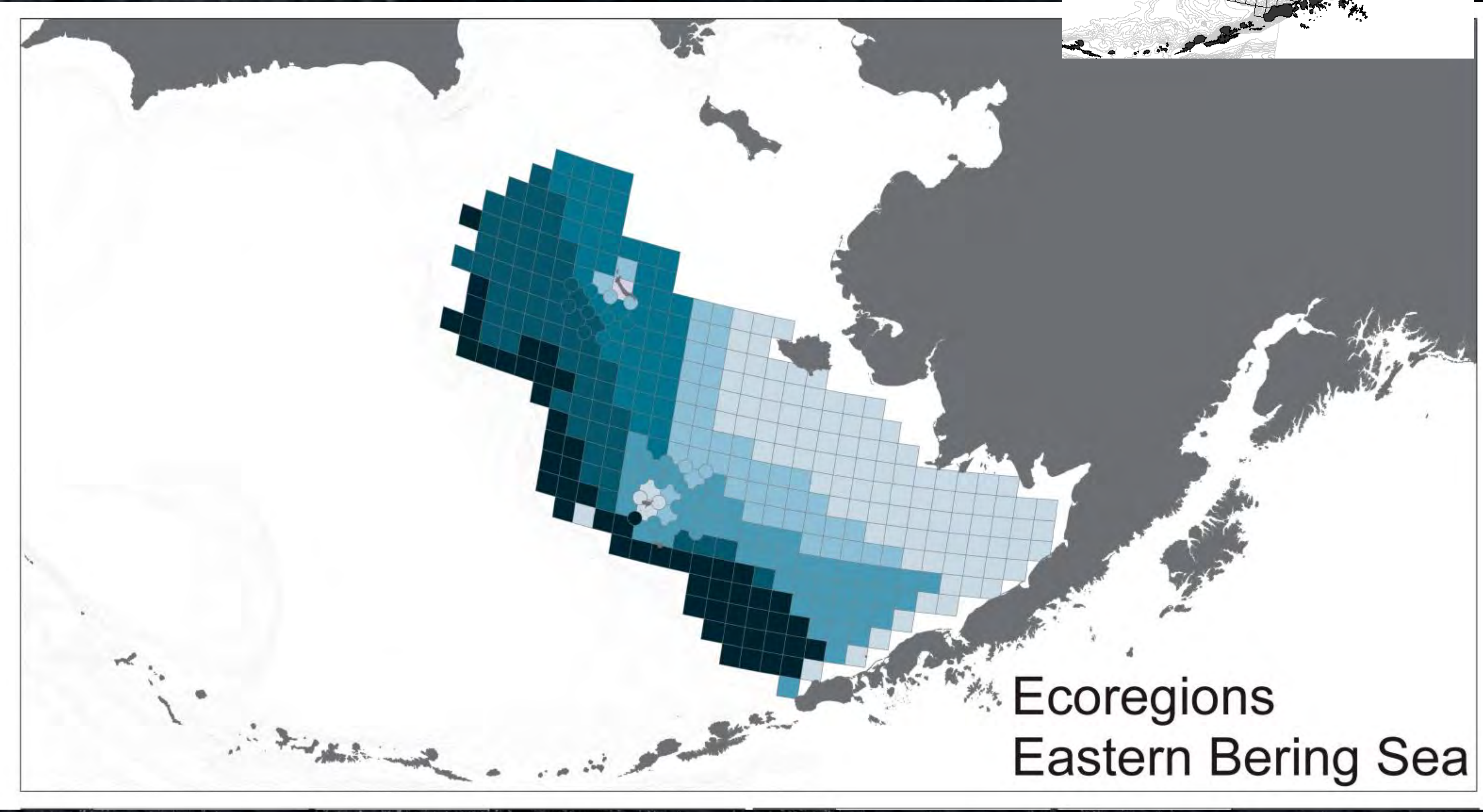
Dissimilarity index for separation of survey stations into ecoregions. Isolation indicates relative distinctness between regions (the Northern region is most distinct).

Ecoregion	No. stations	Maximum dissimilarity	Mean dsissimilarity	Isolation
(1) Inner shelf	101	0.023	0.010	0.900
(2) Middle/inner (south)	48	0.019	0.009	0.965
(3) Southern	59	0.022	0.010	1.155
(4) Northern	50	0.027	0.011	2.057
(5) Middle/outer (north)	64	0.020	0.012	1.035
(6) Shelf break	54	0.018	0.009	0.949

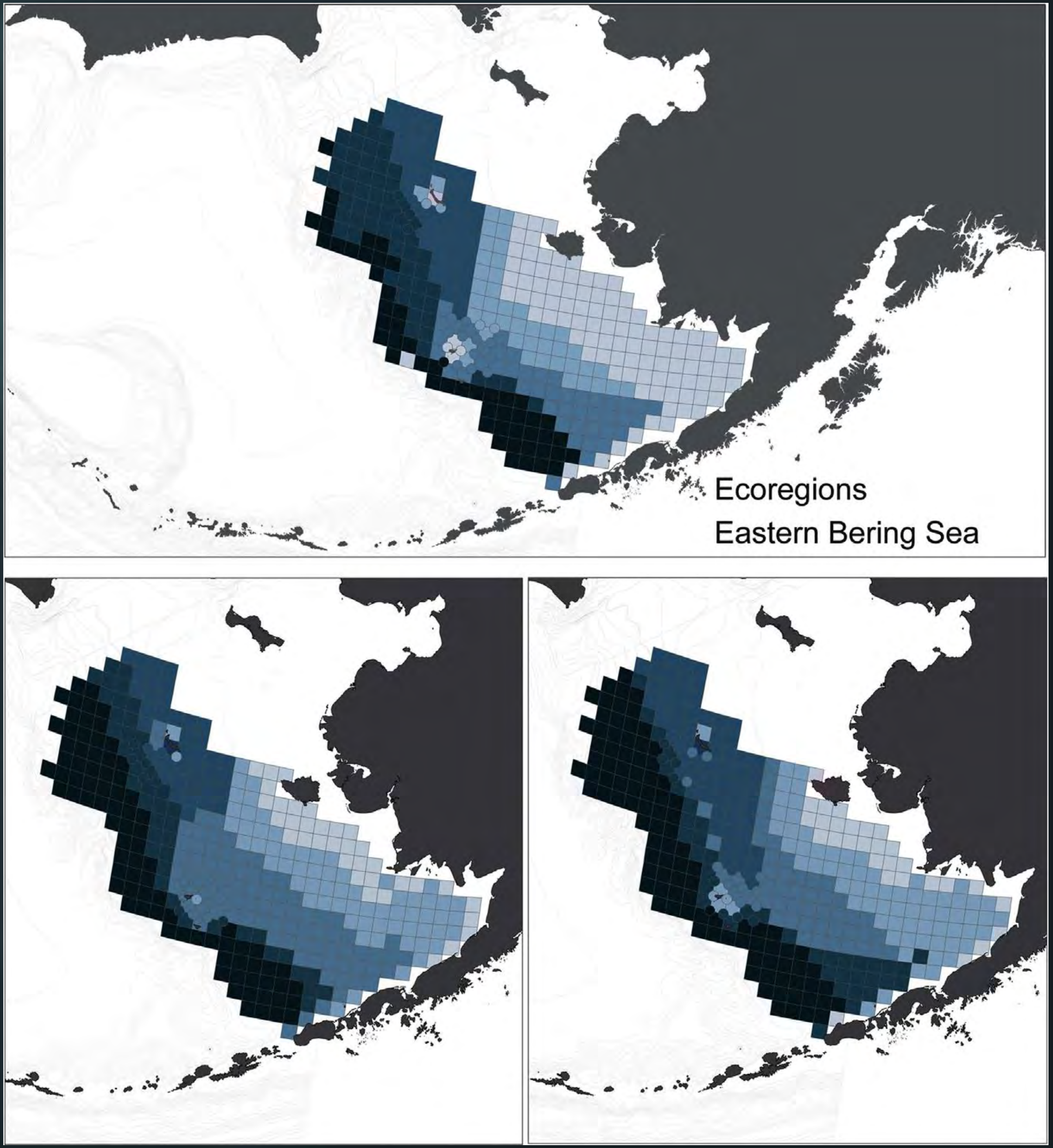


Delineation of Ecoregions (integrated over 30 years)



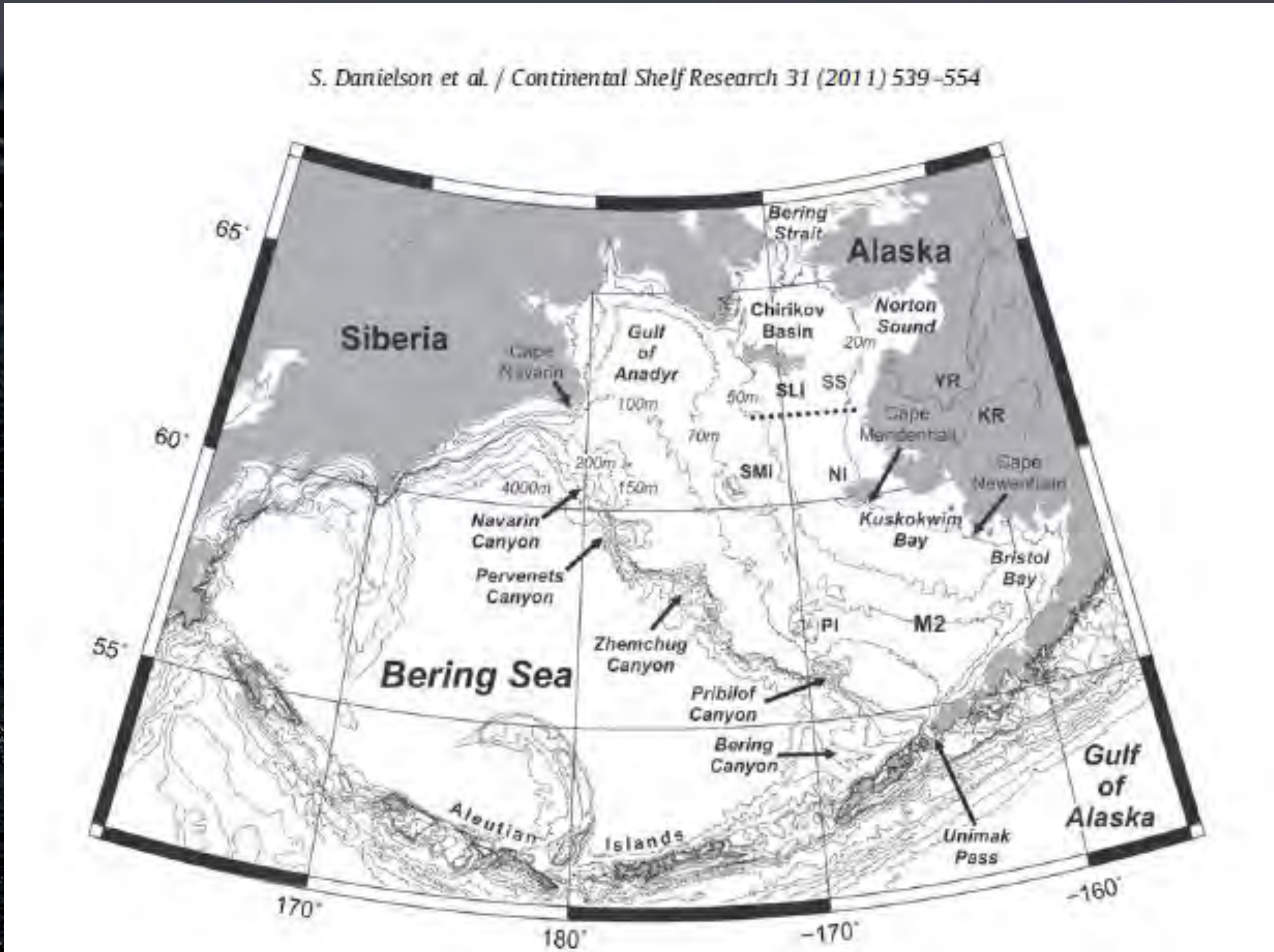


Delineation of ecoregions will shift with different climate regimes

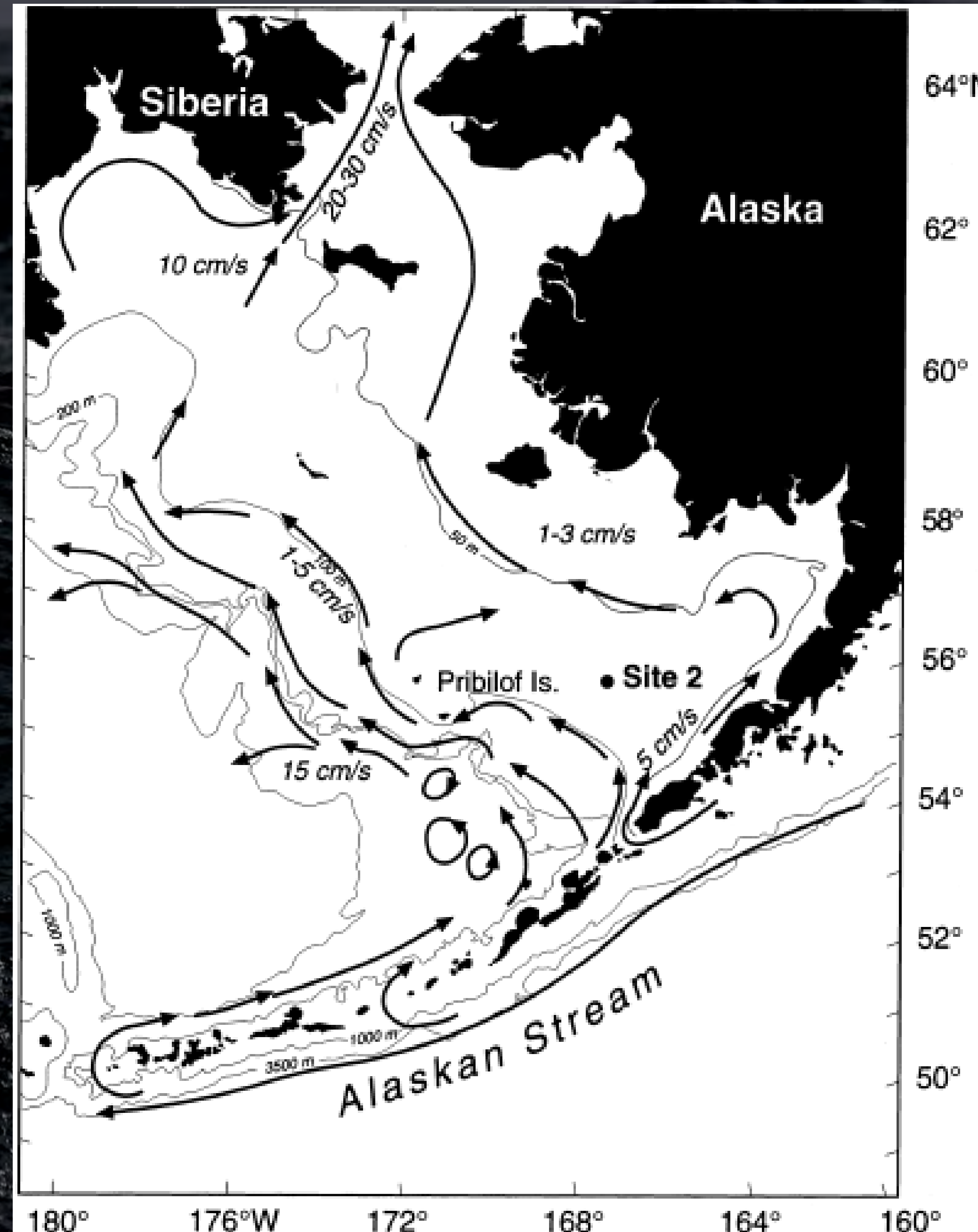


Warm phase (2001-2005)

Cold Phase (2006-2010)



Cross-shelf transport (shelf/basin exchange)

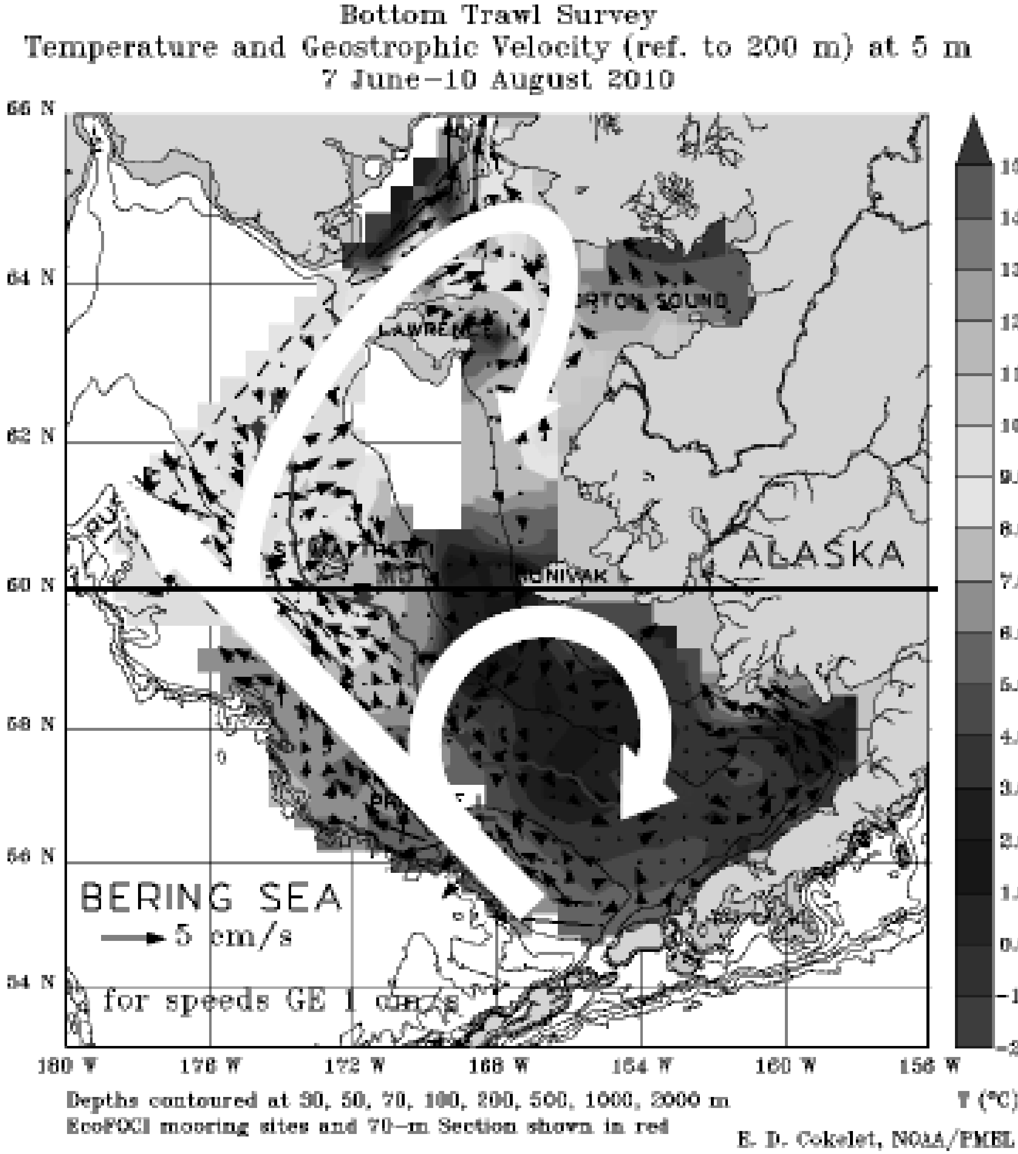


Stabeno, P.J., N.A. Bond, N.B. Kachel, S.A. Salo, J.D. Schumacher. 2001. Fish. Oceanogr.

Surface Currents

A Split Shelf: North/South changes in Currents

Summer time circulation patterns appear to be separate north and south of ~60ºN



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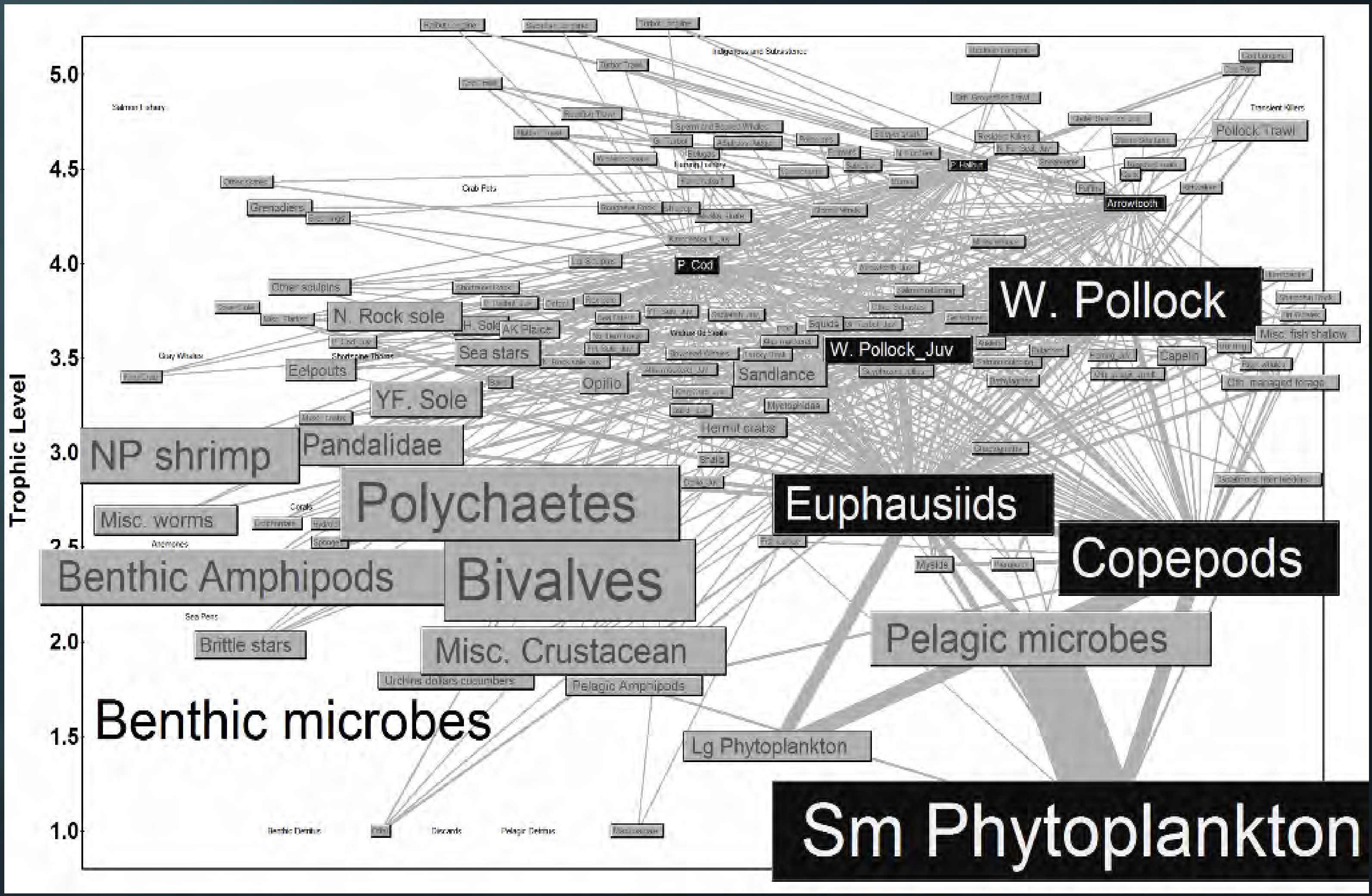
Surface Currents

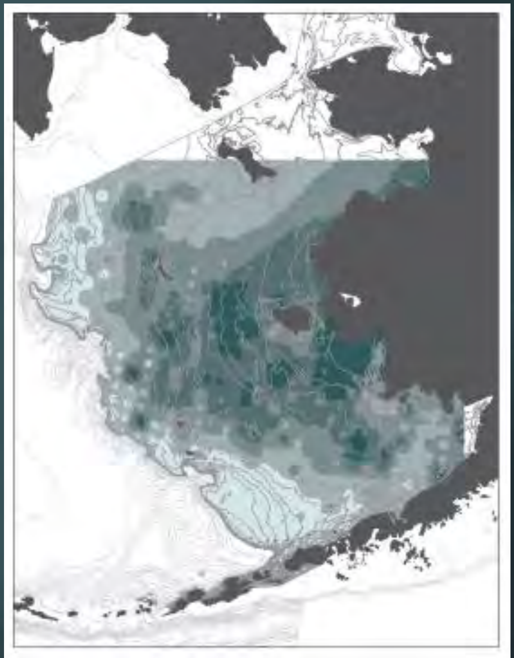
Walleye Pollock

Eastern Bering Sea pollock fisheries have averaged 1.2 million tonnes annually and represent the largest US fishery



Graphic: Kerim Aydin

Walleye Pollock spatial distribution by lifestage (1982-2015)



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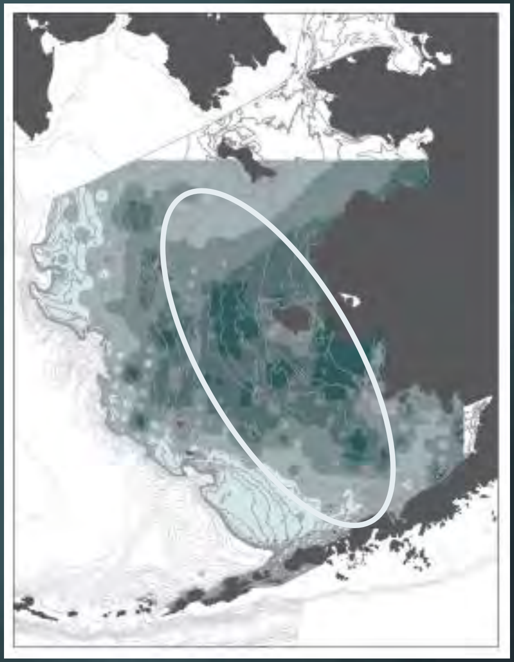

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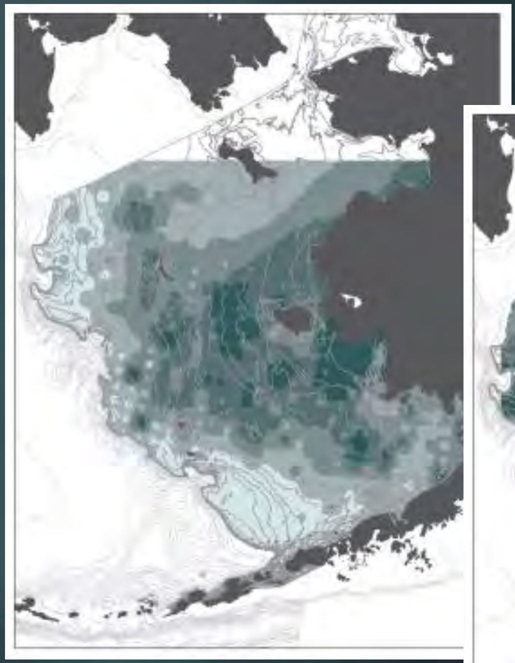

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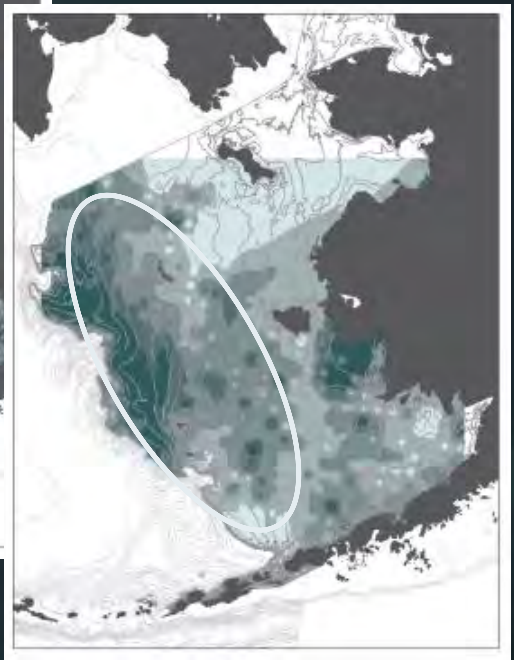

10-20cm

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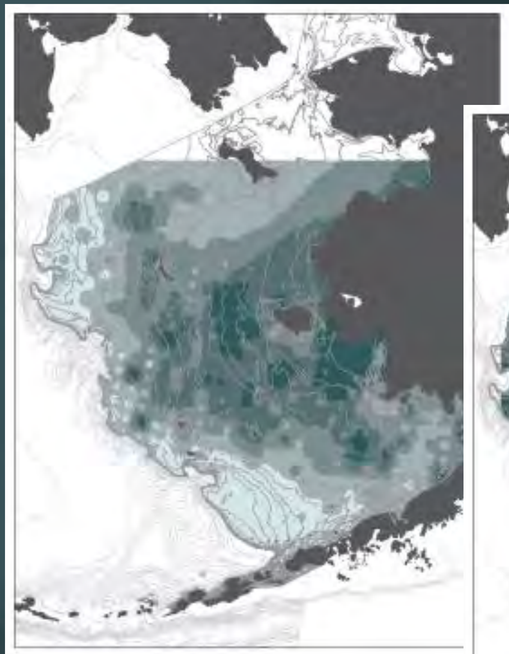

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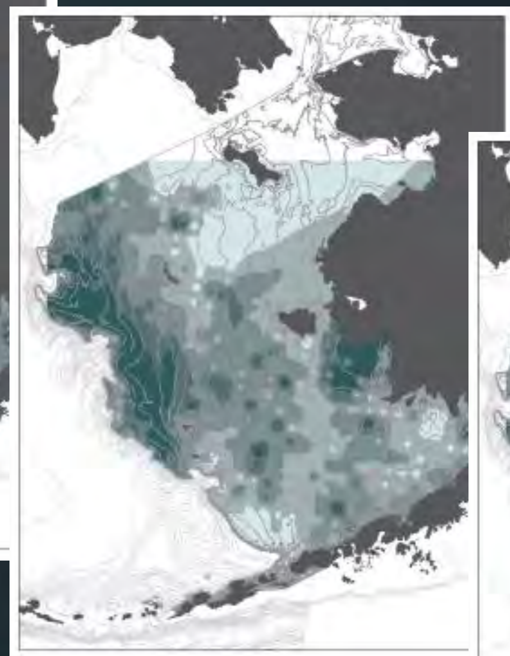
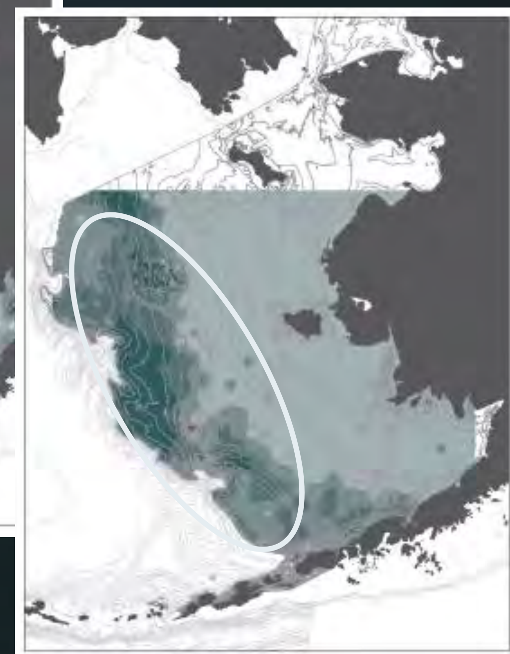
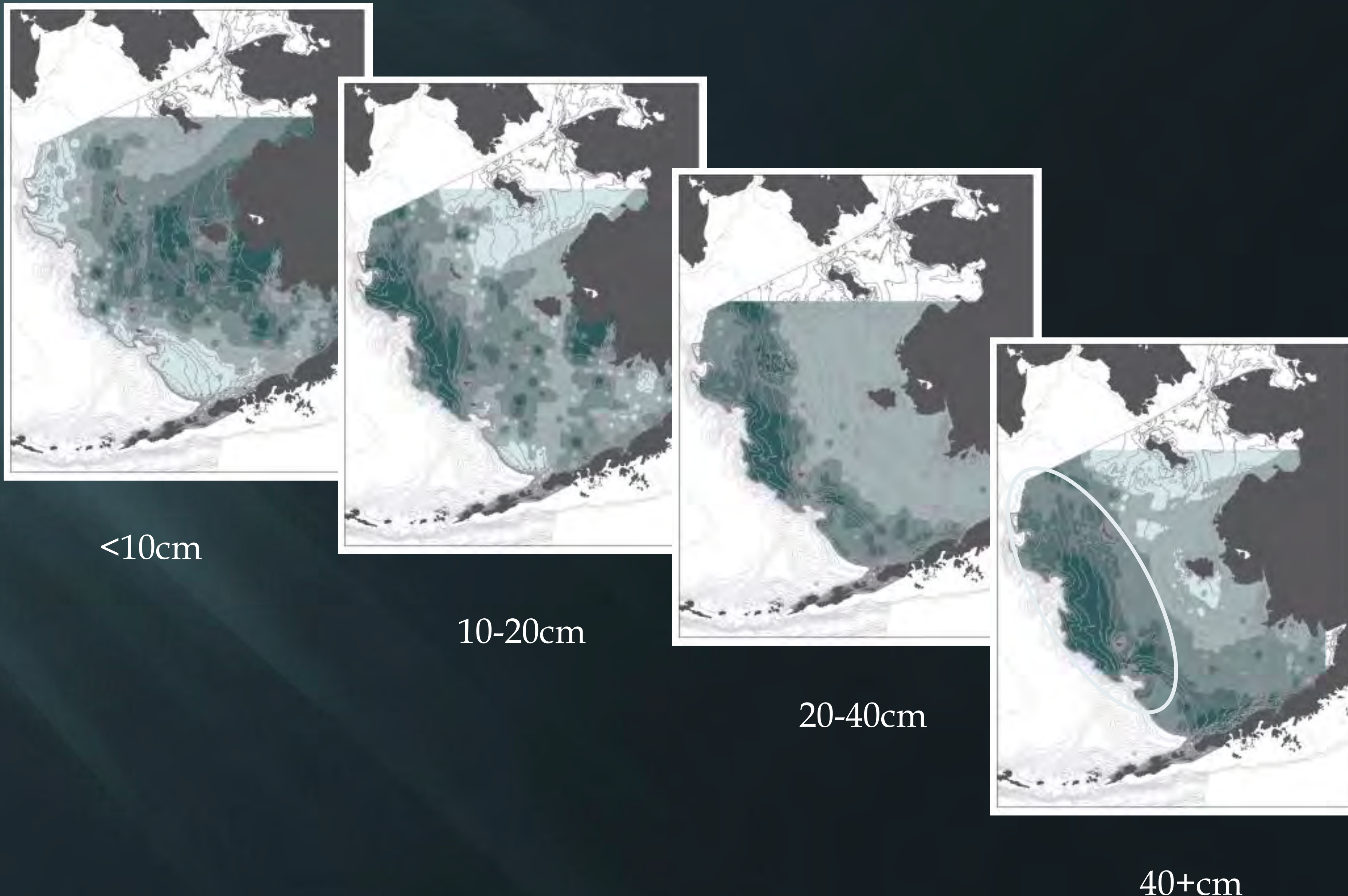


10-20cm



20-40cm

Walleye Pollock spatial distribution by lifestage (1982-2015)

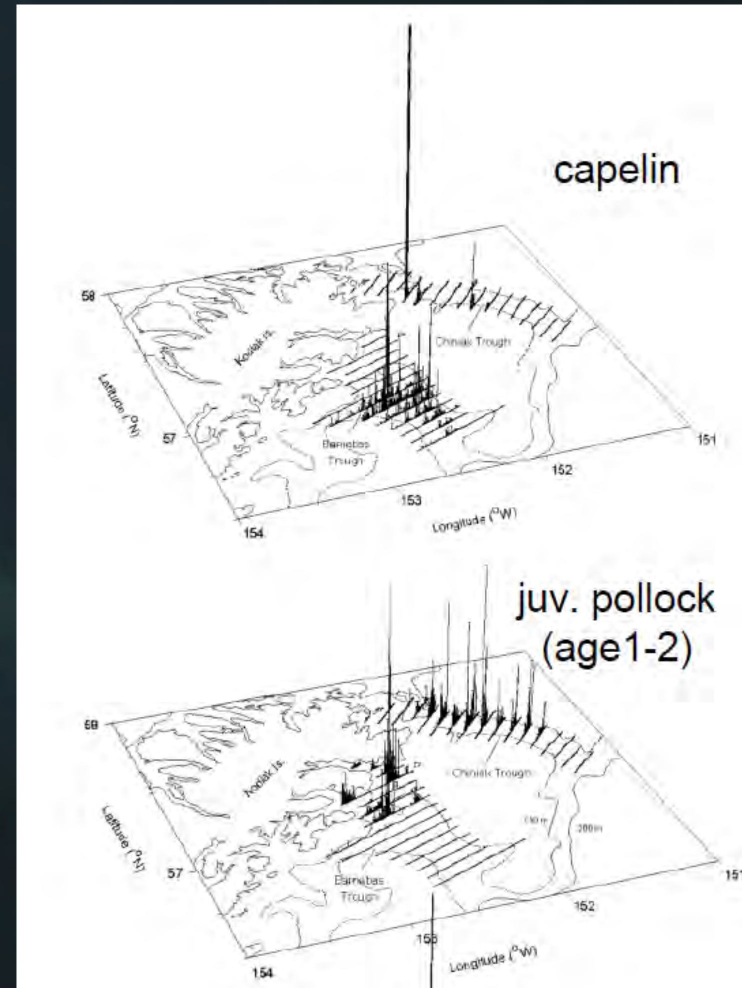


FISHERIES OCEANOGRAPHY Fish. Oceanogr. 16:2, 142–154, 2007

Effect of ocean conditions on the cross-shelf distribution of walleye pollock (*Theragra chalcogramma*) and capelin (*Mallotus villosus*)

ANNE BABCOCK HOLLOWED,[1,*] CHRISTOPHER D. WILSON,[1] PHYLLIS J. STABENO[2] AND SIGRID A. SALO[2]

[1] *Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, USA*
[2] *Pacific Marine Environmental Laboratory, 7600 Sand Point Way NE, Seattle, WA 98115, USA*



Habitat for juvenile walleye pollock and capelin is controlled by different processes.

Capelin distributions are limited by oceanographic conditions
Pollock are controlled by prey availability and predation

Forage Fish: Juvenile Pollock (age-0)

Parker-Stetter, Horne, Urmy, Farley, Eisner

Forage Fish: Capelin

Parker-Stetter, Horne, Urmy, Farley, Eisner

Effects of climate variations on pelagic ocean habitats and their role in structuring forage fish distributions in the Bering Sea

Anne B. Hollowed [a,*], Steven J. Barbeaux [a], Edward D. Cokelet [c], Ed Farley [b], Stan Kotwicki [a], Patrick H. Ressler [a], Cliff Spital [a,b,c], Christopher D. Wilson [a]

[a] *Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115, USA*
[b] *Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, Auke Bay Laboratory, 17109 Point Lena Loop Road, Juneau, AK 99801, USA*
[c] *Pacific Marine Environmental Laboratory, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115, USA*

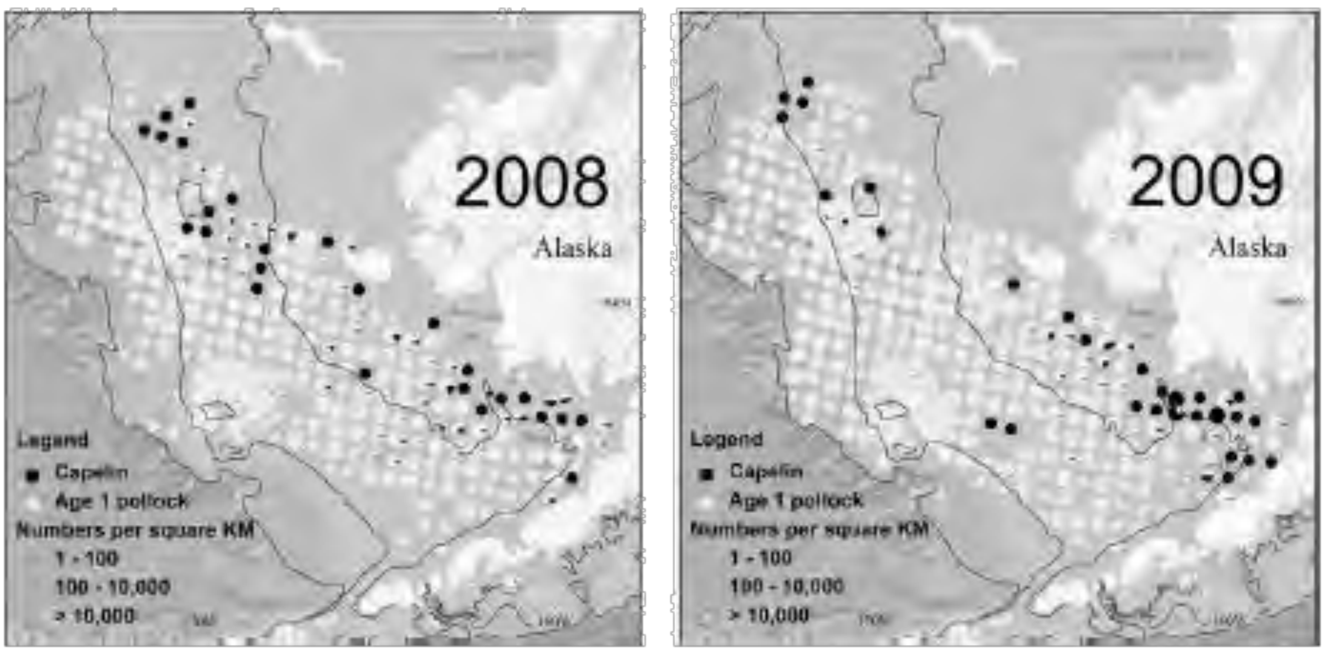
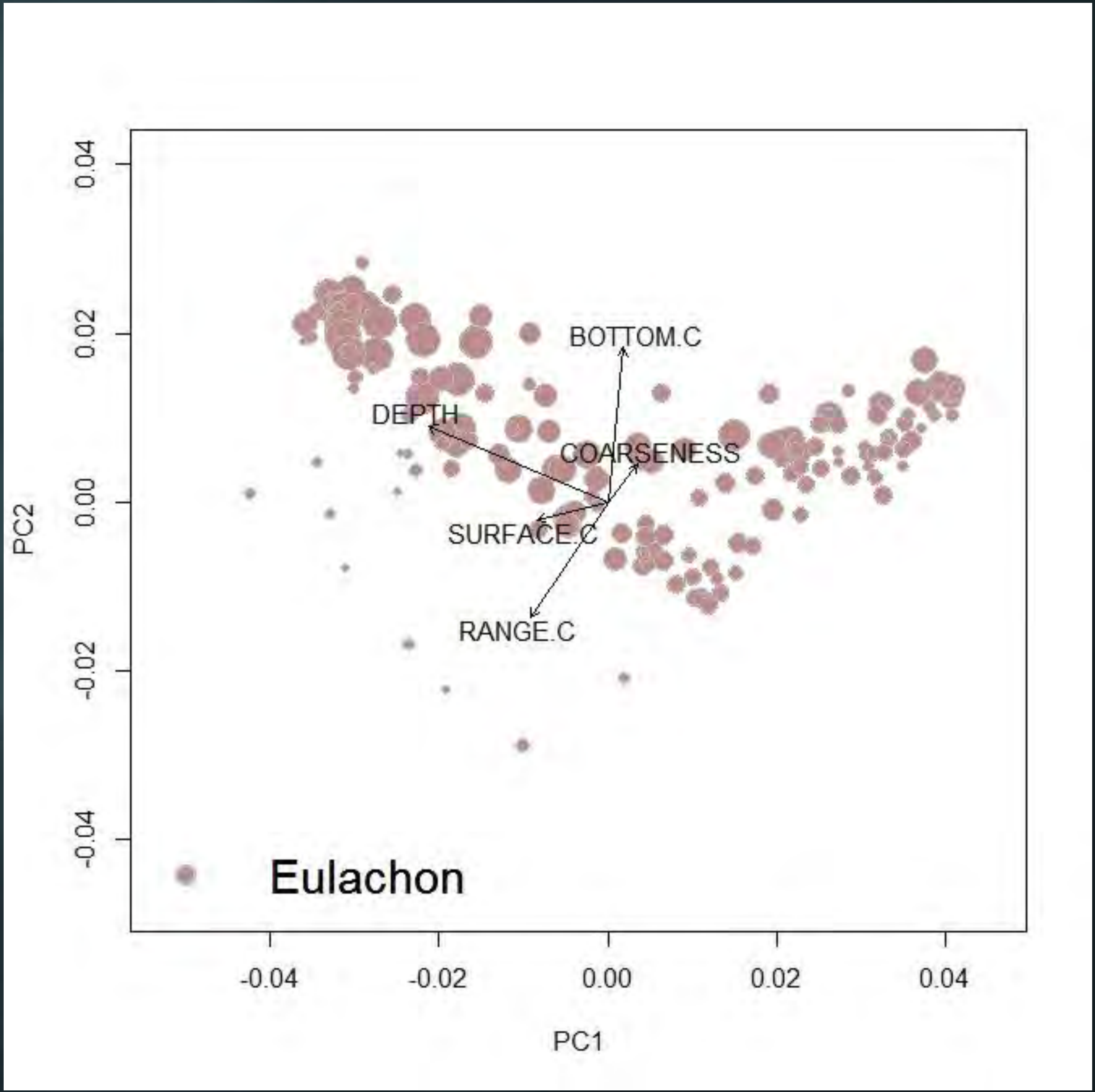
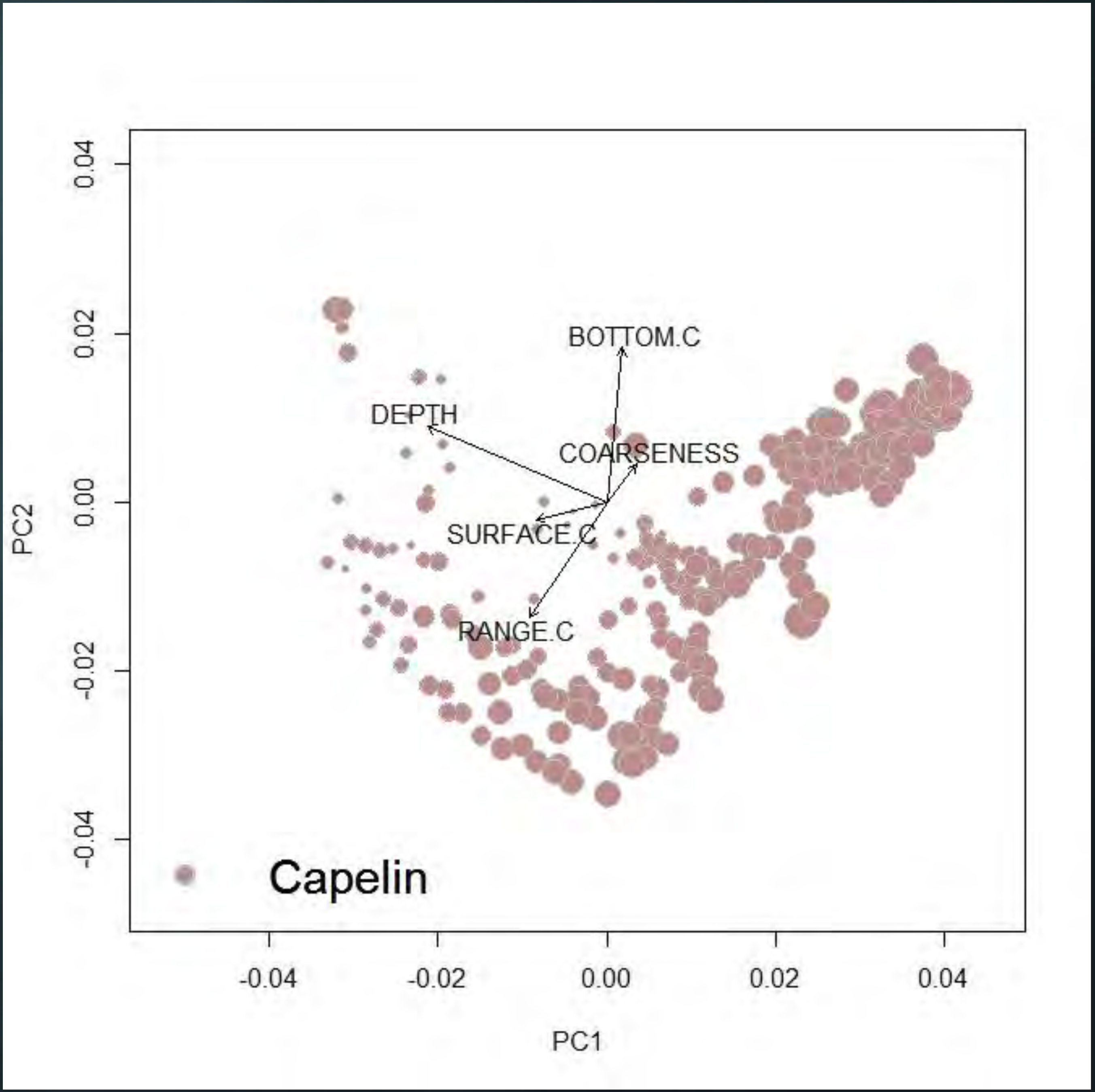


Fig. 8. Spatial distribution and co-occurrence of age-1 pollock and capelin from NMFS bottom trawl survey in July 2004-2009. Contour lines as in Fig. 1.

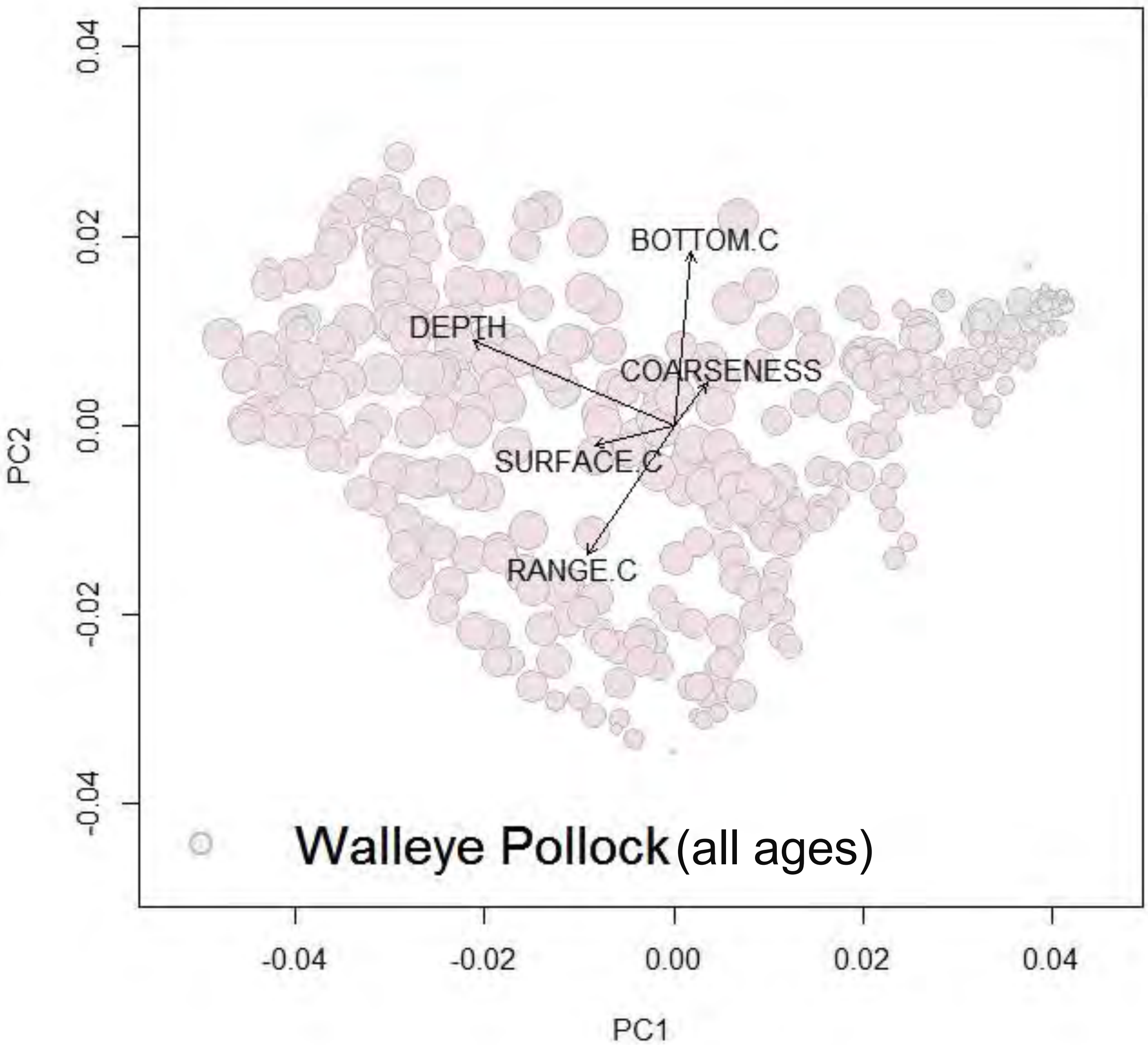
Overlap of juvenile pollock and capelin higher in cold years



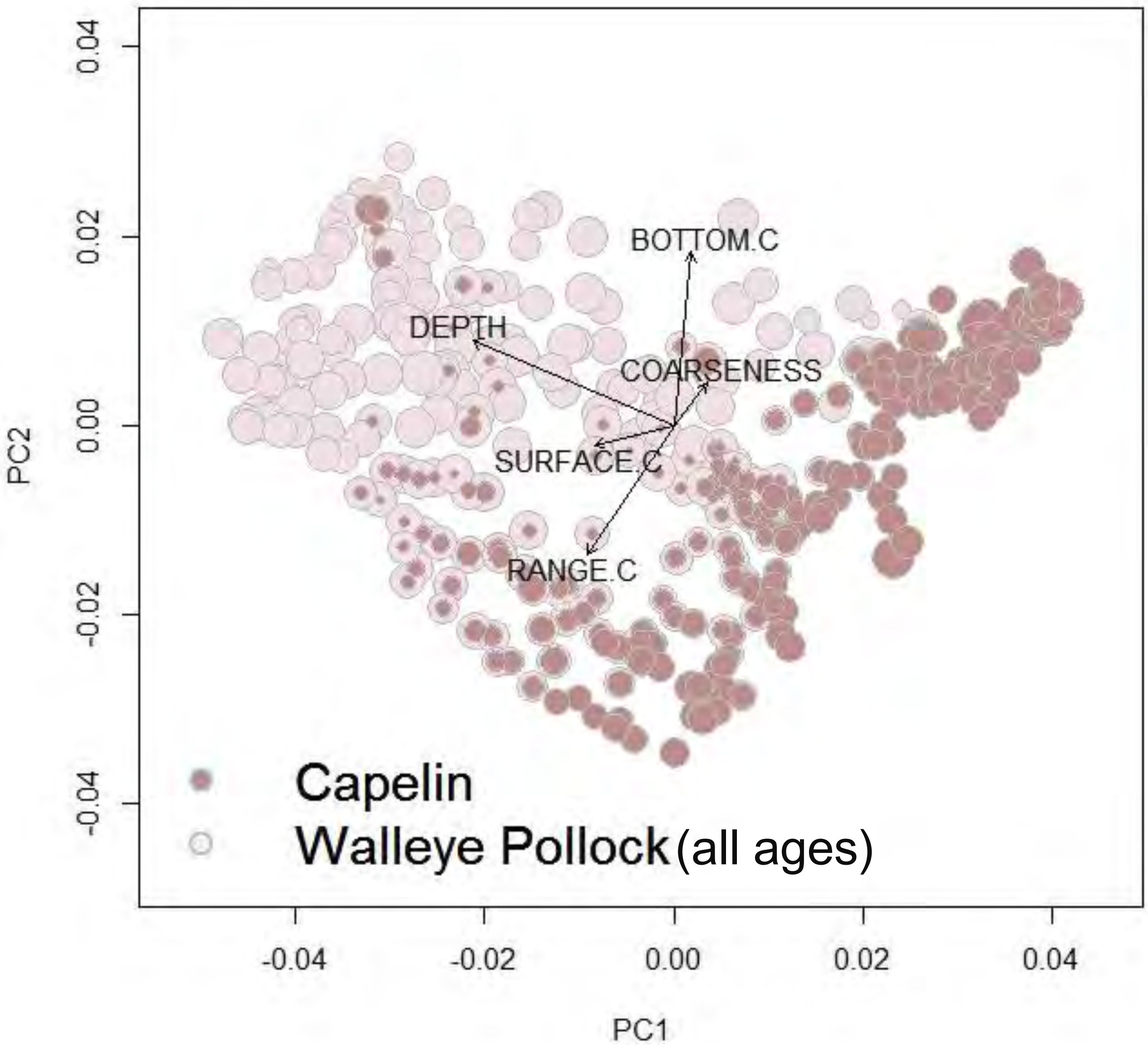
0.04
0.02
0.00
-0.02
-0.04
PC2
BOTTOM.C
DEPTH
COARSENESS
SURFACE.C
RANGE.C
Eulachon
-0.04
-0.02
0.00
0.02
0.04
PC1



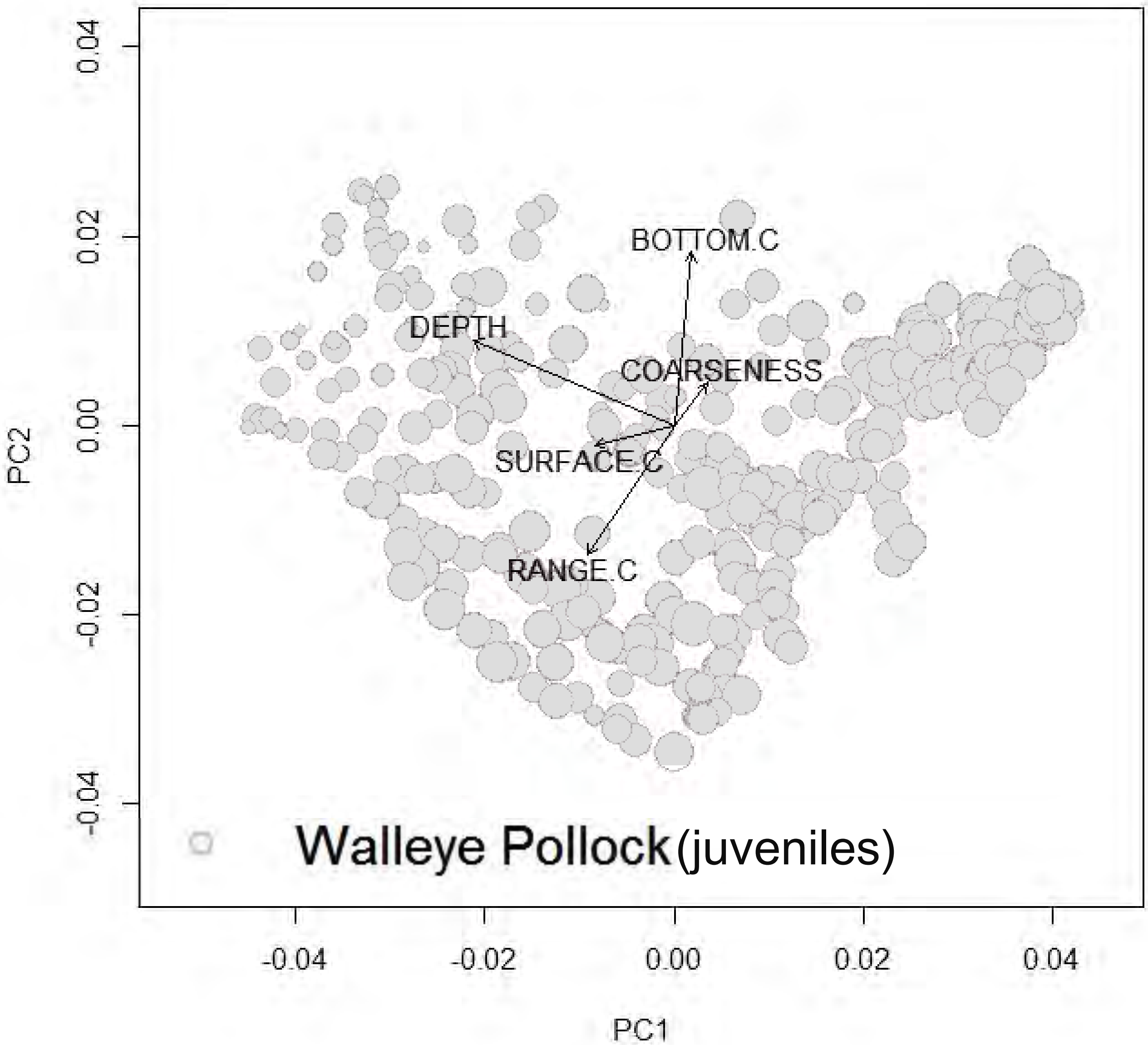
0.04
0.02
0.00
-0.02
-0.04
PC2
-0.04
-0.02
0.00
0.02
0.04
PC1
BOTTOM.C
DEPTH
COARSENESS
SURFACE.C
RANGE.C
Capelin



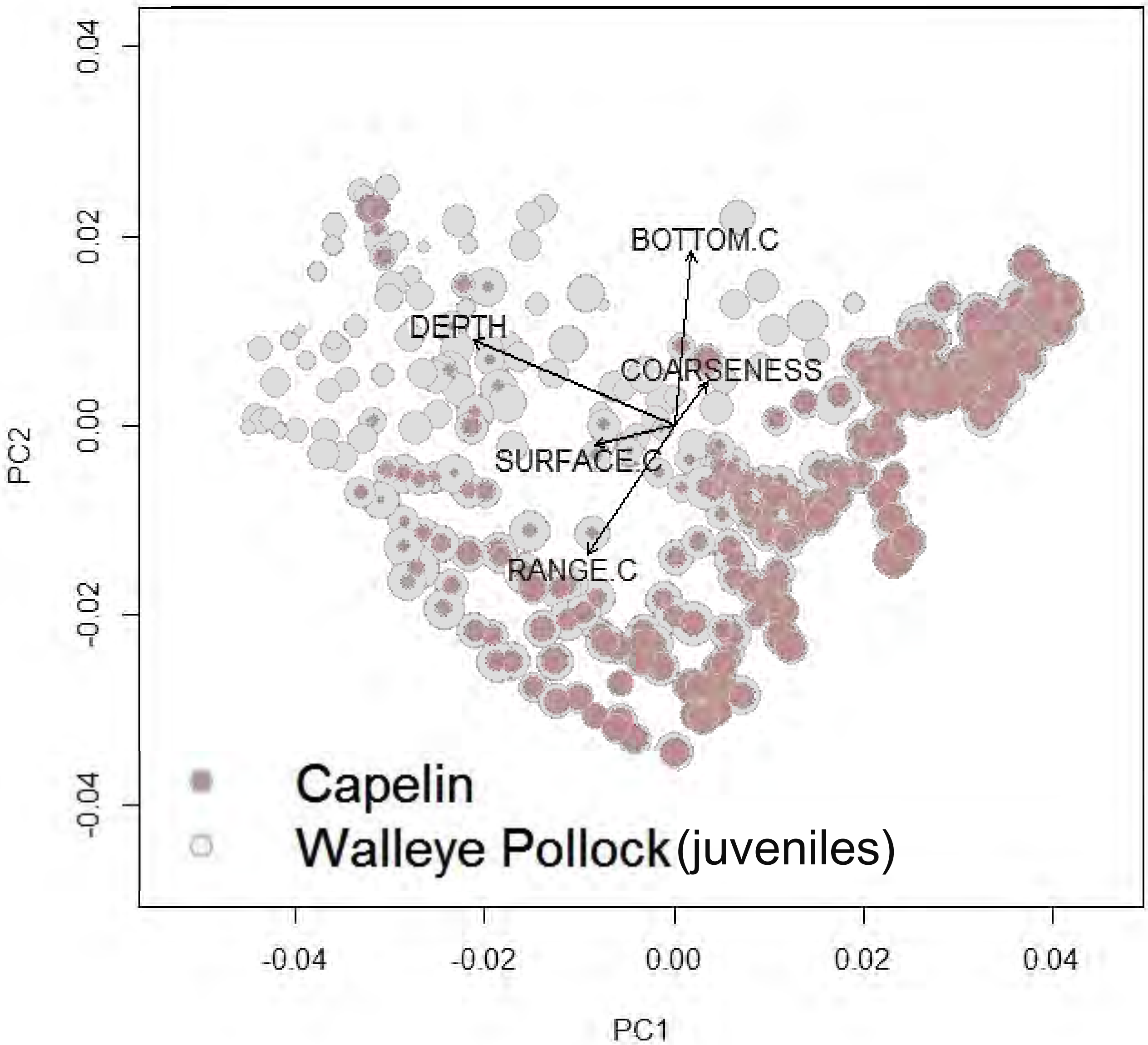
BOTTOM.C
DEPTH
COARSENESS
SURFACE.C
RANGE.C
Walleye Pollock (all ages)
0.04
0.02
0.00
-0.02
-0.04
PC2
PC1



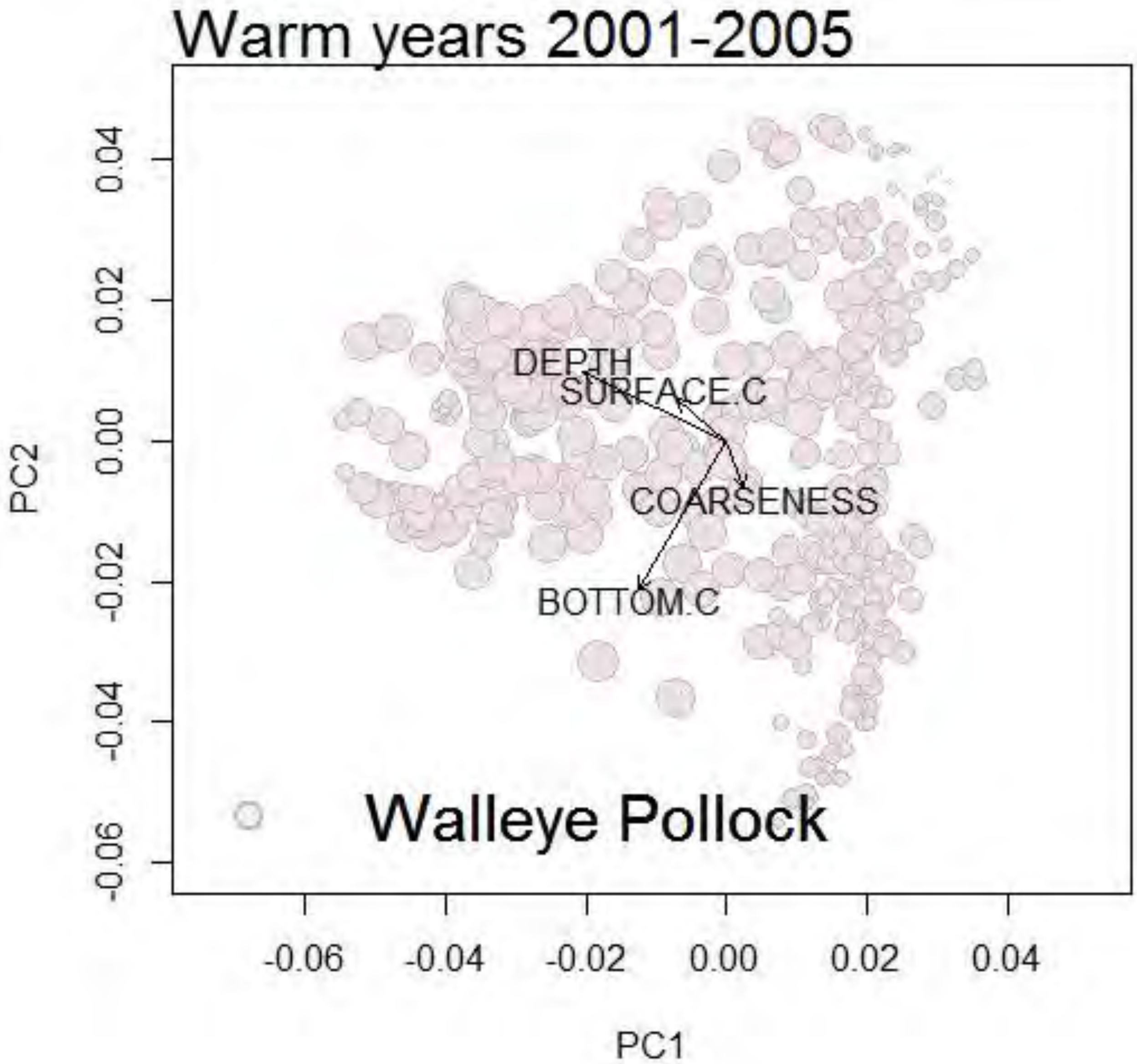
BOTTOM.C
DEPTH
COARSENESS
SURFACE.C
RANGE.C
Capelin
Walleye Pollock (all ages)
0.04
0.02
0.00
-0.02
-0.04
PC2
-0.04
-0.02
0.00
0.02
0.04
PC1



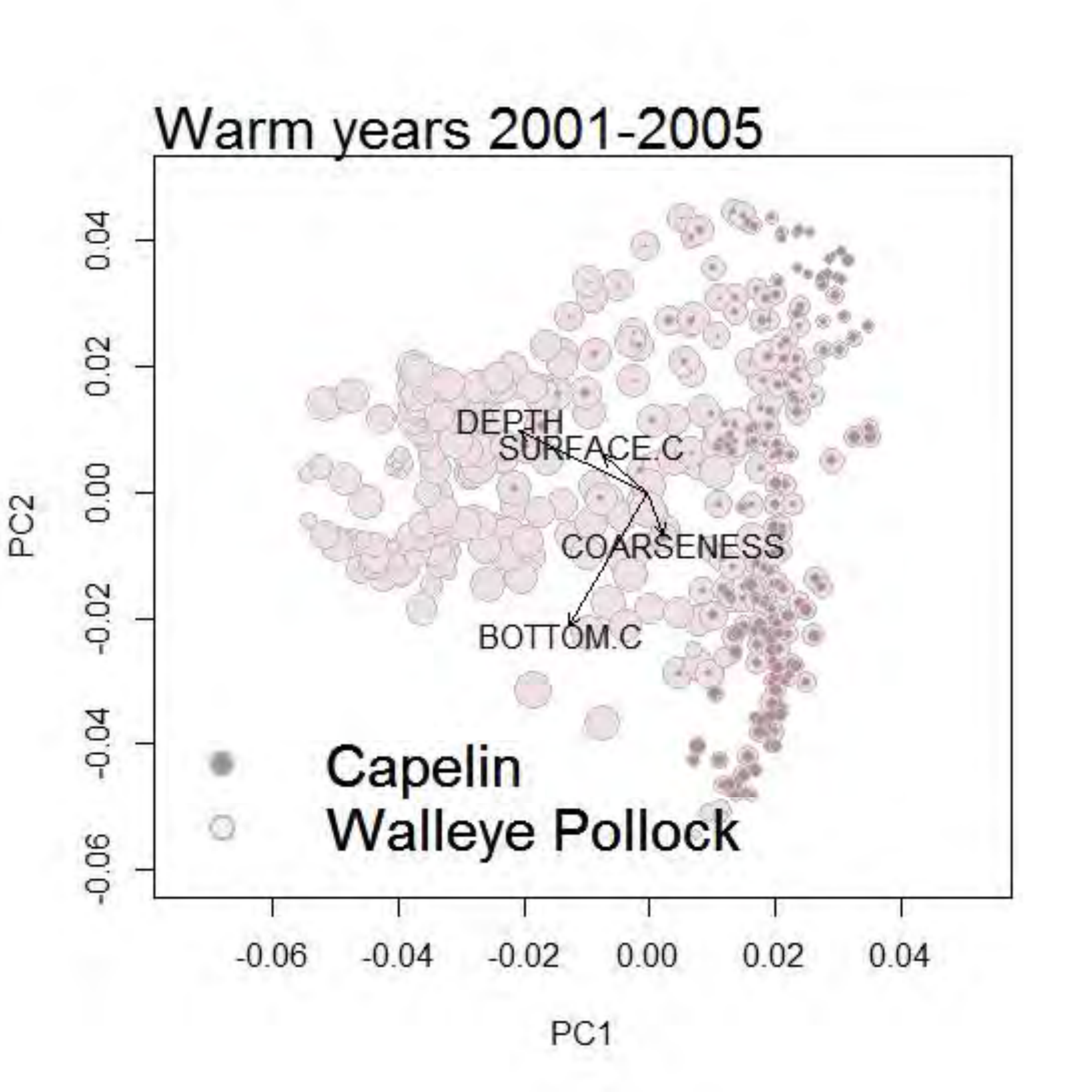
0.04
0.02
0.00
-0.02
-0.04
PC2
BOTTOM.C
DEPTH
COARSENESS
SURFACE.C
RANGE.C
Walleye Pollock (juveniles)
-0.04
-0.02
0.00
0.02
0.04
PC1



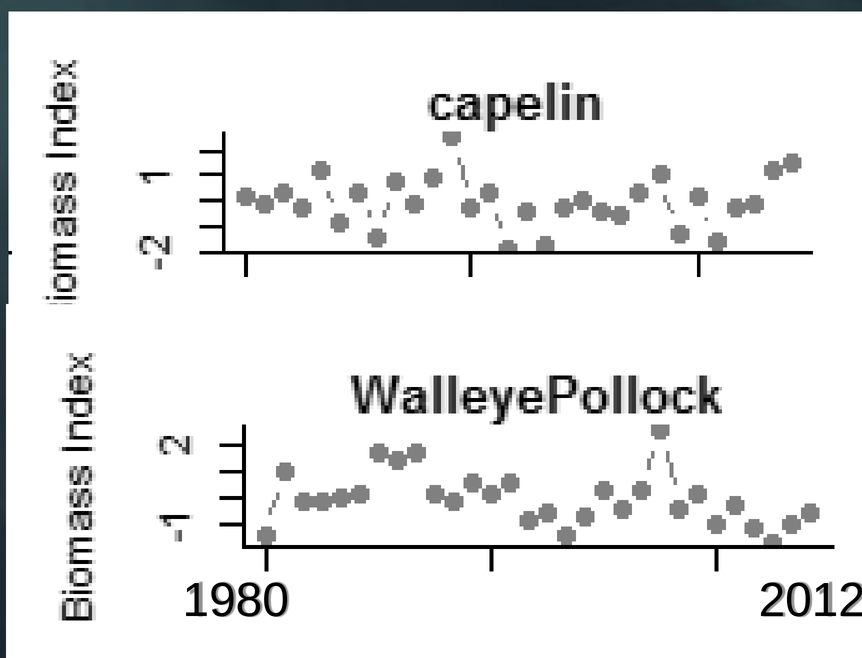
0.04
0.02
0.00
-0.02
-0.04
PC2
-0.04
-0.02
0.00
0.02
0.04
PC1
BOTTOM.C
DEPTH
COARSENESS
SURFACE.C
RANGE.C
Capelin
Walleye Pollock (juveniles)

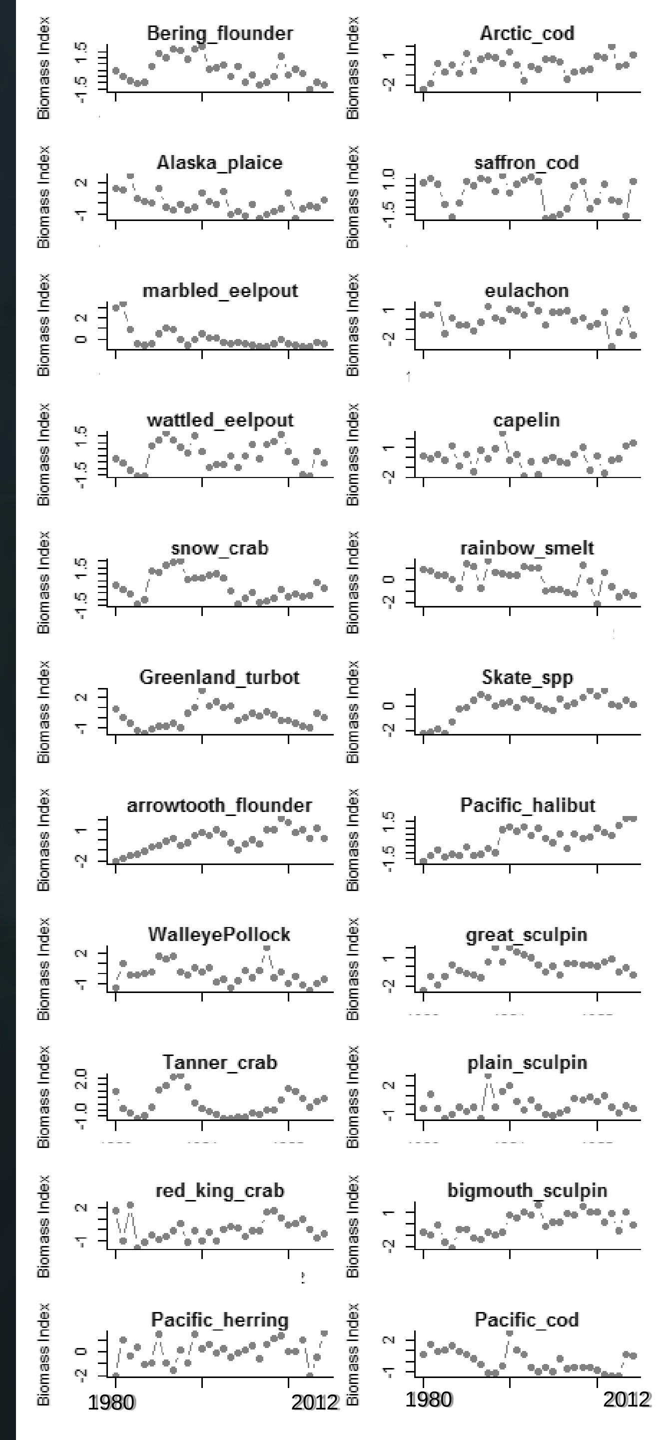


Warm years 2001-2005
DEPTH
SURFACE.C
COARSENESS
BOTTOM.C
Walleye Pollock
PC1
PC2
-0.06
-0.04
-0.02
0.00
0.02
0.04


Warm years 2001-2005
DEPTH
SURFACE.C
COARSENESS
BOTTOM.C
Capelin
Walleye Pollock
PC2
PC1
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.06
-0.04
-0.02
0.00
0.02
0.04

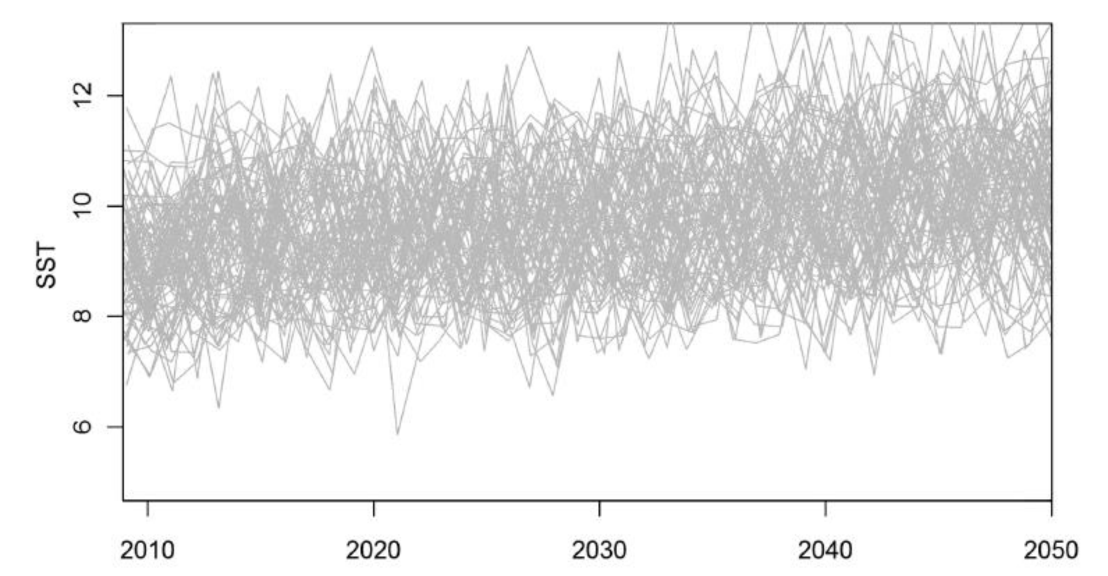
Time series of relative biomass for range of species in the Bering Sea in past years





Integrating Ecosystem Aspects and Climate Change Forecasting into Stock Assessments

by Anne B. Hollowed, Teresa A'mar, Steven Barbeaux, Nicholas Bond, James N. Ianelli, Paul Spencer, and Thomas Wilderbuer

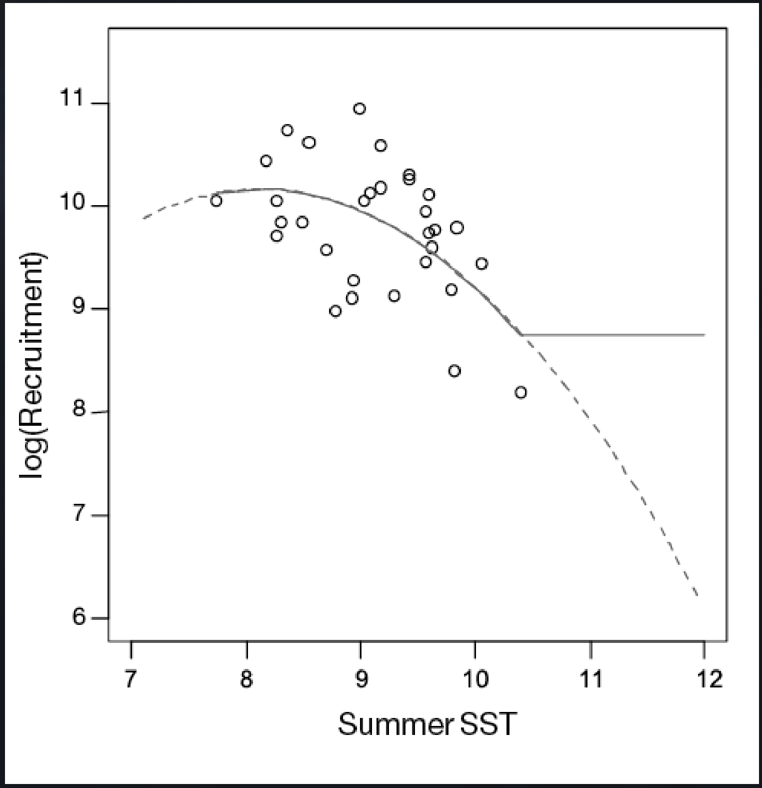


Time series of future Bering Sea surface temperature based on climate models

ICES Journal of Marine Science (2011), 68(6), 1297–1304. doi:10.1093/icesjms/fsr010

Evaluating management strategies for eastern Bering Sea walleye pollock (*Theragra chalcogramma*) in a changing environment

James N. Ianelli[1]*, Anne B. Hollowed[1], Alan C. Haynie[1], Franz J. Mueter[2], and Nicholas A. Bond[3]



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Evaluating management strategies for eastern Bering Sea walleye pollock (*Theragra chalcogramma*) in a changing environment

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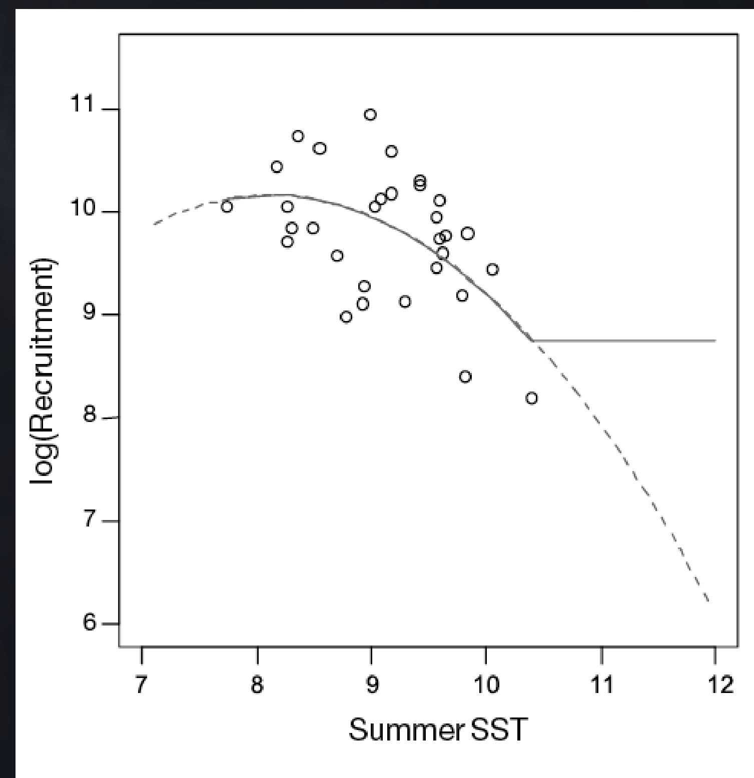
Factors affecting recruitment:

(i) ice and temperature determine early growth;

(ii) stratification during the first summer affects growth and vulnerability to predation;

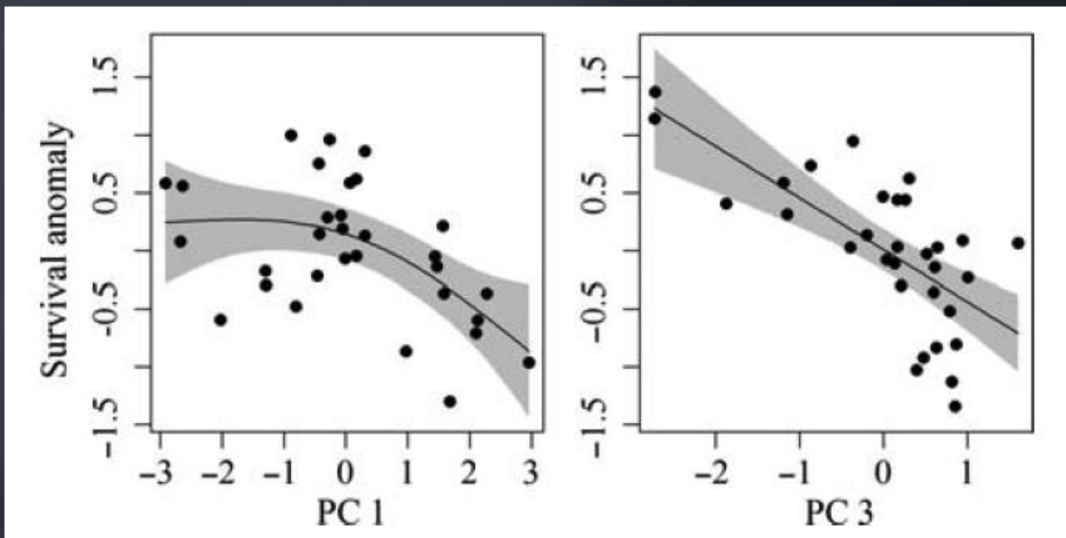
(iii) predation is influenced by the spatial overlap between juvenile pollock and their predators



ICES Journal of Marine Science (2011), 68(6), 1284–1296. doi:10.1093/icesjms/fsr022

Expected declines in recruitment of walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea under future climate change

Franz J. Mueter[1*], Nicholas A. Bond[2], James N. Ianelli[3], and Anne B. Hollowed[3]



Factors affecting recruitment:

(i) Recruitment and survival decrease with increasing temperature (Mueter et al. 2011)

ICES Journal of Marine Science (2011), 68(6), 1284–1296. doi:10.1093/icesjms/fsr022

Expected declines in recruitment of walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea under future climate change

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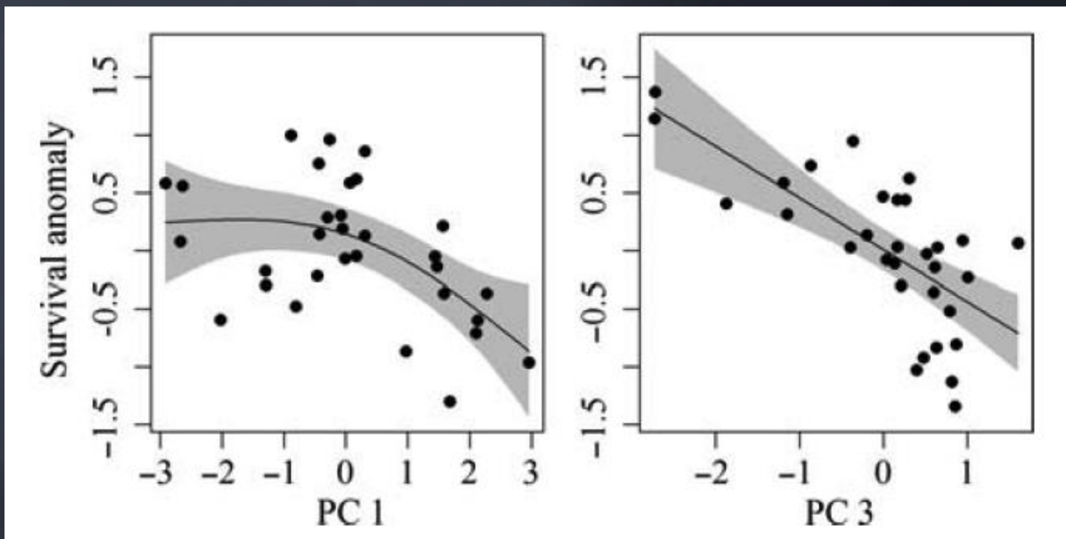
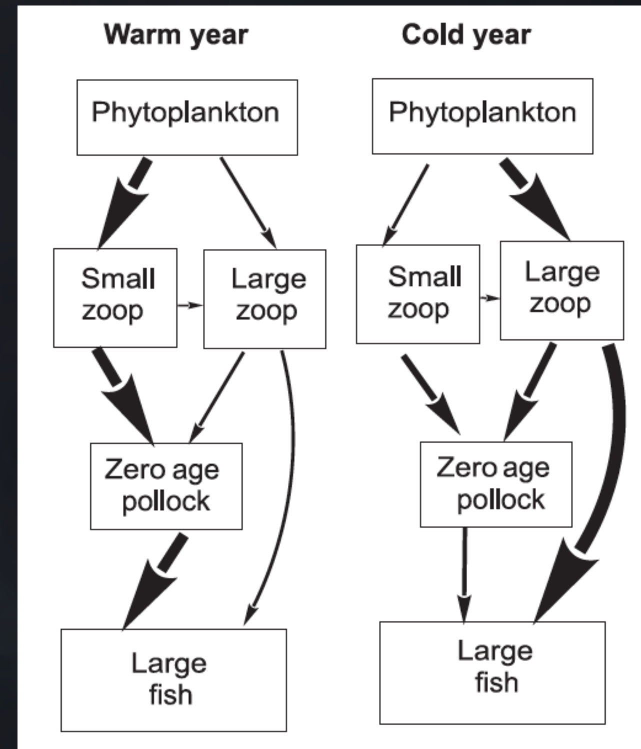


Coyle et al. 2011



Factors affecting recruitment:

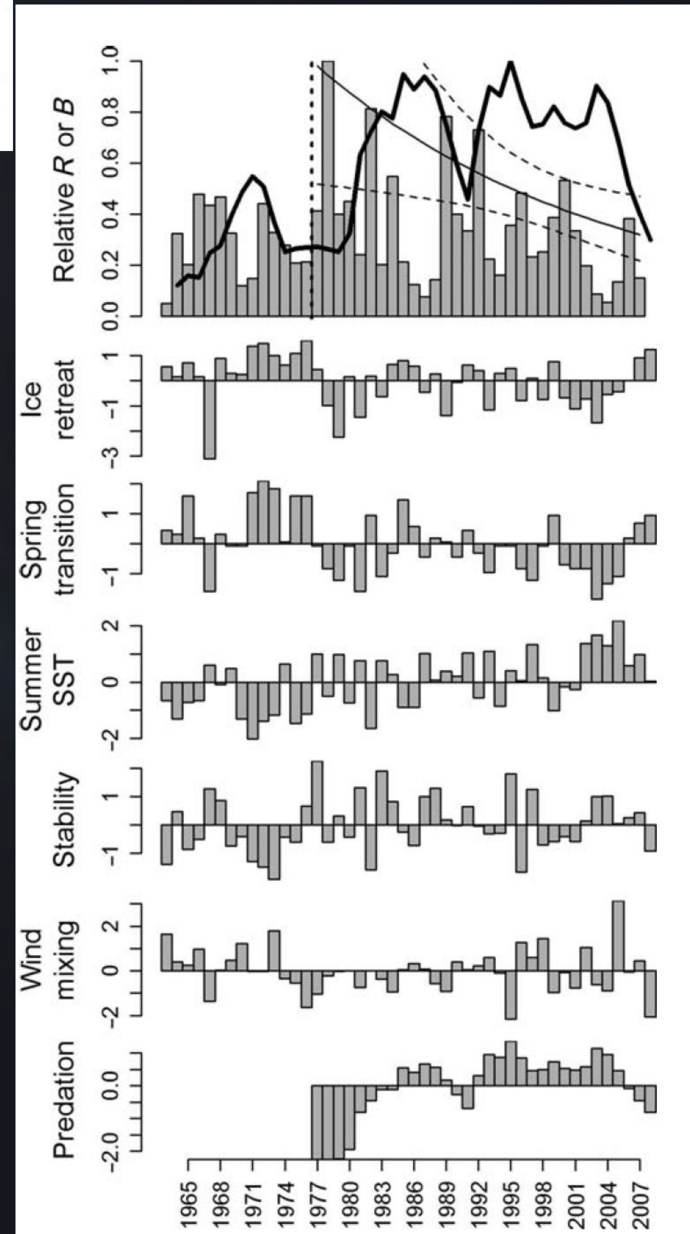
(i) Recruitment and survival decrease with increasing temperature (Mueter et al. 2011)
(ii) Predation is stronger in warm years (Coyle et al. 2011)

ICES Journal of Marine Science (2011), 68(6), 1297–1304. doi:10.1093/icesjms/fsr010

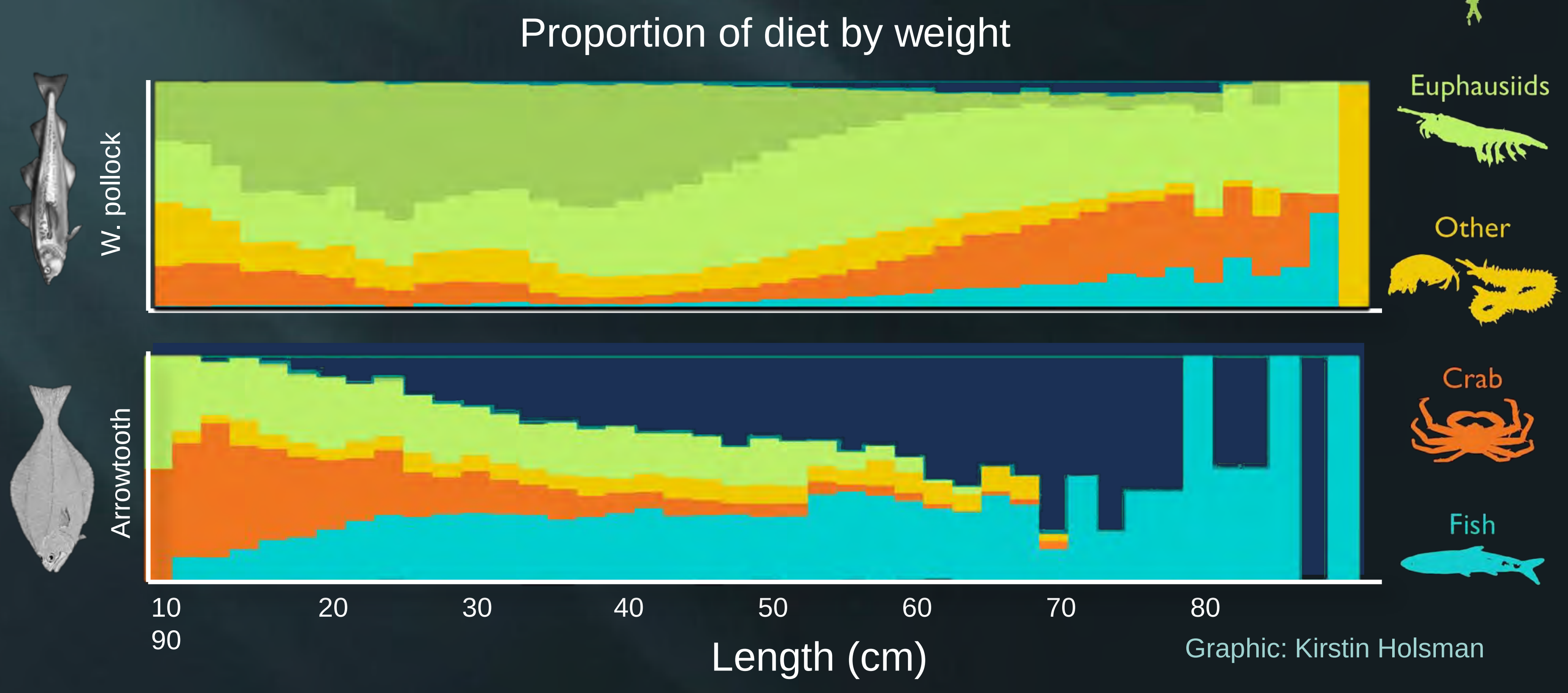
Evaluating management strategies for eastern Bering Sea walleye pollock (*Theragra chalcogramma*) in a changing environment

James N. Ianelli[1*], Anne B. Hollowed[1], Alan C. Haynie[1], Franz J. Mueter[2], and Nicholas A. Bond[3]

Time series of pollock recruitment (bars), based on stock assessment estimates and anomaly time series of environmental variables



Competition and Predation

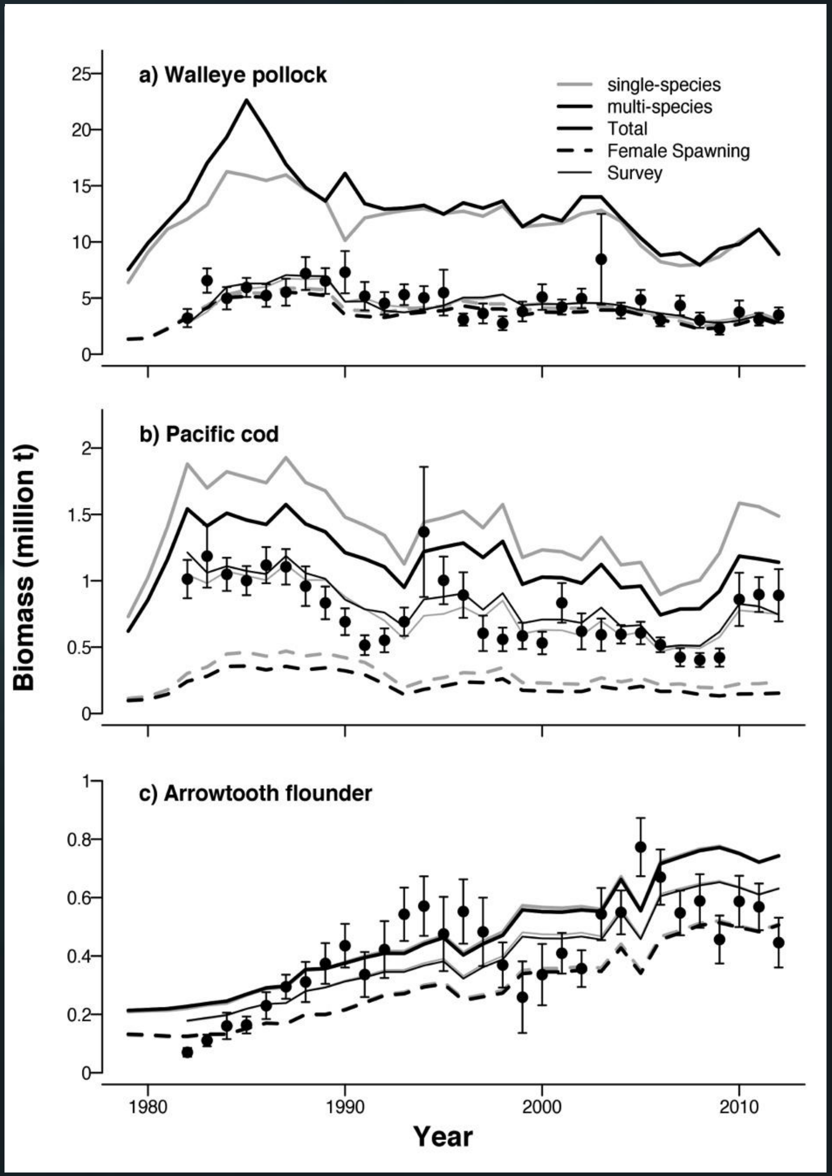


MSMt

Residual Natural Mortality

Predation Natural Mortality

$$Z_{ij,y} = M1_{ij} + M2_{ij,y} + F_{ij,y}$$



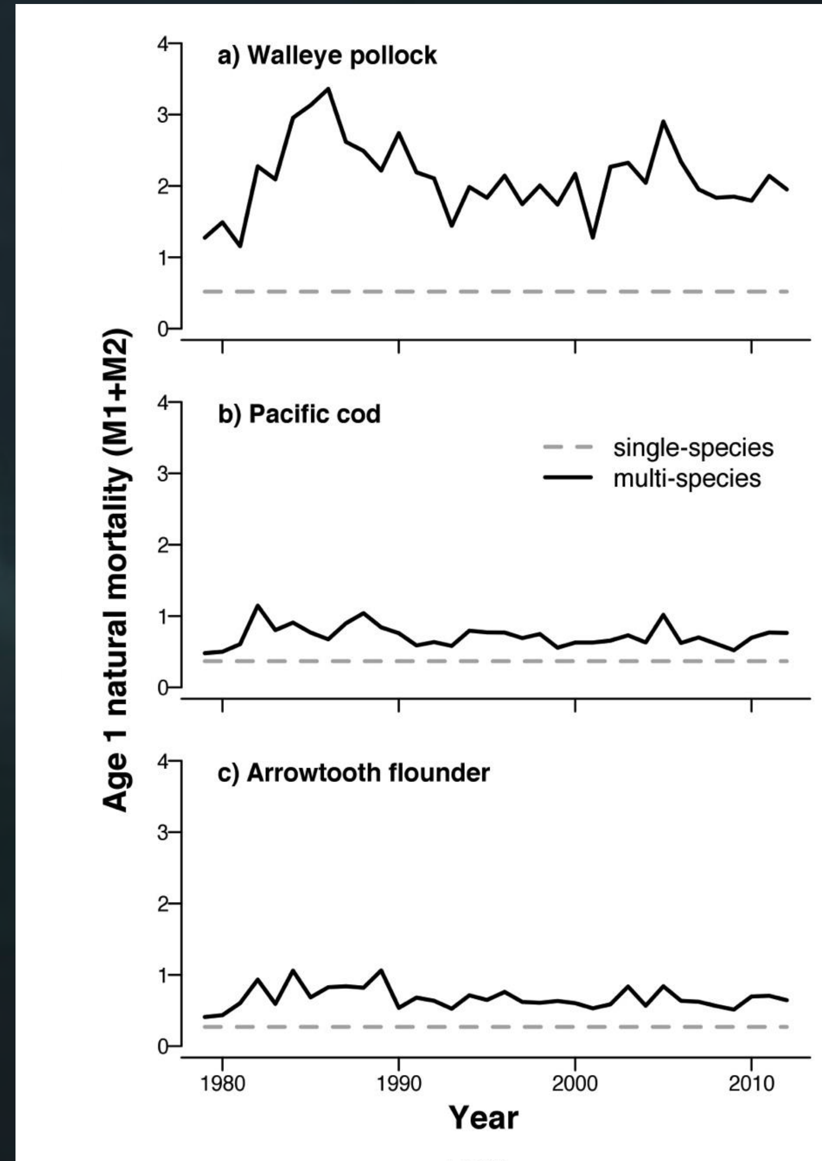
Graphic: Kirstin Holsman

MSMt

Residual Natural Mortality

Predation Natural Mortality

$$Z_{ij,y} = \mathrm{M1}_{ij} + \mathrm{M2}_{ij,y} + F_{ij,y}$$



Graphic: Kirstin Holsman

As a first cut…
recruitment deviations

As a first cut… recruitment deviations

More habitat will reduce density dependent constraints (linear relationship)

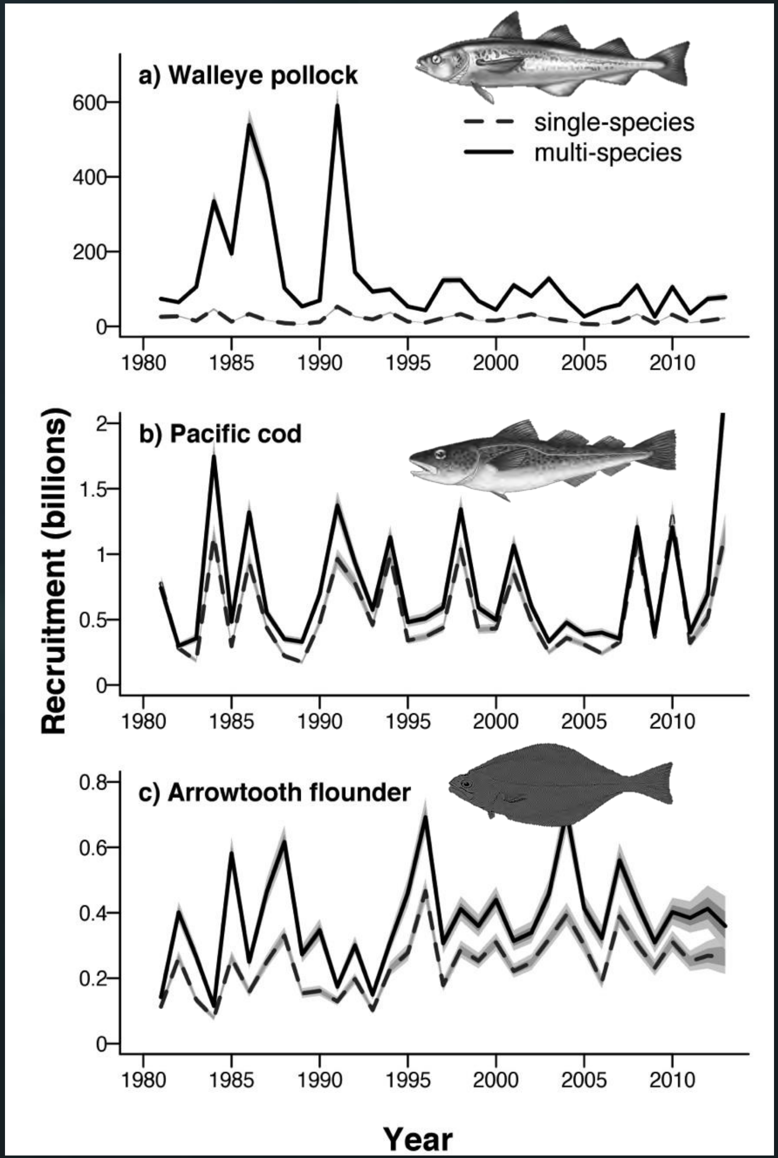
As a first cut…
recruitment deviations

More habitat will reduce density dependent constraints (linear relationship)

recruitment

$$log(R_t) = log(\alpha \cdot B_{t-1}) - \beta_1 \cdot B_{t-1}$$

productivity carrying capacity



Graphic: Kirstin Holsman

As a first cut… recruitment deviations

More habitat will reduce density dependent constraints (linear relationship)

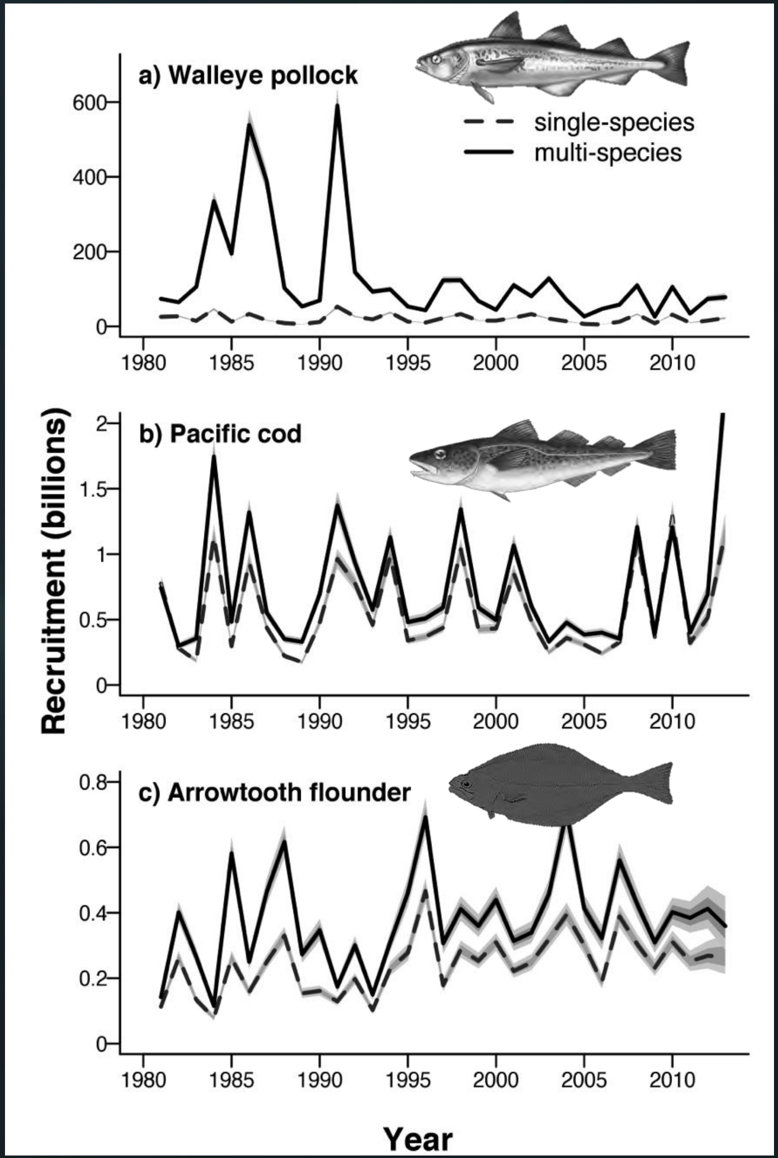
recruitment

$$log(R_t) = log(\alpha \cdot B_{t-1}) - \beta_1 \cdot B_{t-1} + \sum \beta_k \cdot X_{k,t} + \varepsilon,$$

productivity

carrying capacity

environmental effects on carrying capacity

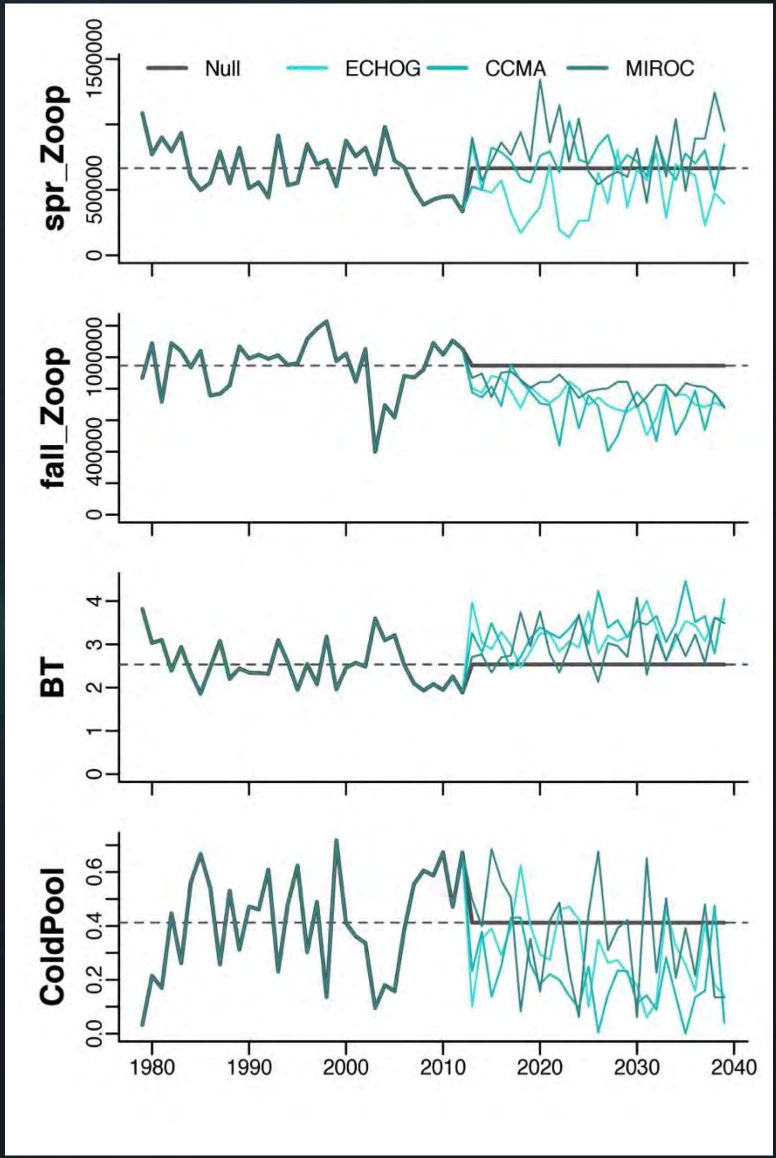


Graphic: Kirstin Holsman

As a first cut… recruitment deviations

More habitat will reduce density dependent constraints (linear relationship)

ROMS/ NPZ Indices



Graphic: Kirstin Holsman

recruitment

$$log(R_t) = log(\alpha \cdot B_{t-1}) - \beta_1 \cdot B_{t-1} + \sum \beta_k \cdot X_{k,t} + \varepsilon,$$

productivity

carrying capacity

environmental effects on carrying capacity

As a first cut… (retrospective)

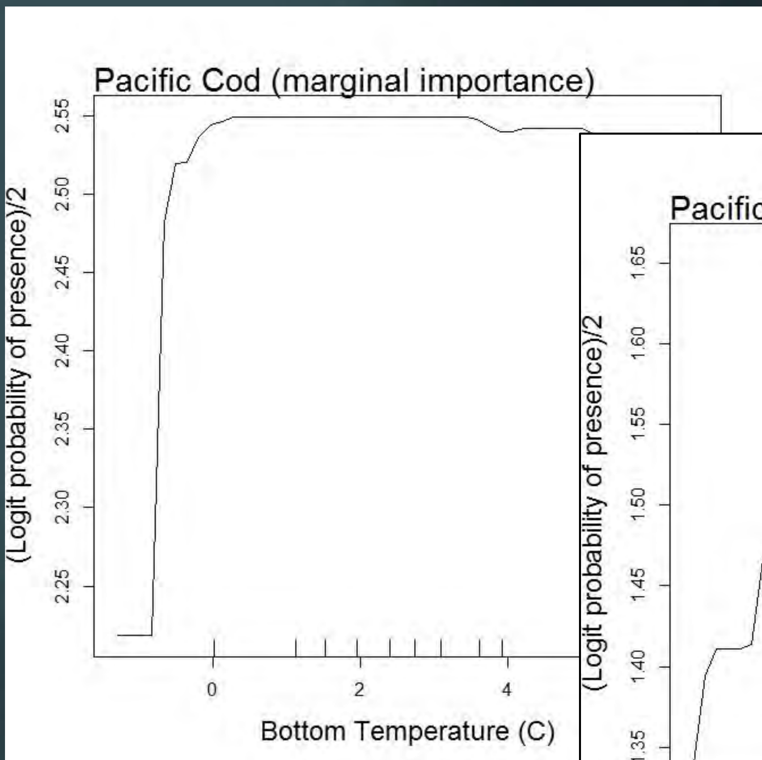
(1) Applied random forest output to determine threshold tolerances

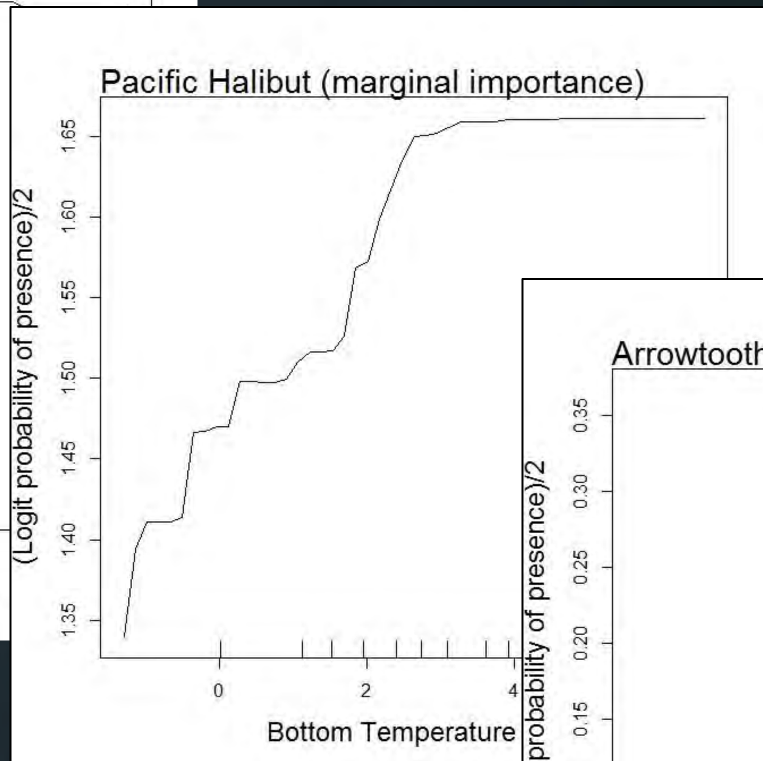
(2) Used ROMS to determine environmental parameters and copepod and euphasusiid abundance within a spatial extent that matched biological data

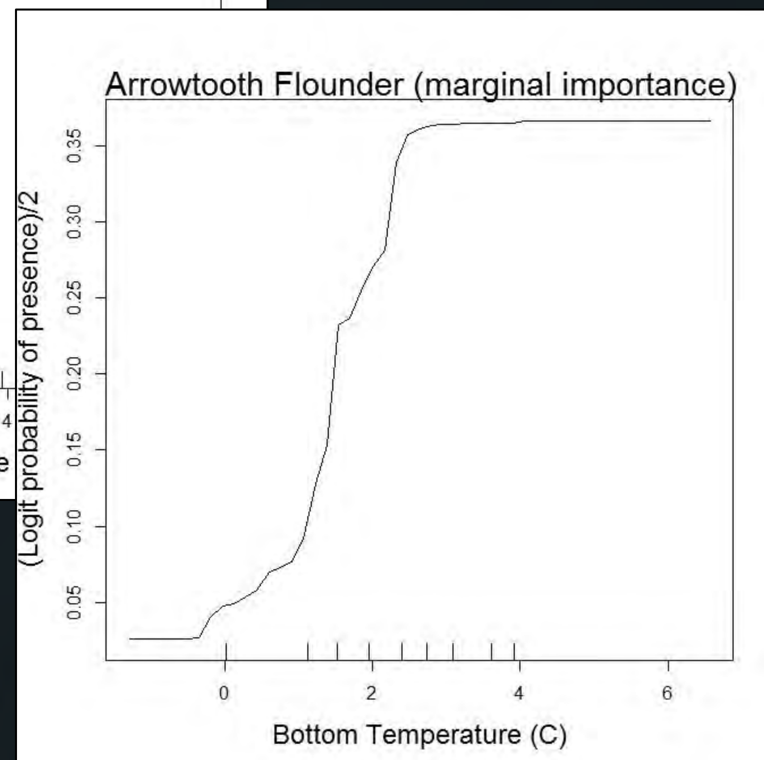
(3) Developed output for:
- (i) overlap of pollock and arrowtooth
- (ii) copepod abundance
- (iii) environmental thresholds

(4) Applied covariates to explore whether this explains recruitment deviates

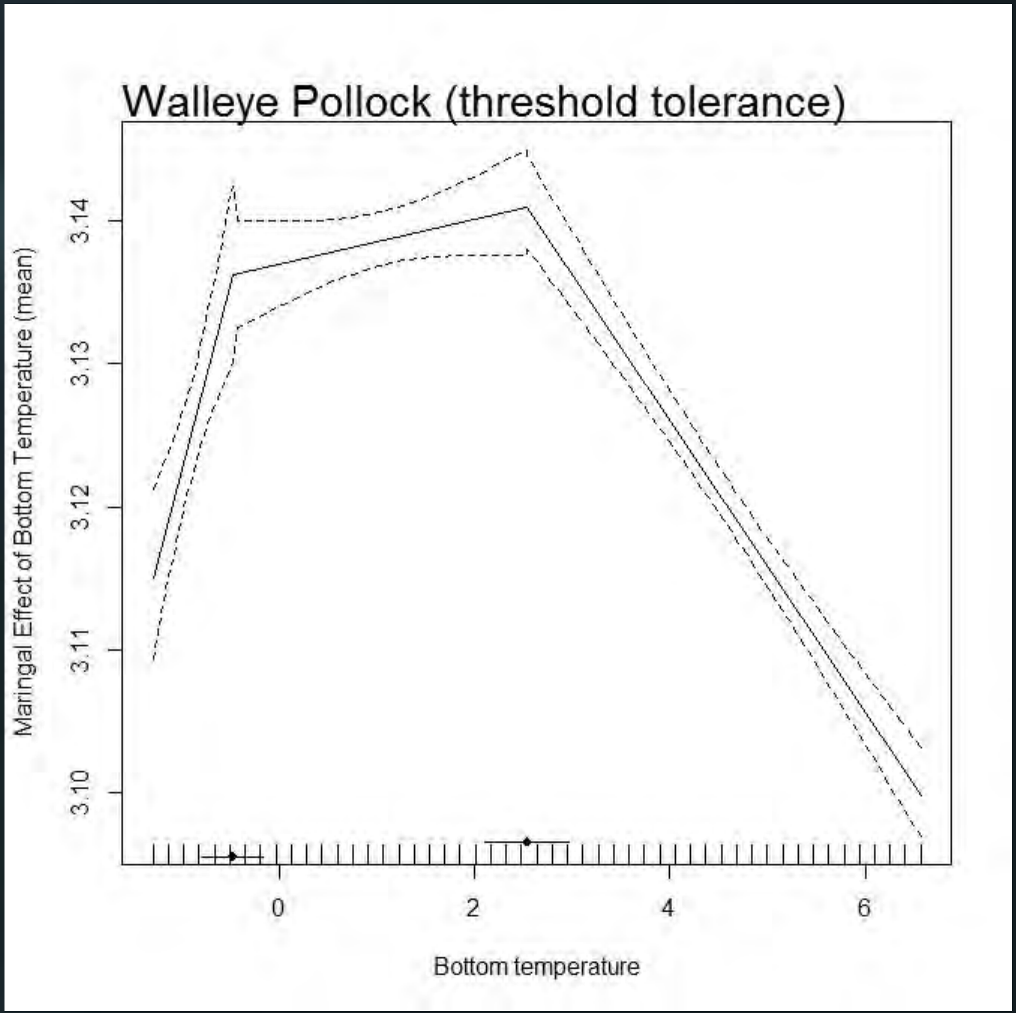
Partial Dependence Plots



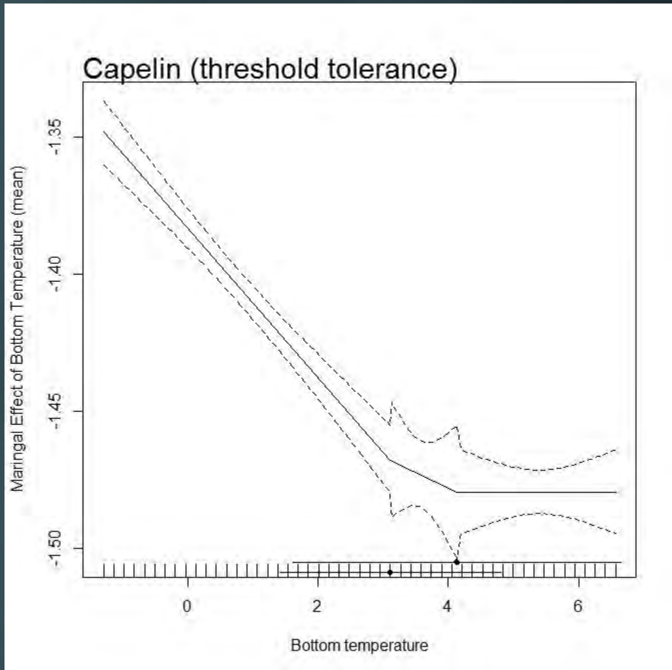


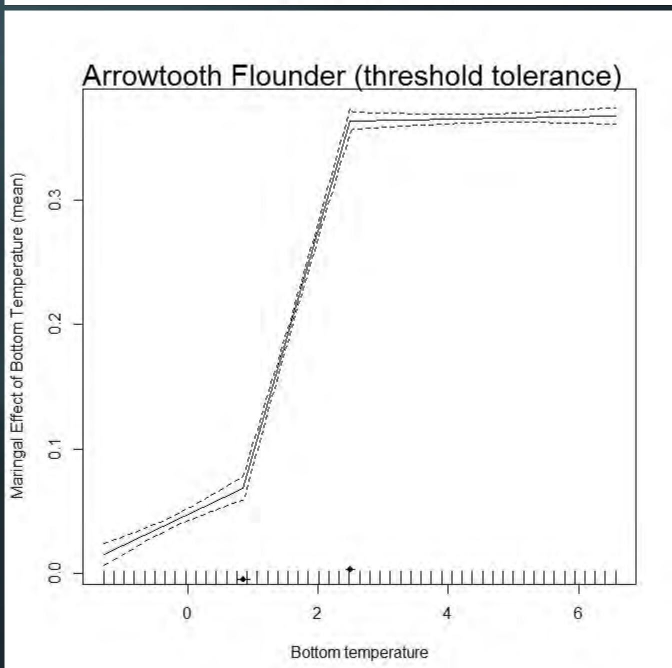


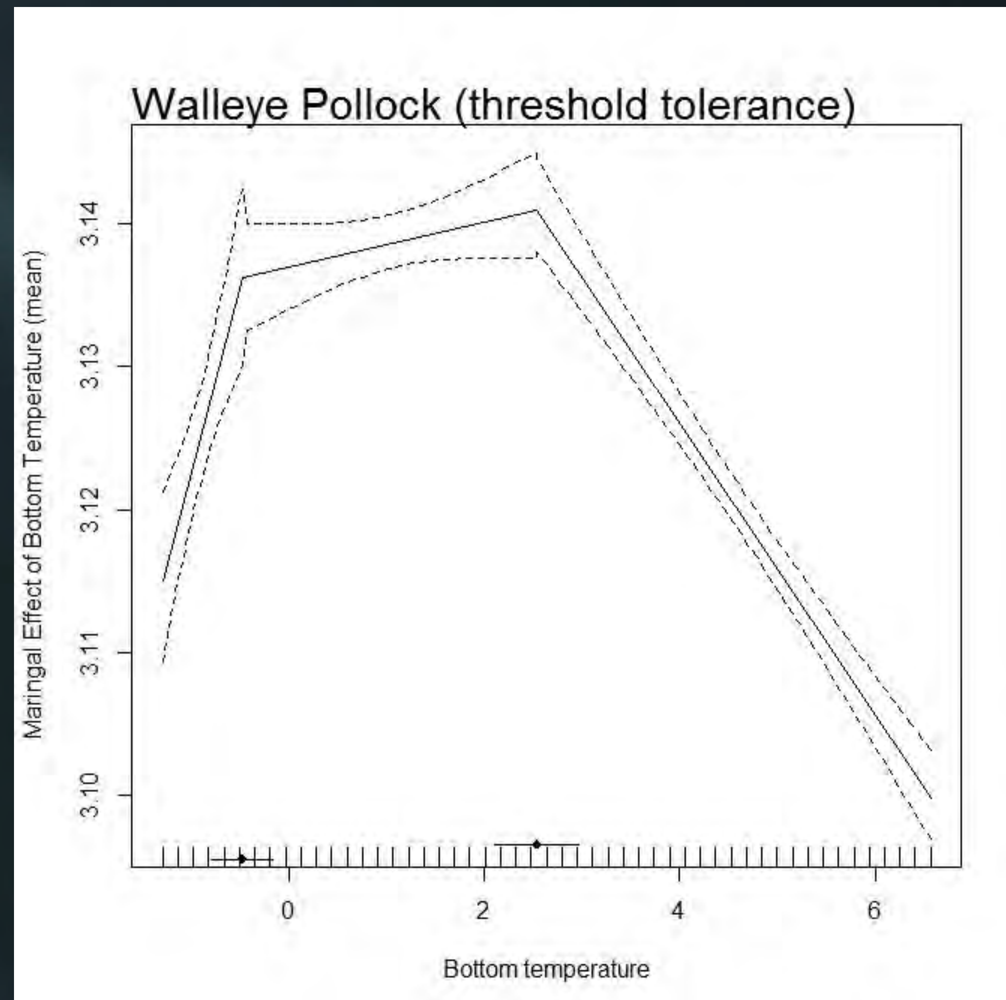
Marginal importance is determined given a regression function (e.g. species presence) dependent on multiple variables



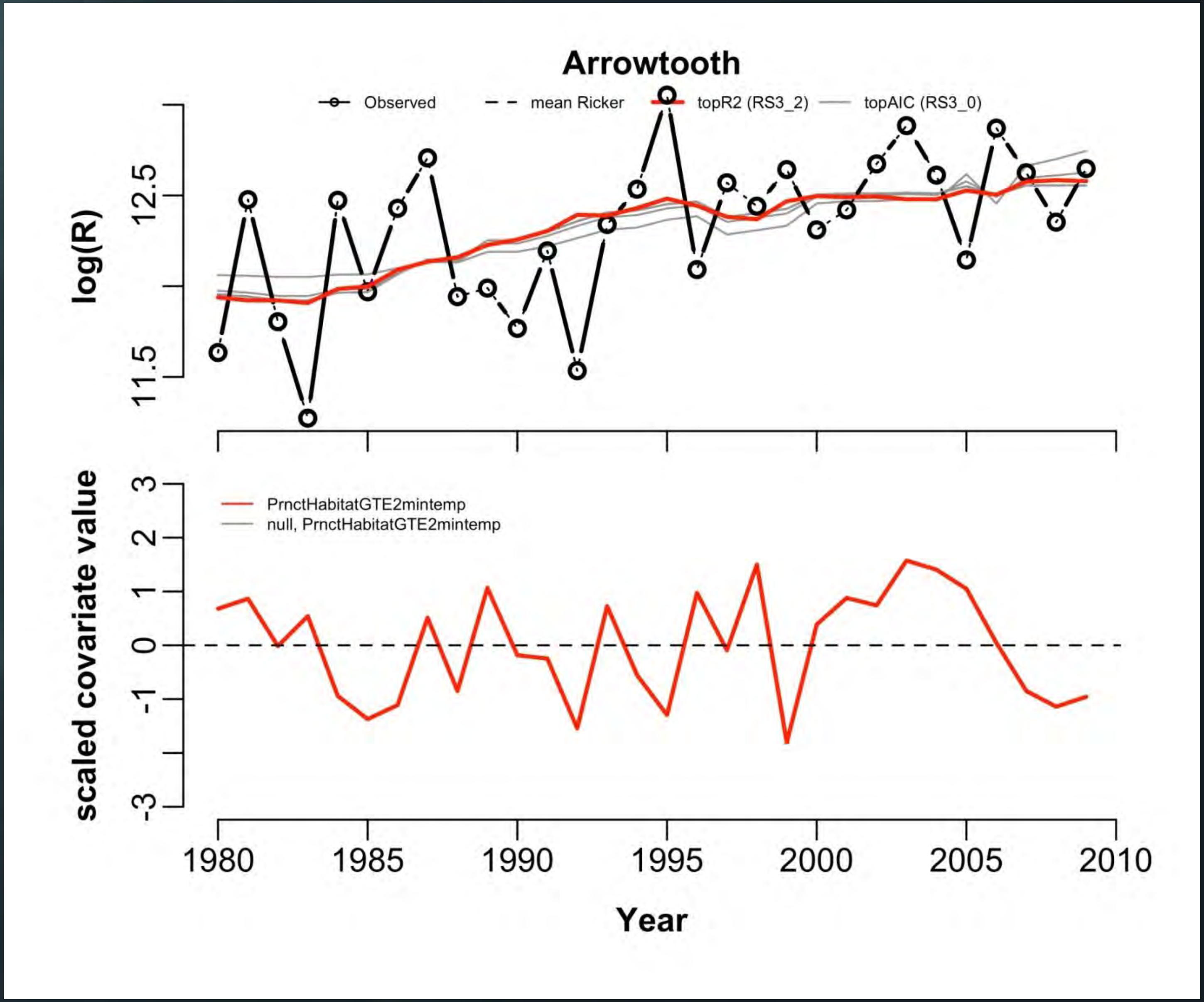
Used a linear regression model with bootstrapping to determine breakpoints where the linear relation changes (distinct segments)


Capelin (threshold tolerance)
Maringal Effect of Bottom Temperature (mean)
-1.35
-1.40
-1.45
-1.50
0
2
4
6
Bottom temperature

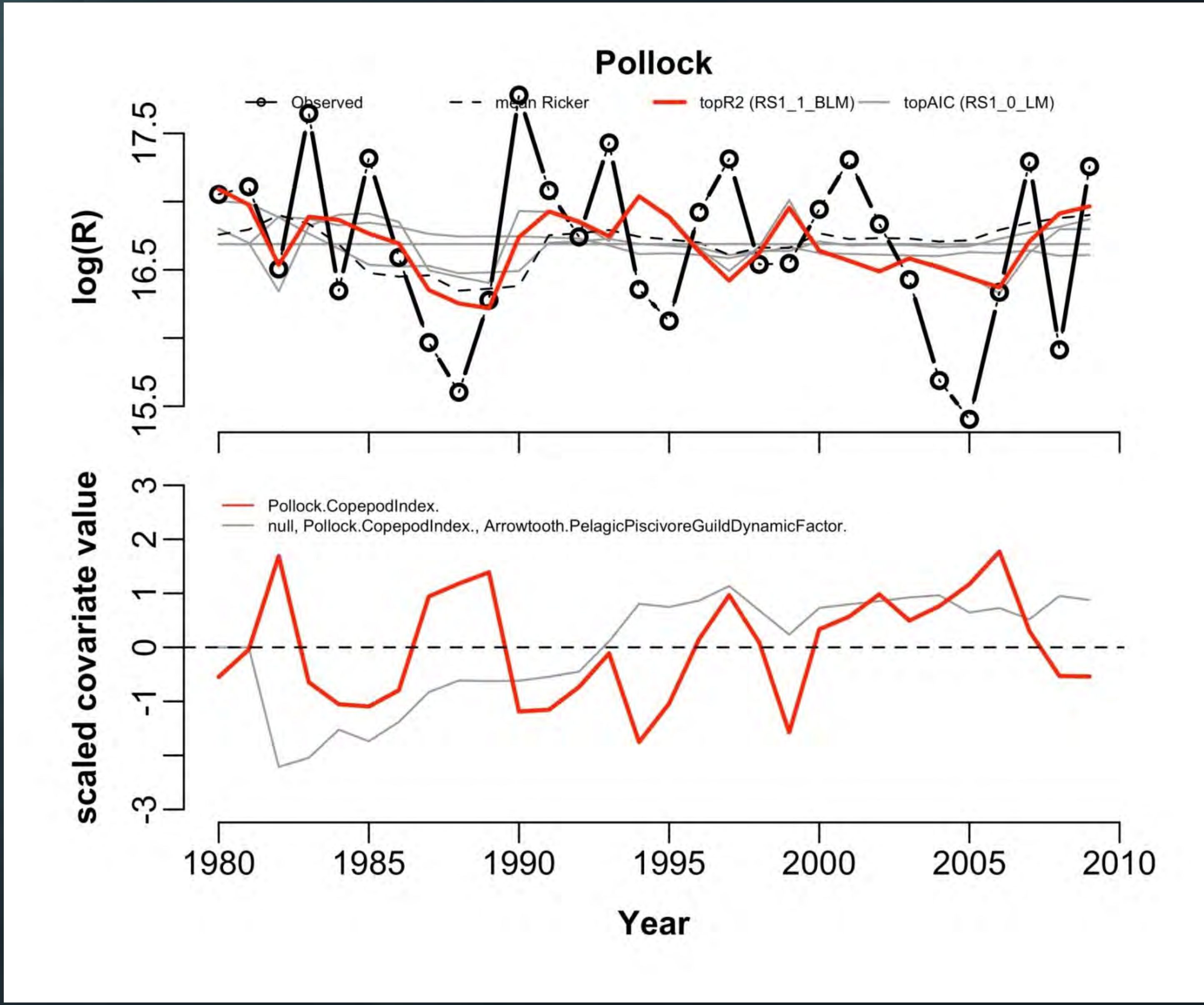

Arrowtooth Flounder (threshold tolerance)
Maringal Effect of Bottom Temperature (mean)
0.0
0.1
0.2
0.3
0
2
4
6
Bottom temperature


Walleye Pollock (threshold tolerance)
Maringal Effect of Bottom Temperature (mean)
3.10
3.11
3.12
3.13
3.14
0
2
4
6
Bottom temperature

Covariate: Percent habitat with temperature in tolerance range (>2°C)



Covariate: Relative availability of copepods within juvenile pollock habitat



Next…

forward projection given ROMS estimates of ecoregion volume

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J. Reum, M. Hunsicker,
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S. Zador, T. Buckley,
S. Parker-Stetter, P. Livingston
J. Hoff, B. McConnaughey

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