Do marine species follow shifting ocean temperatures?

Insights from bottom trawl surveys in North America

Malin Pinsky

Mike Fogarty, Boris Worm, Jorge Sarmiento, Simon Levin

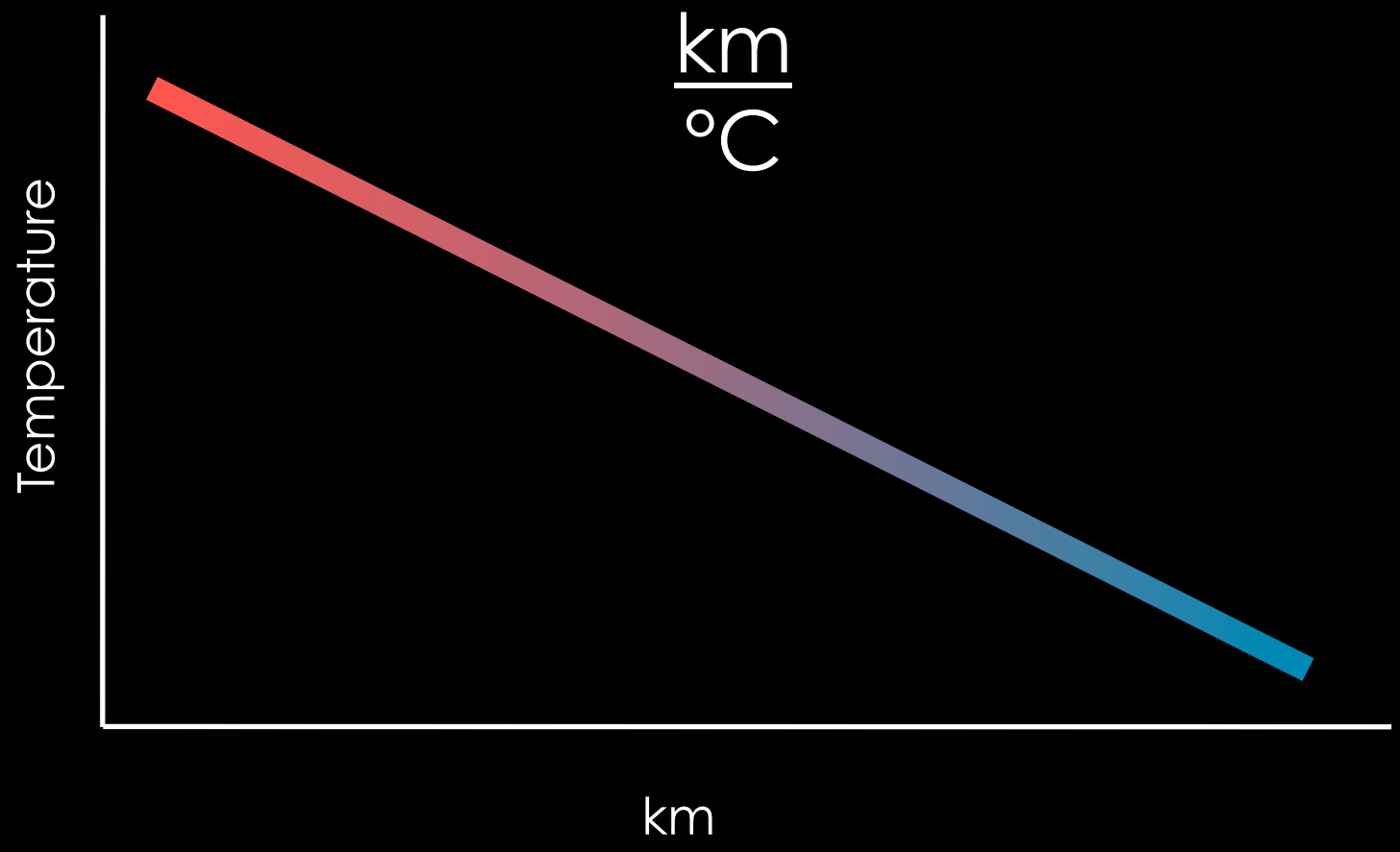
PRINCETON UNIVERSITY

NOAA

DALHOUSIE UNIVERSITY

Smith Fellows

Climate velocity



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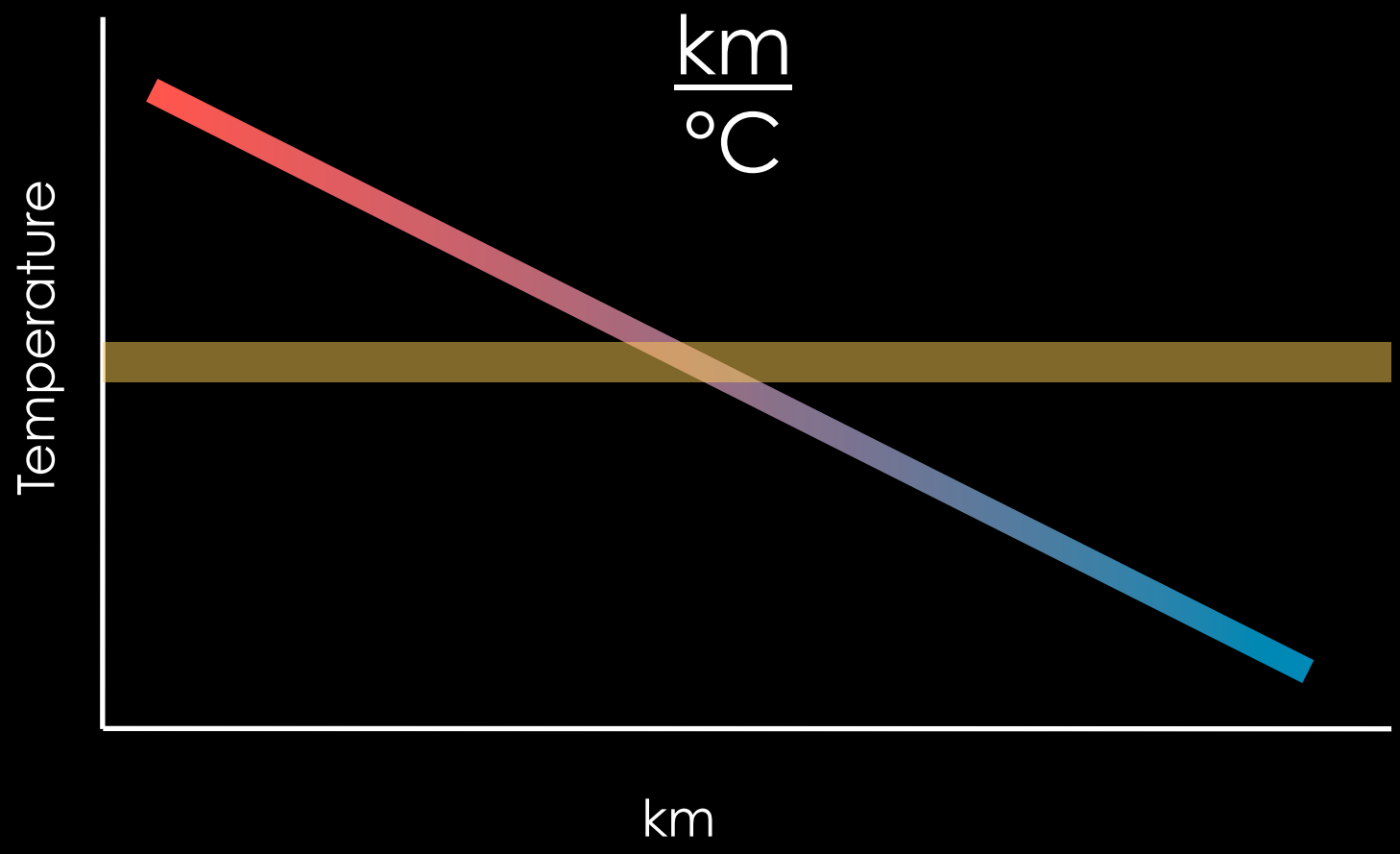

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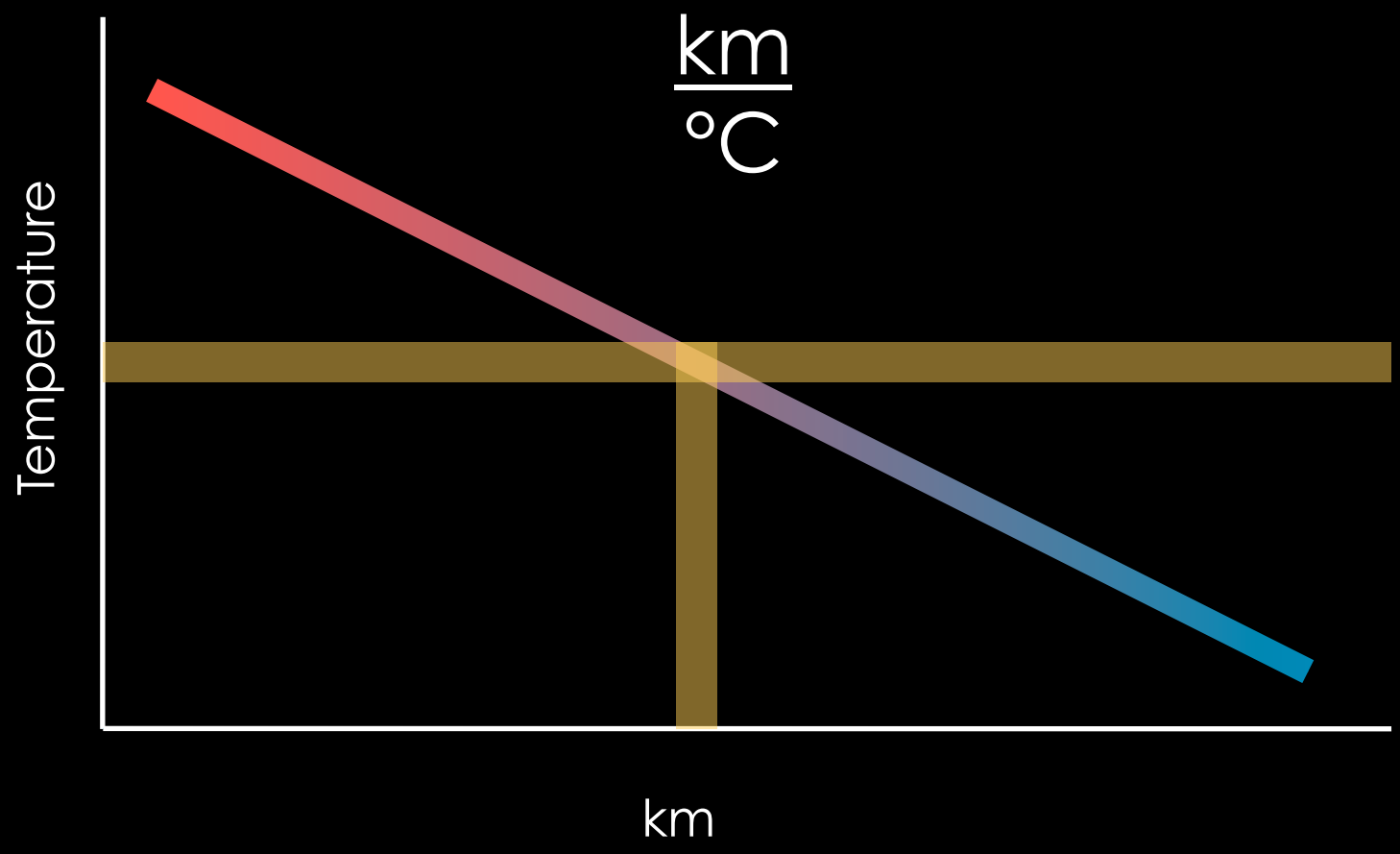

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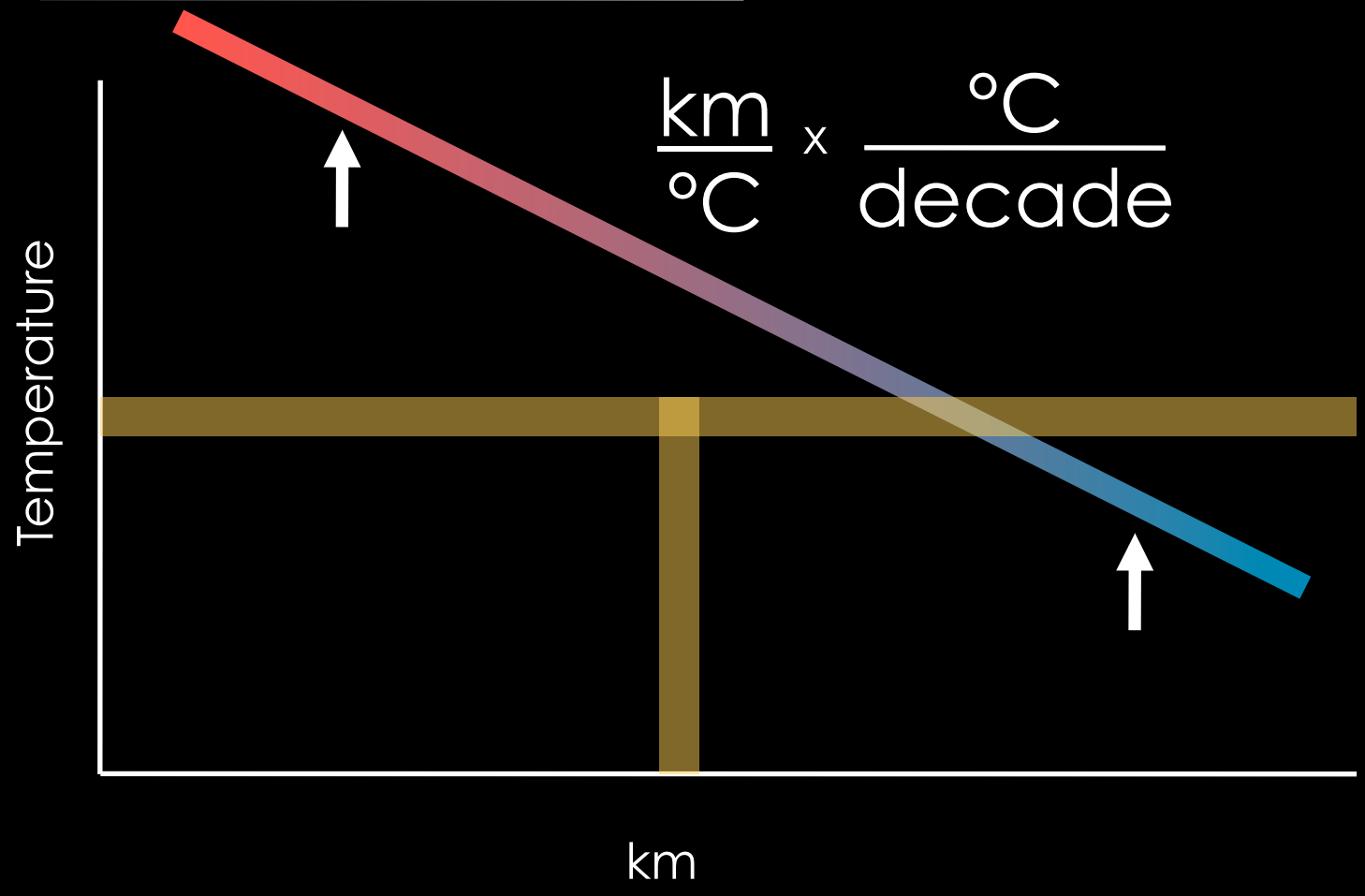
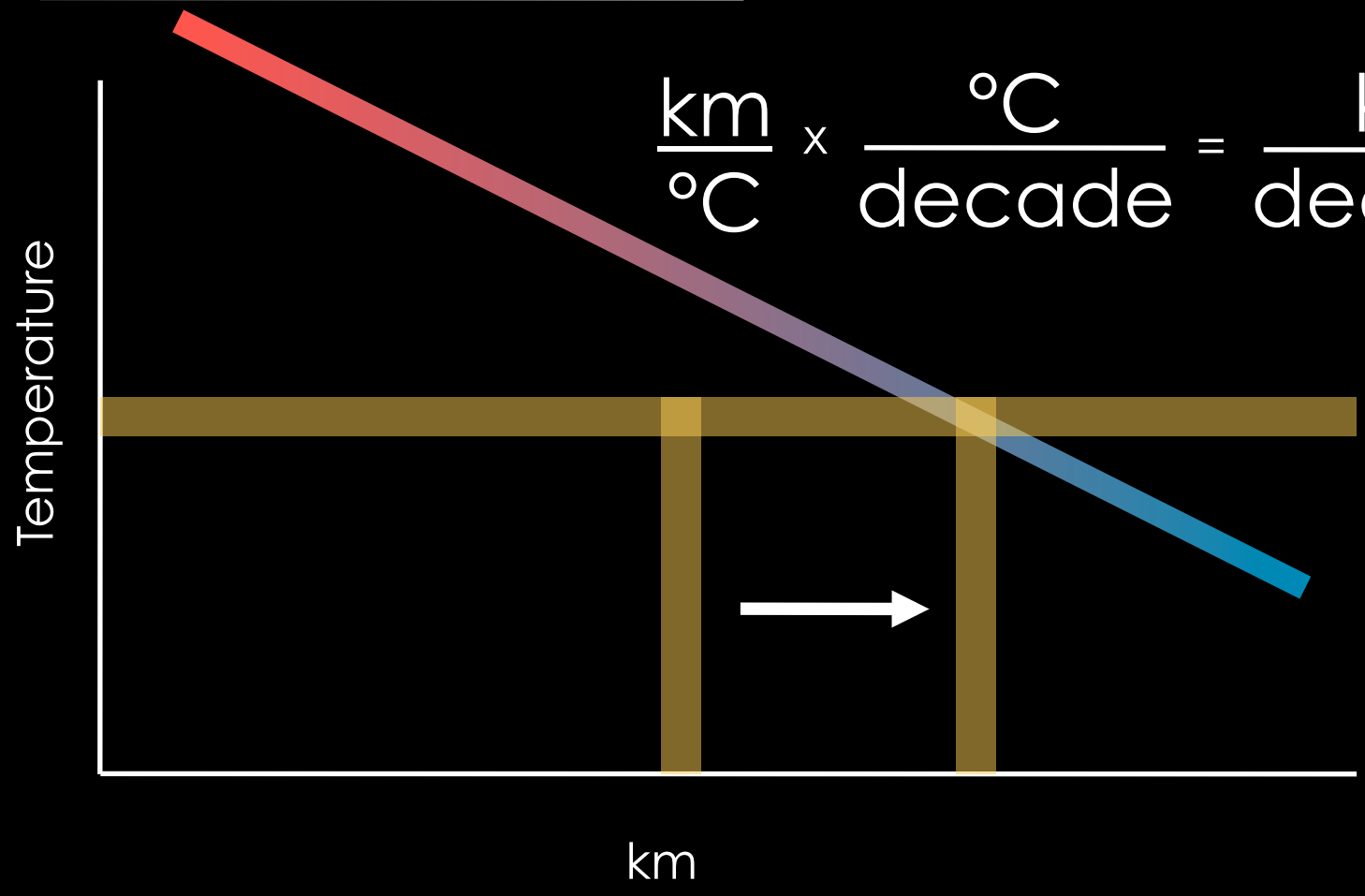


Climate velocity

$$\frac{\text{km}}{°\text{C}} \times \frac{°\text{C}}{\text{decade}} = \frac{\text{km}}{\text{decade}}$$



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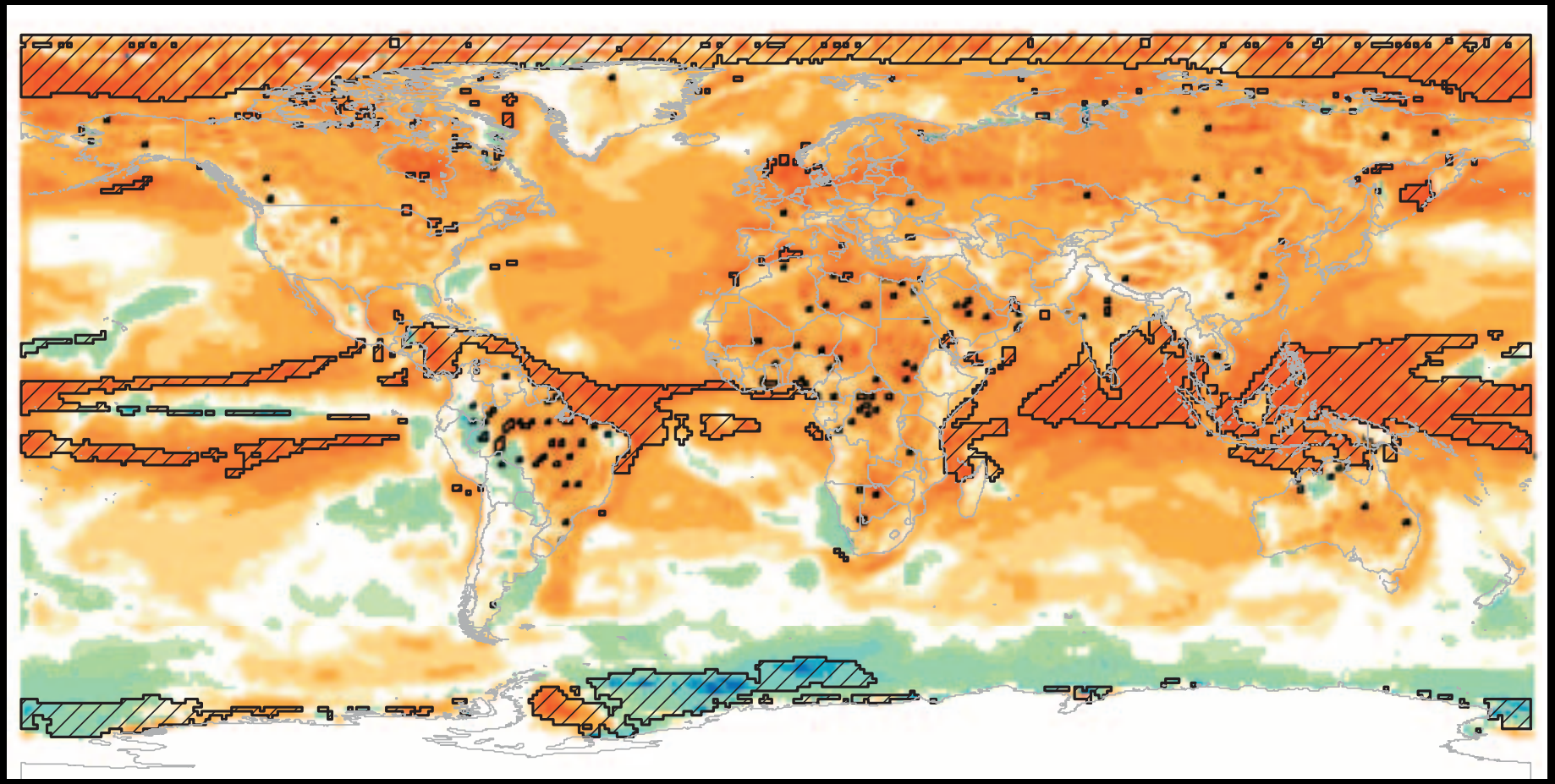
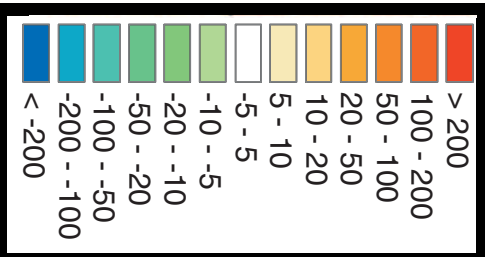
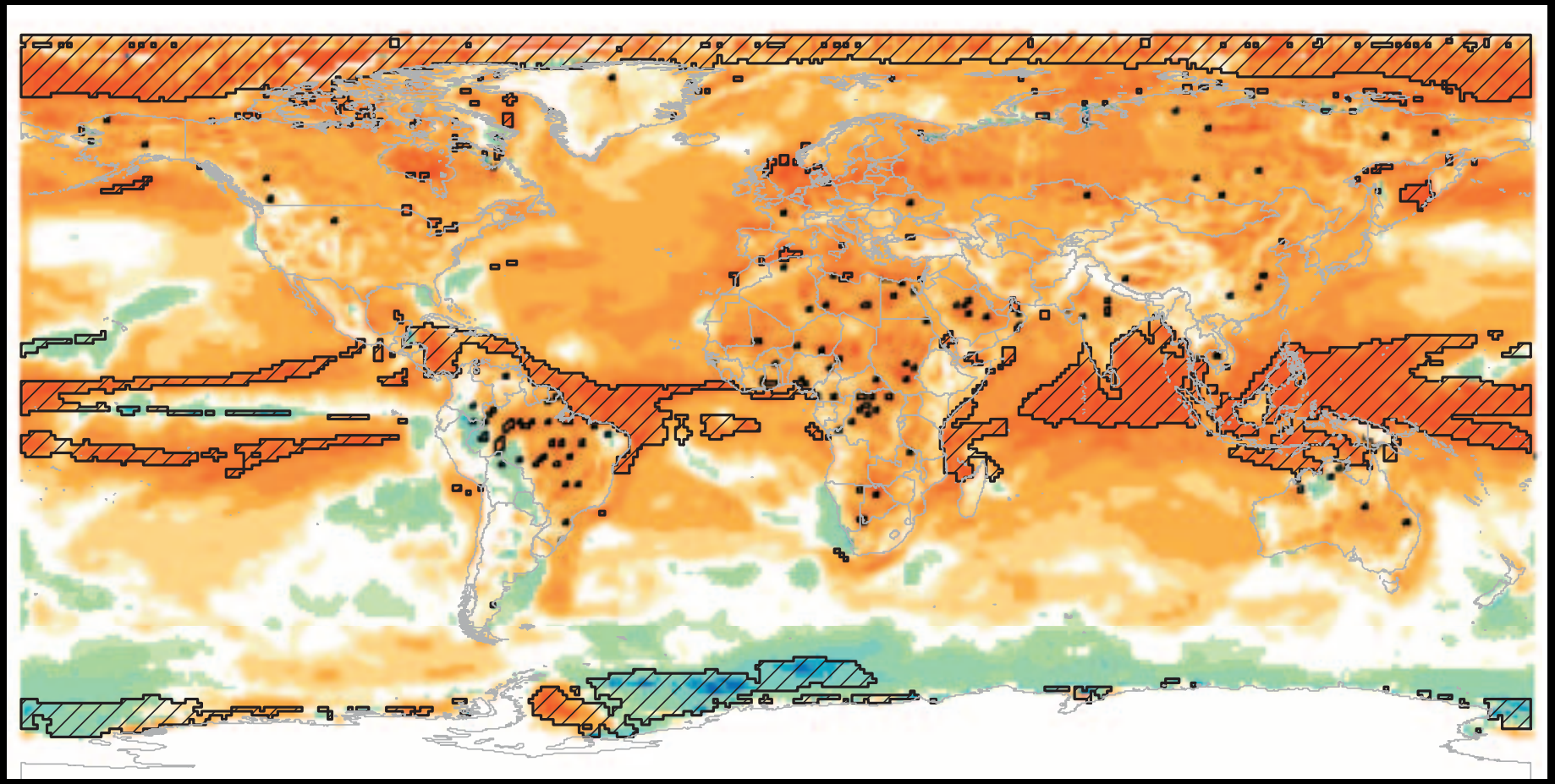


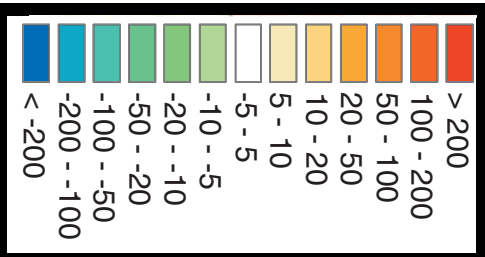


Velocity (km/decade)
1960-2009

Burrows et al. 2011 *Science*

Will species track climate velocity?





Velocity (km/decade)
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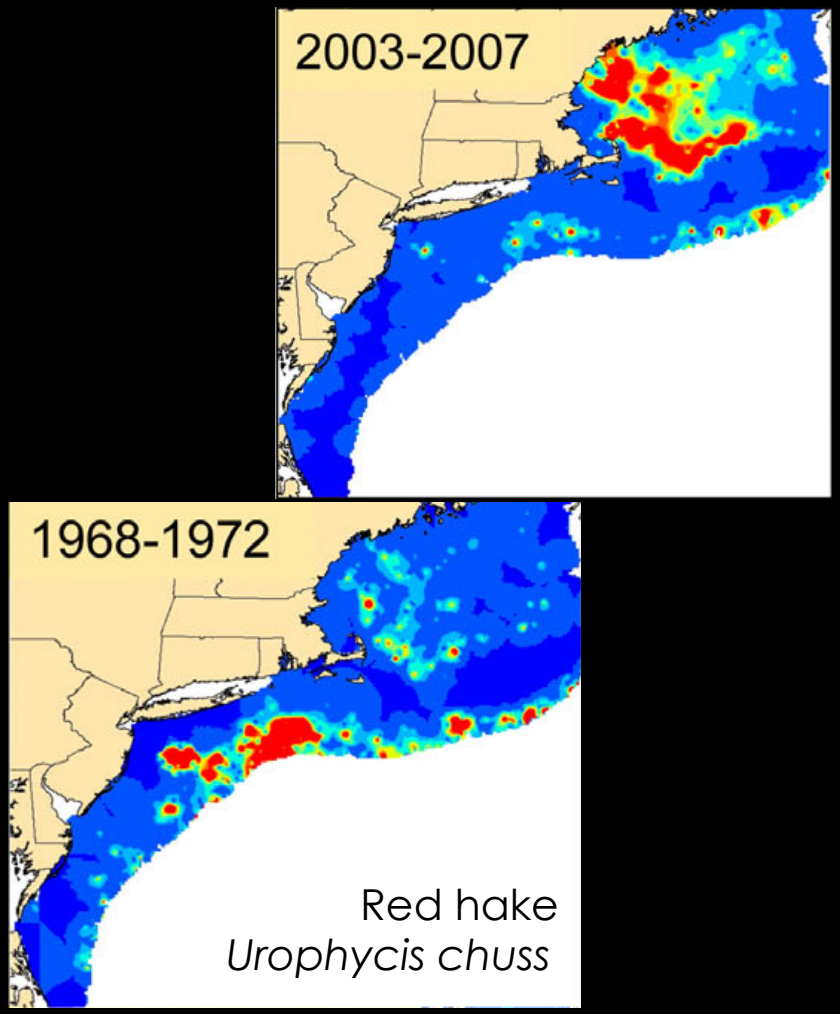
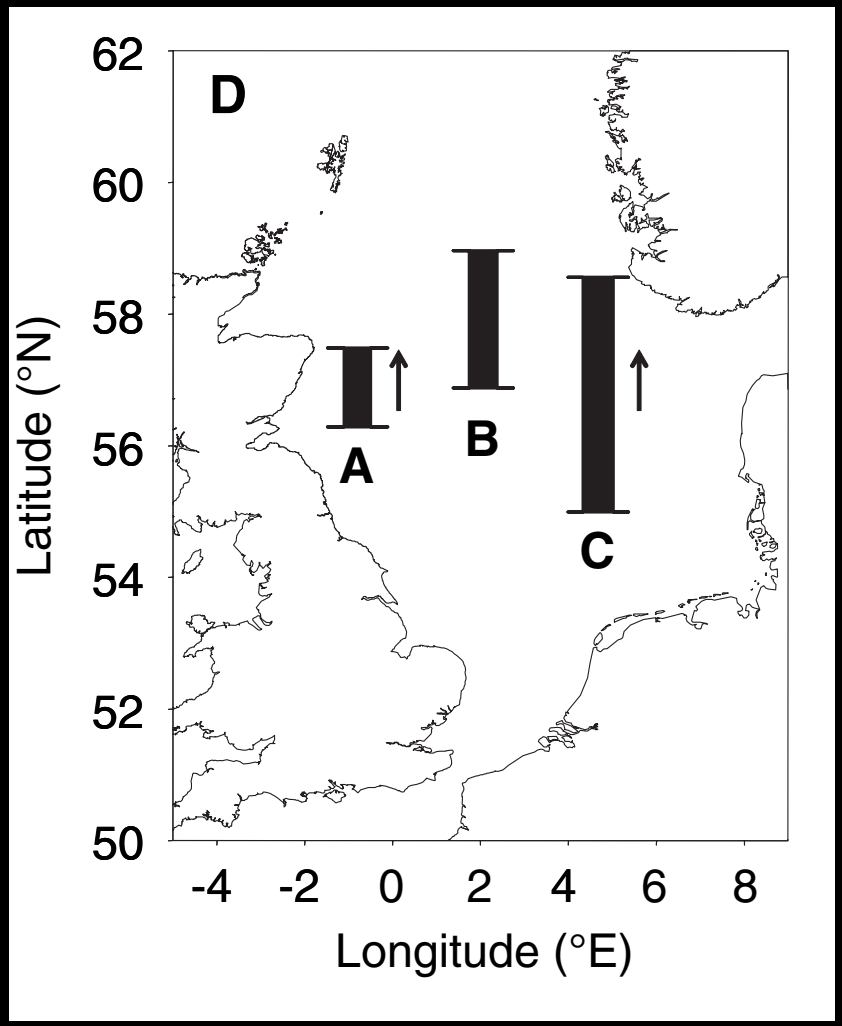
Burrows et al. 2011 *Science*

Range shifts around the world

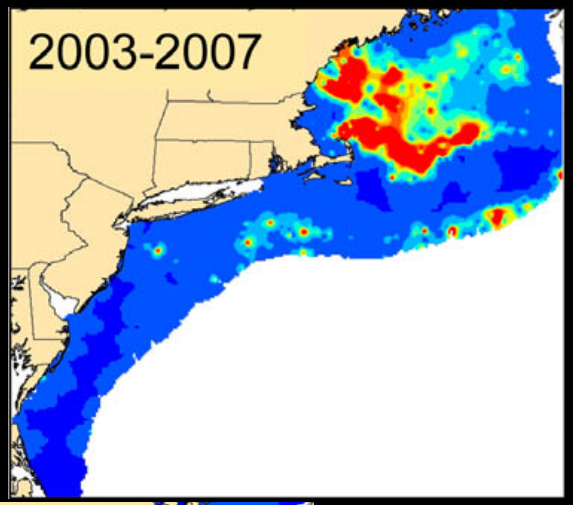


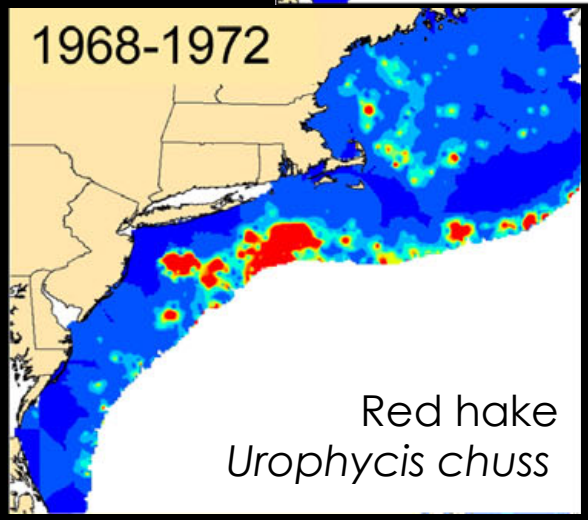


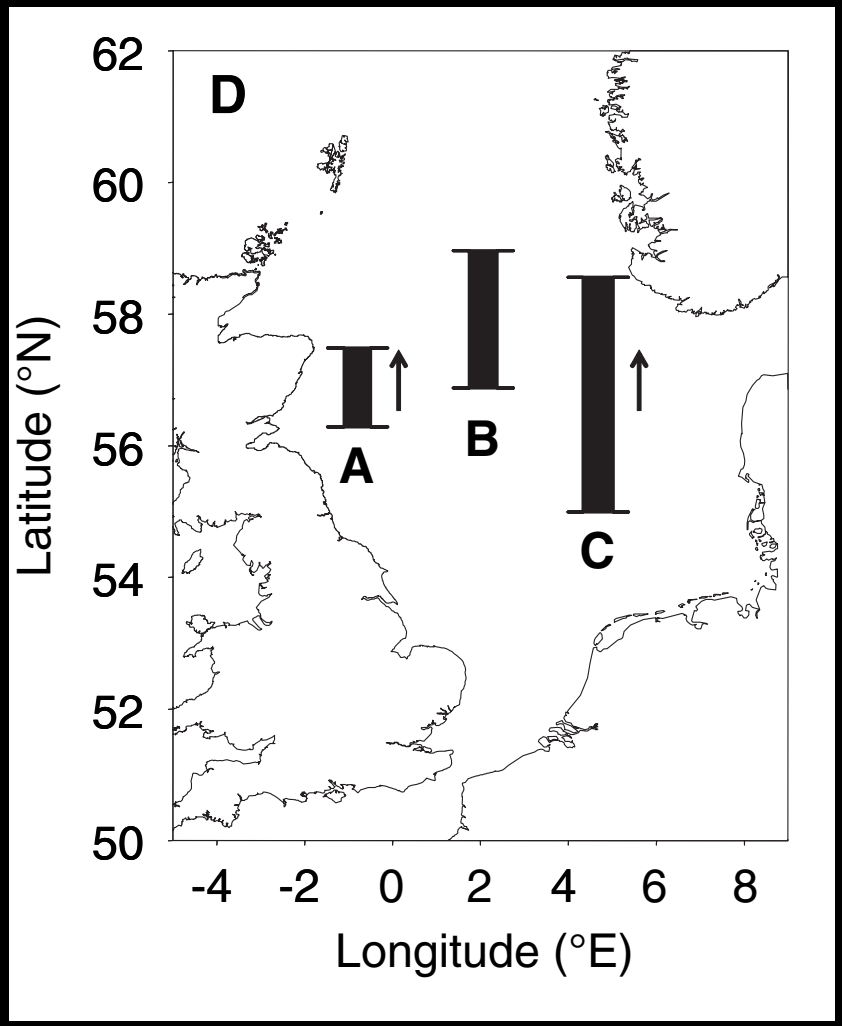
Nye et al. 2009 *Marine Ecology Progress Series*

Perry et al. 2005 *Science*

Idiosyncratic and unpredictable?







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The complexity of a shifting range

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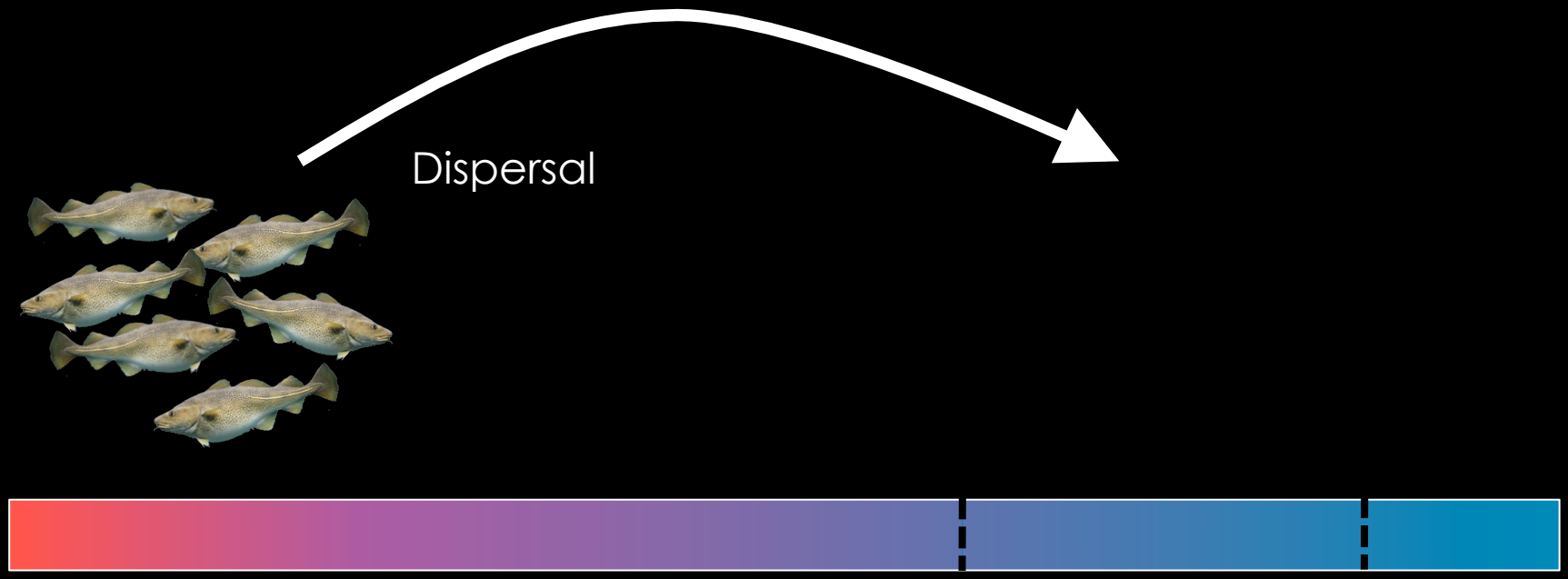

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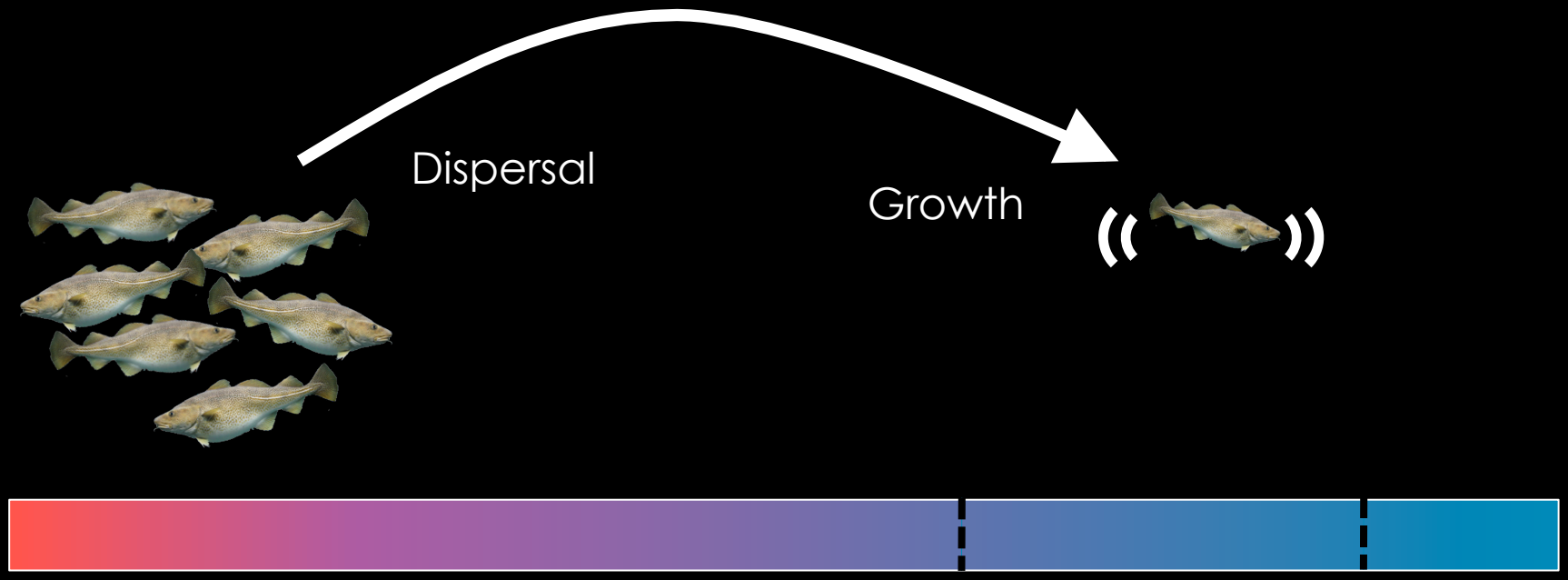

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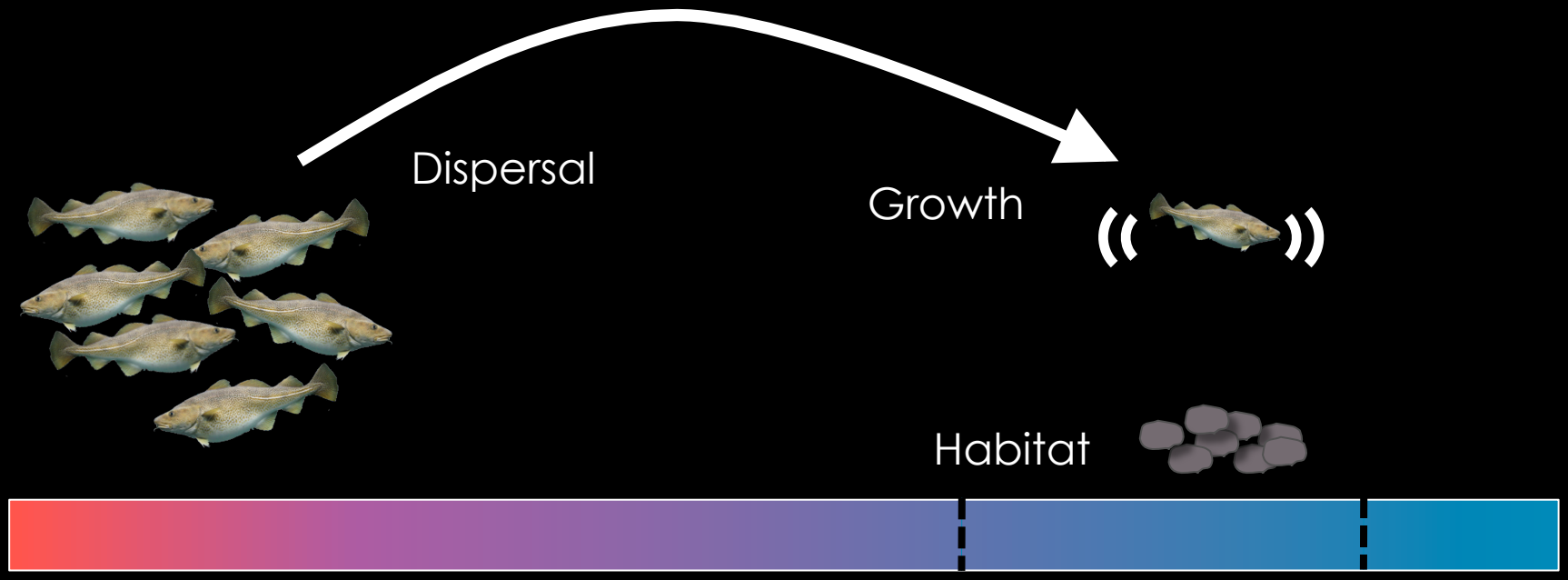

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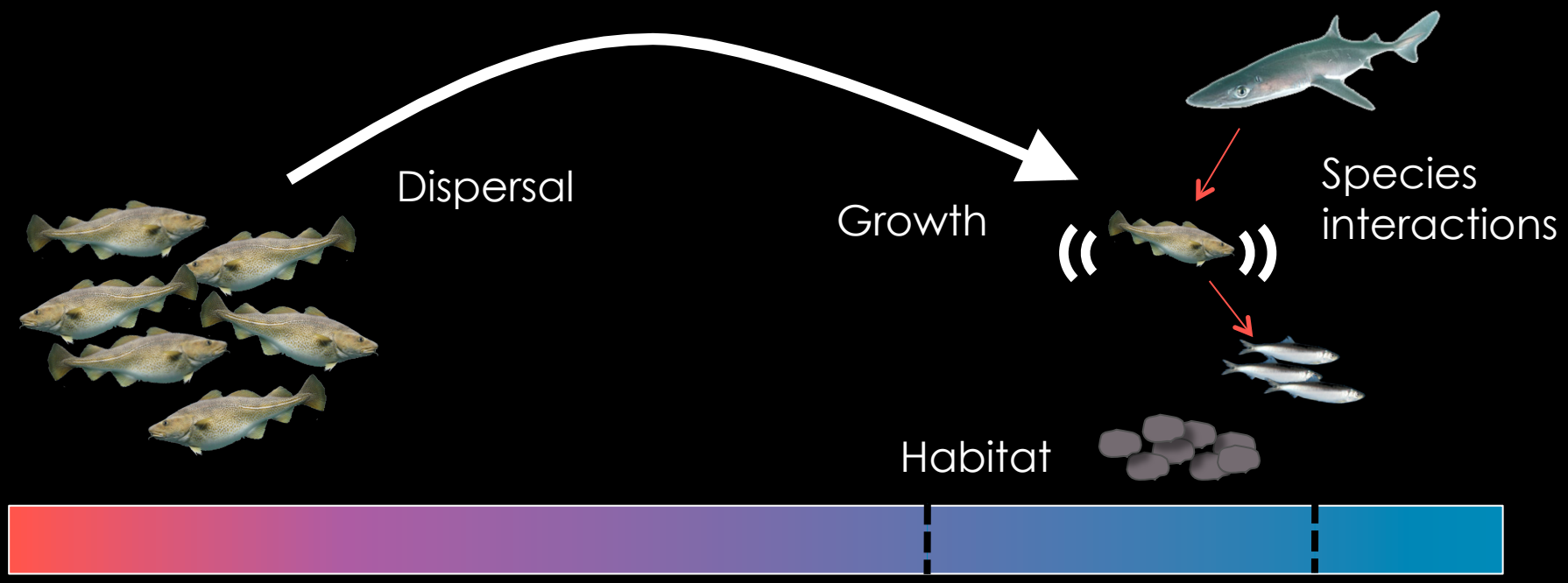

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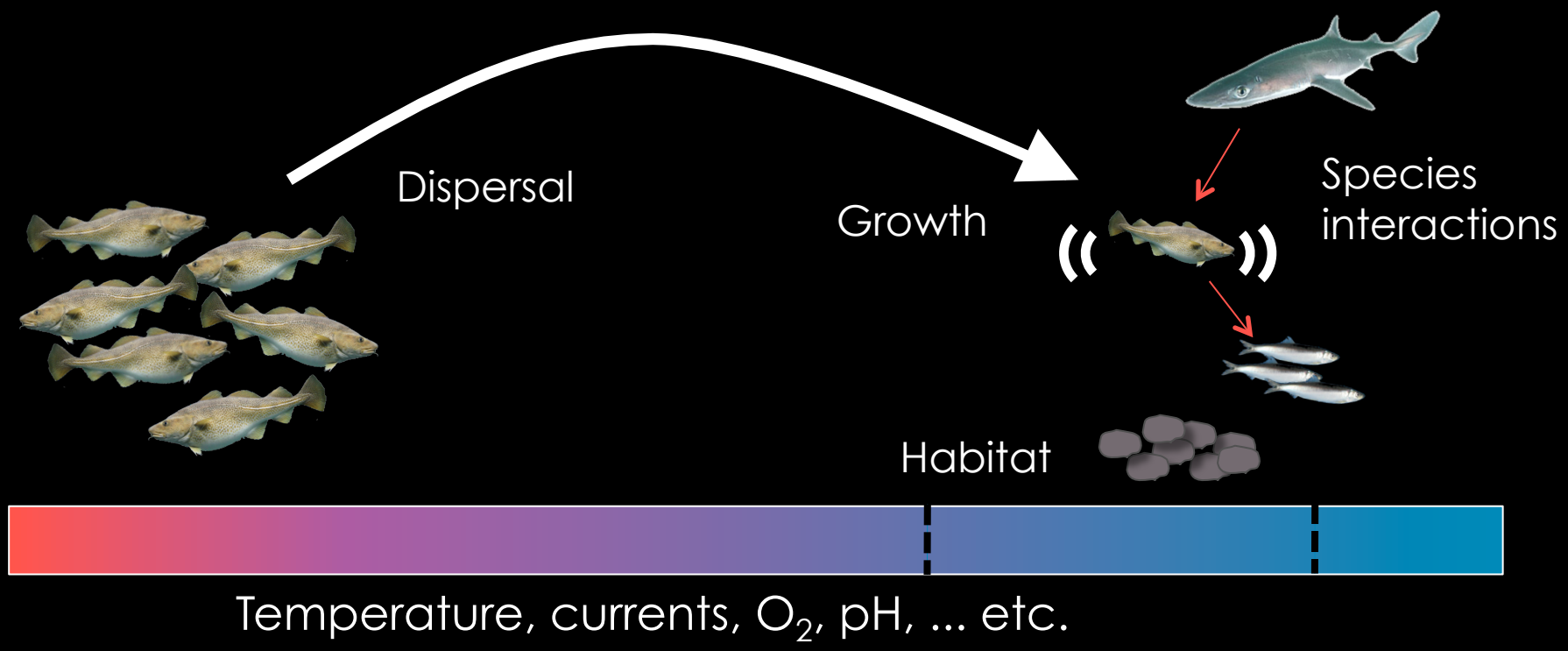

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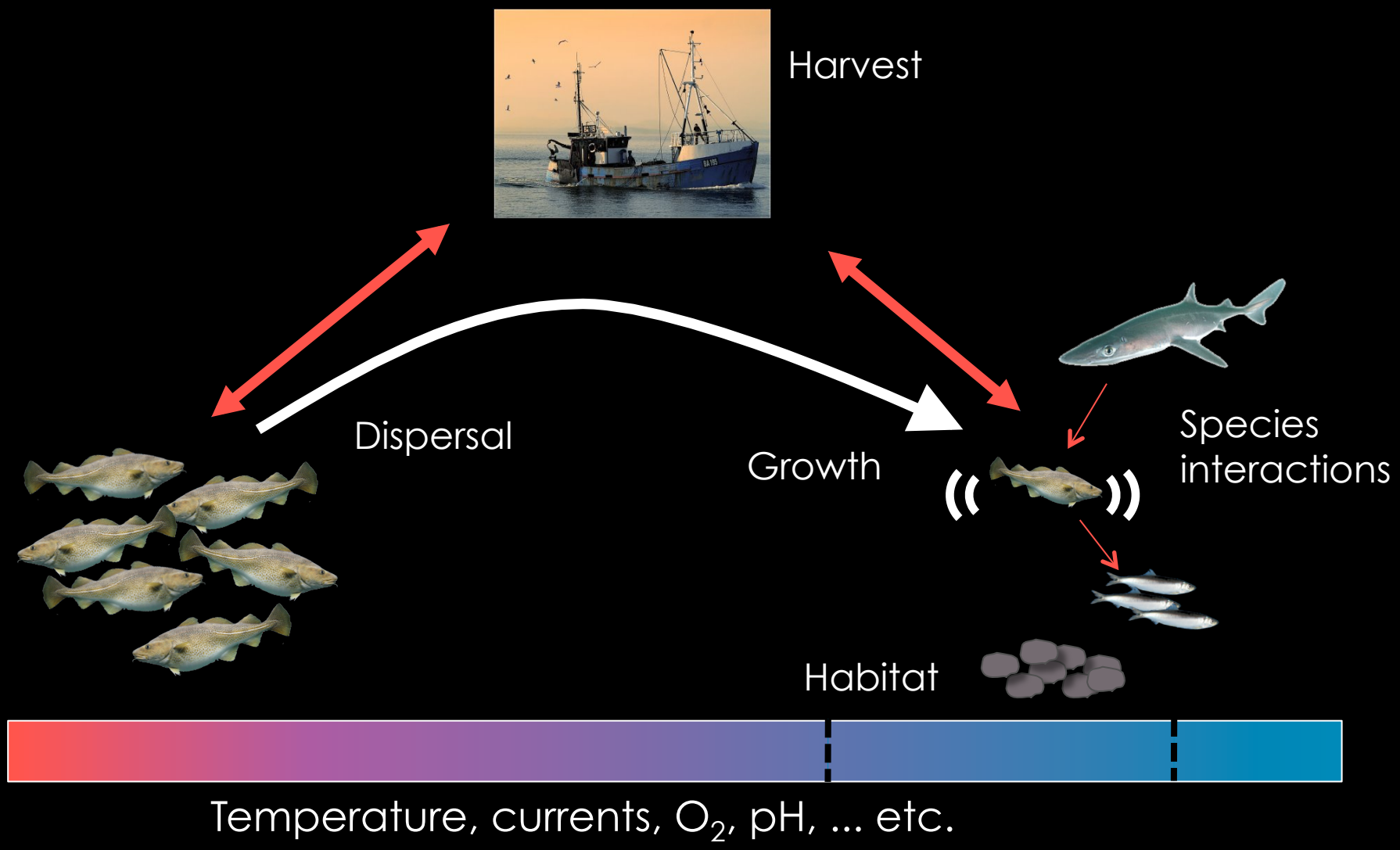

Outline

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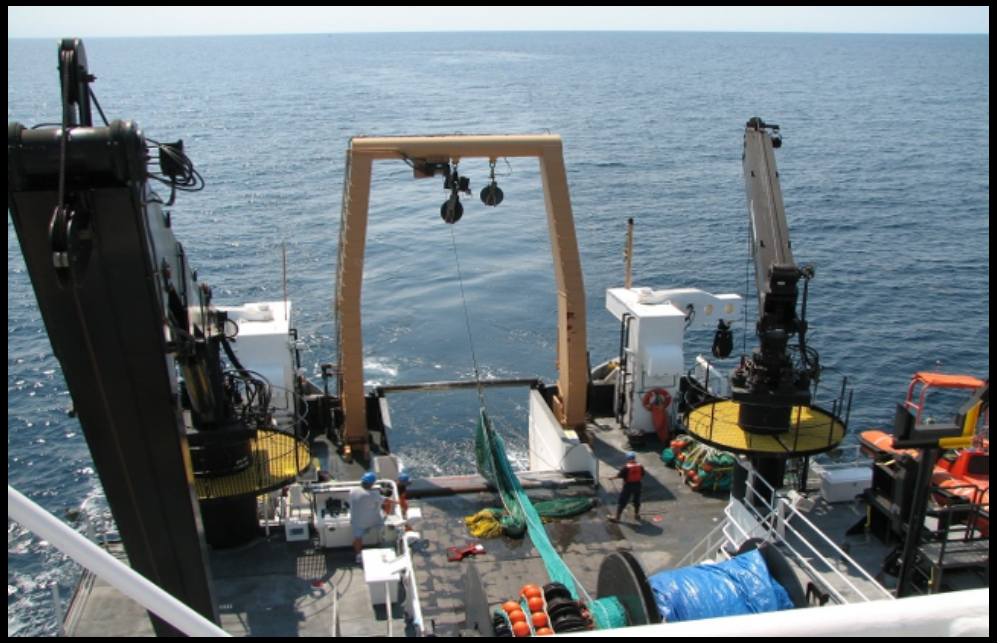
Species distribution data

Bottom trawl surveys

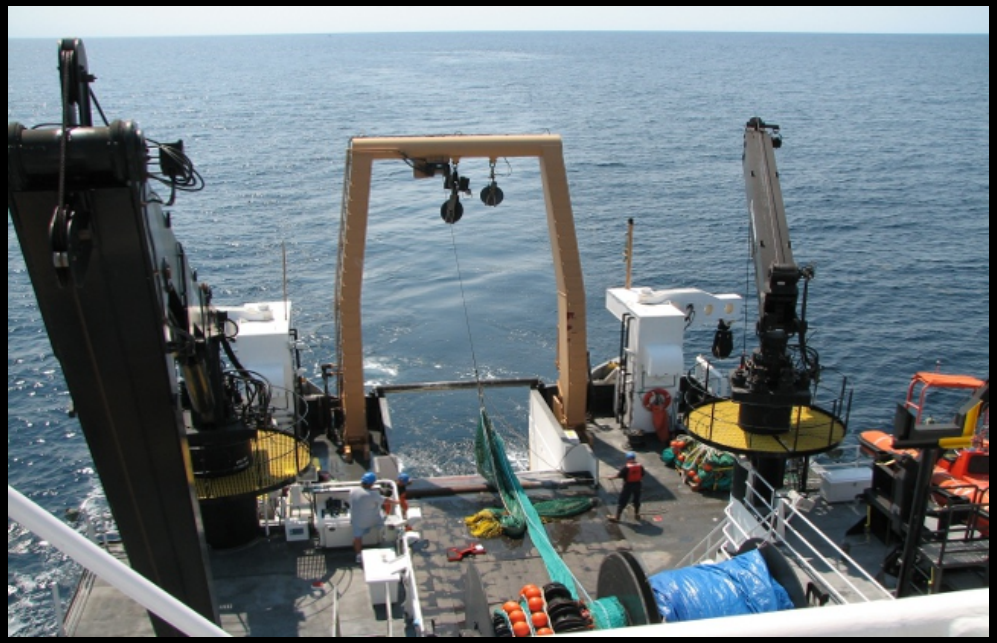
- 17-41 years long



Species distribution data

Bottom trawl surveys

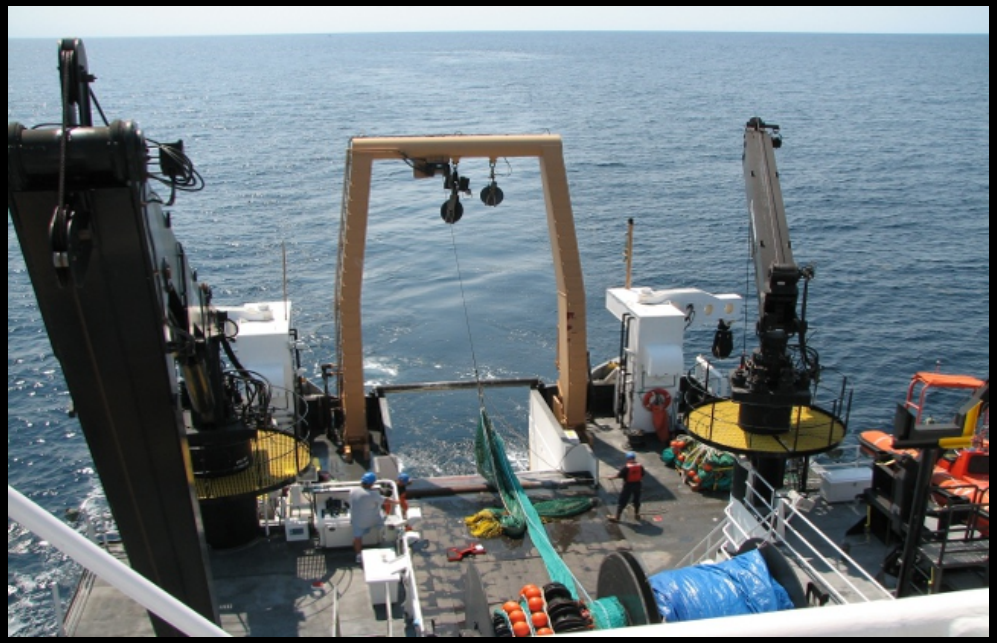
- 17-41 years long
- Fish and invertebrates



Species distribution data

Bottom trawl surveys

- 17-41 years long
- Fish and invertebrates
- Surface and bottom temperature



Eastern Bering Shelf
1982-2011
Gulf of AK
1984-2011
S. Gulf of St.
Lawrence
1971-2009
Newfoundland
1995-2011
Aleutian Is.
1980-2010
East Coast
1968-2008
Scotian Shelf
1970-2011
West Coast
1977-2004
Gulf of Mexico
1987-2011

Standardizing the surveys

- Trimmed to taxa sampled every year
  - 721 populations across 422 taxa

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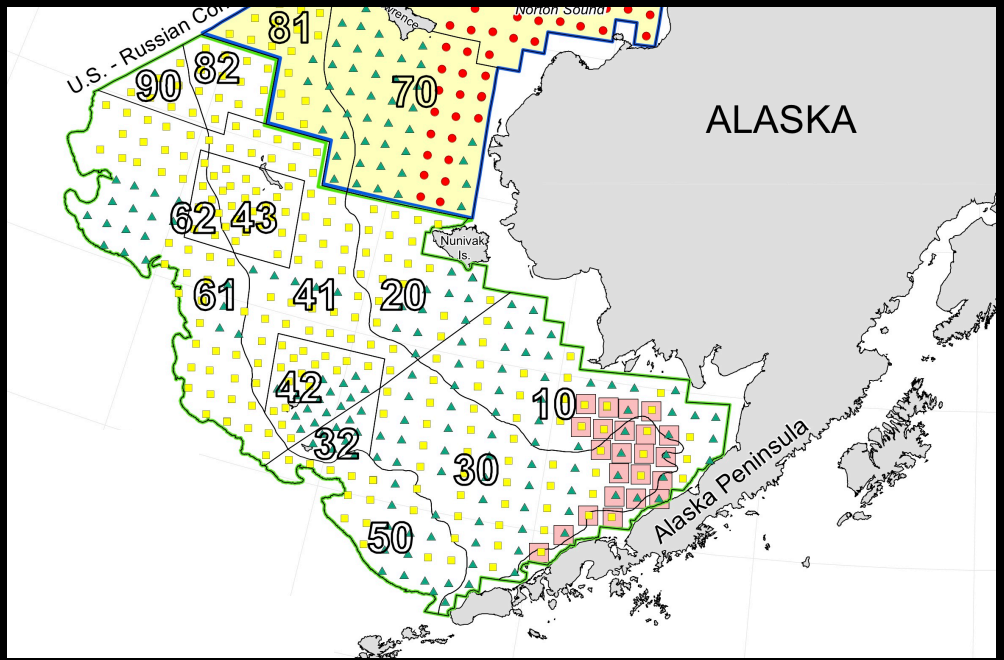
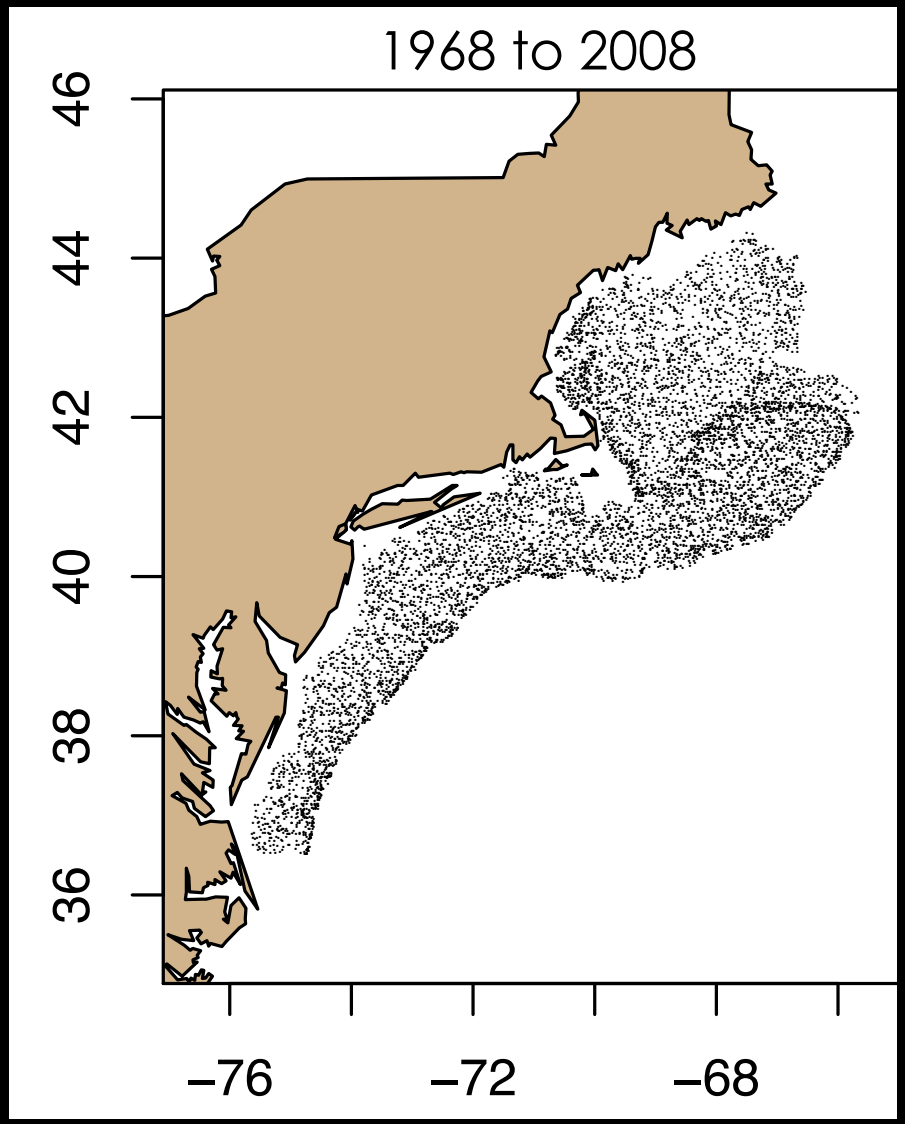


Standardizing the surveys

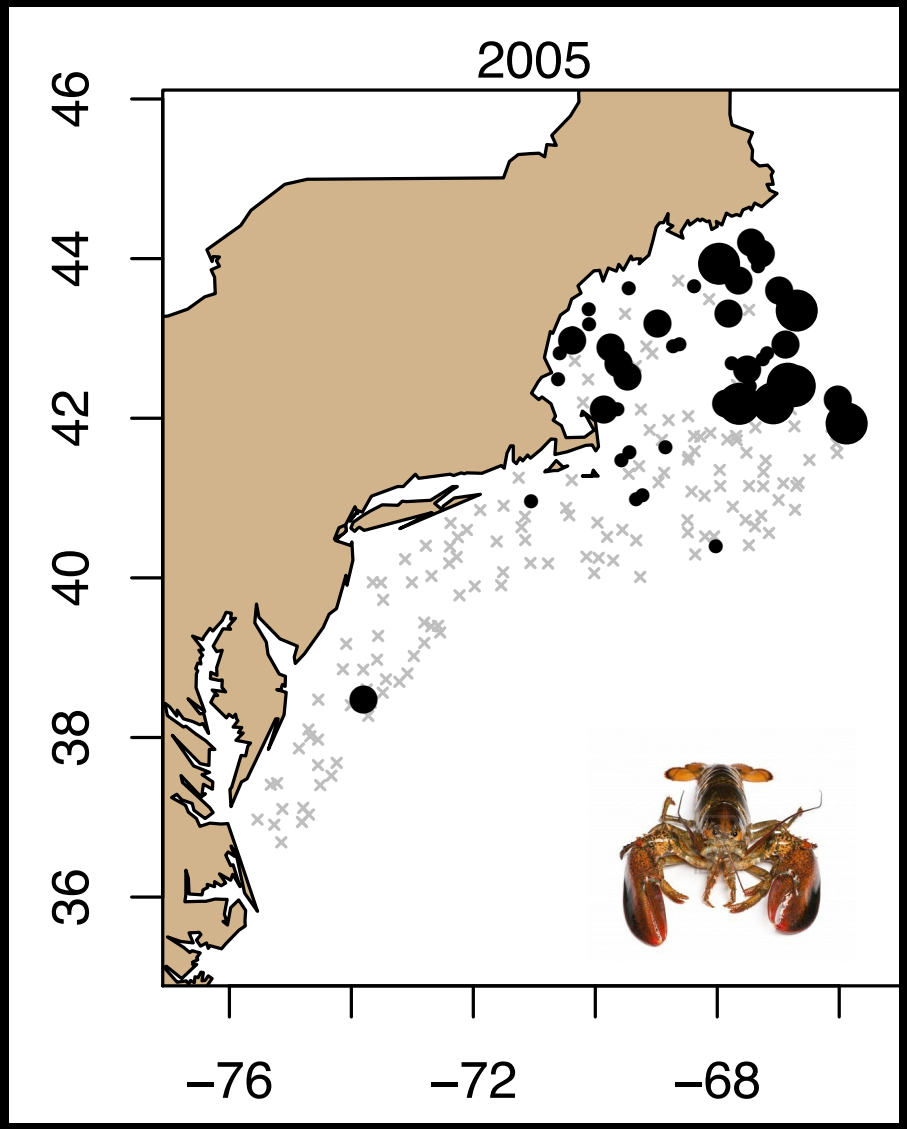
- Trimmed to taxa sampled every year
  - 721 populations across 422 taxa
- Trimmed to a fixed set of strata
- Corrected for towed area

Example: Northeast U.S. Spring



- 41 years
- 8,785 tows
- 30 min @ 6.5 km/hr

American lobster (*Homarus americanus)*



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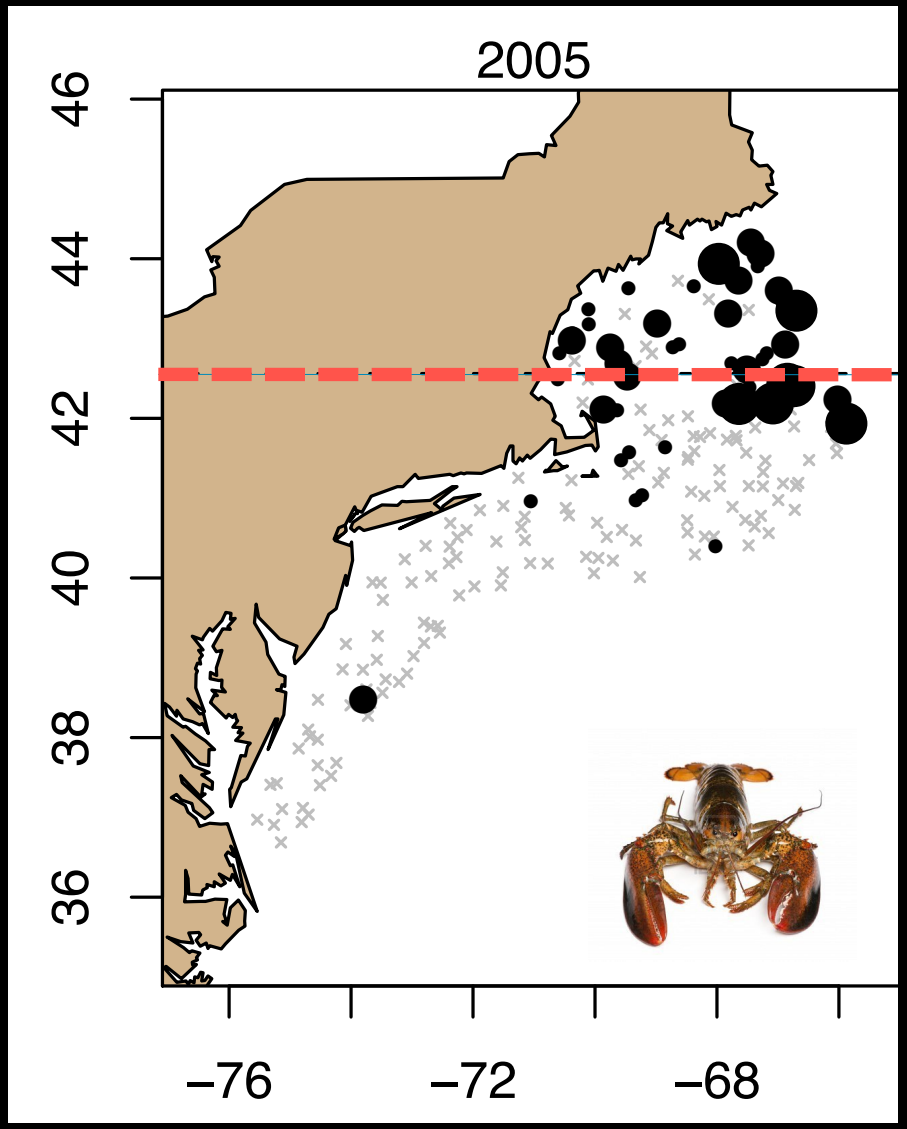
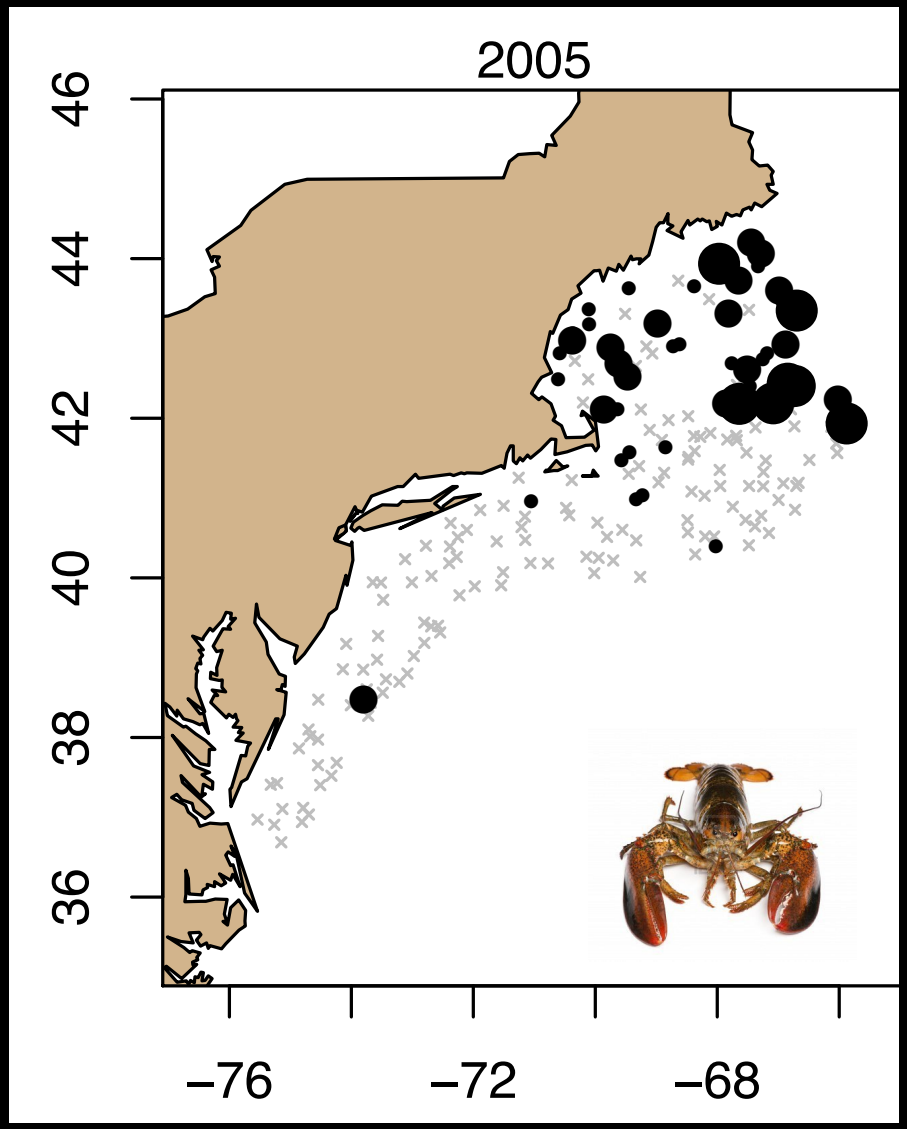
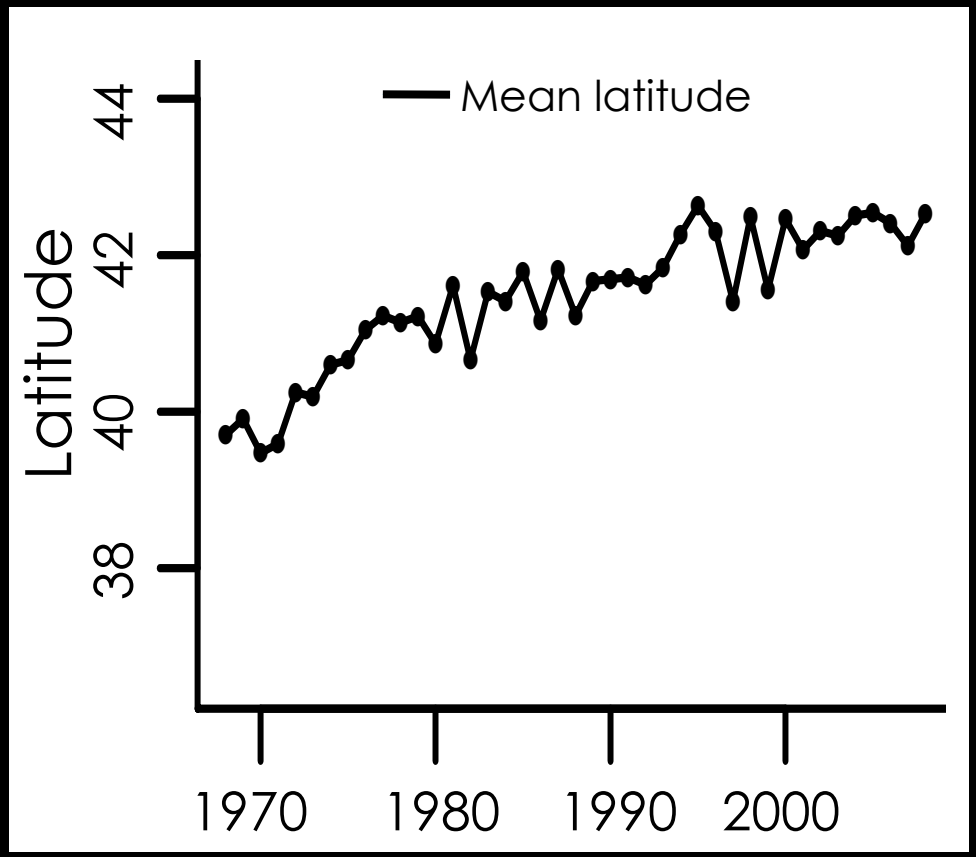


Biomass-weighted mean latitude

American lobster (*Homarus americanus*)





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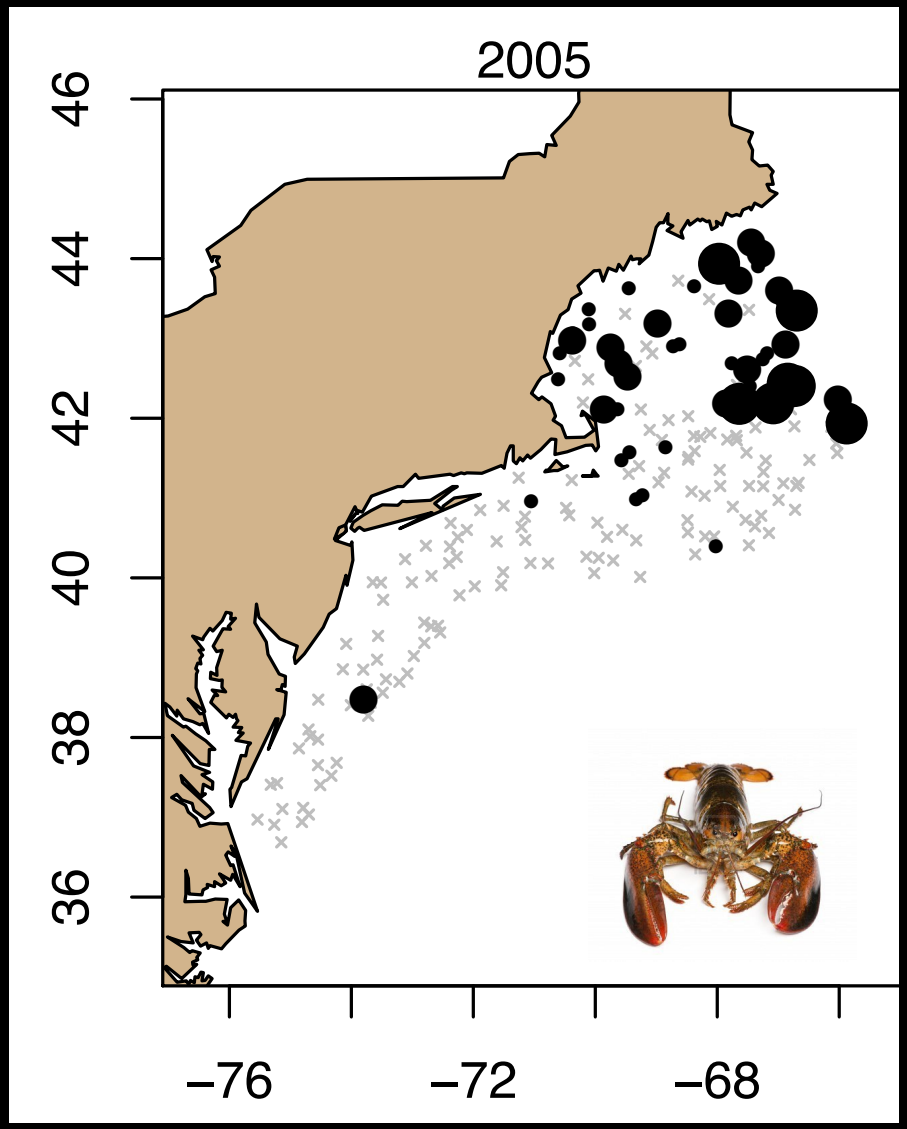
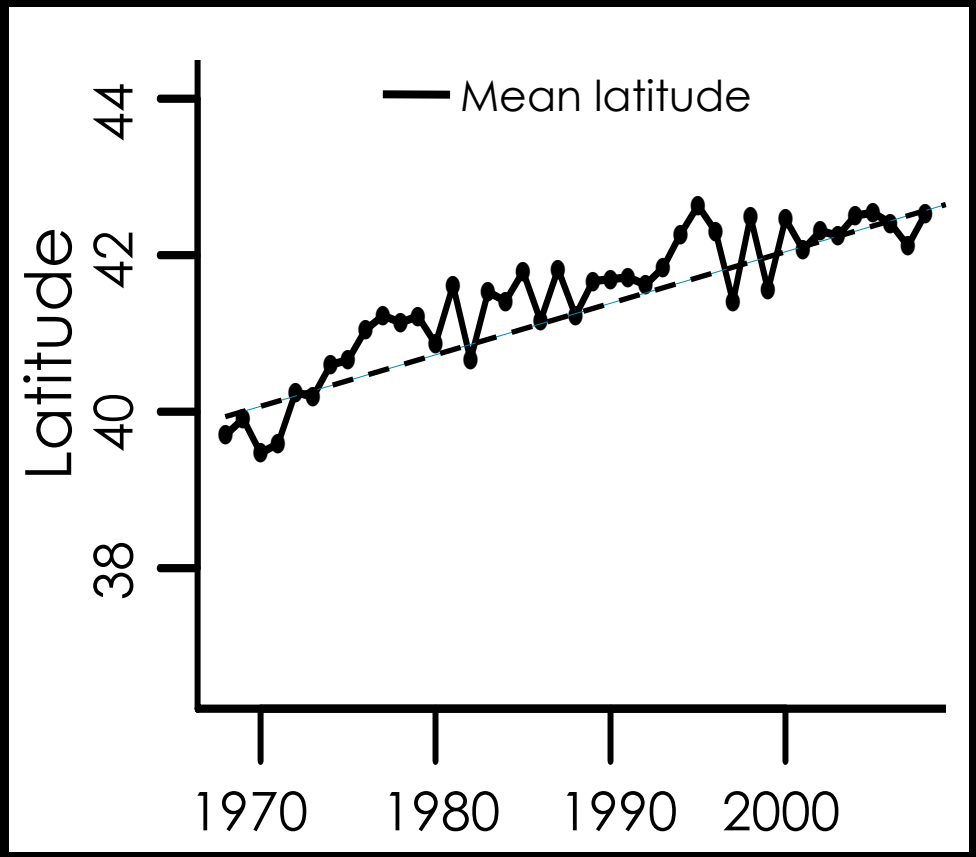
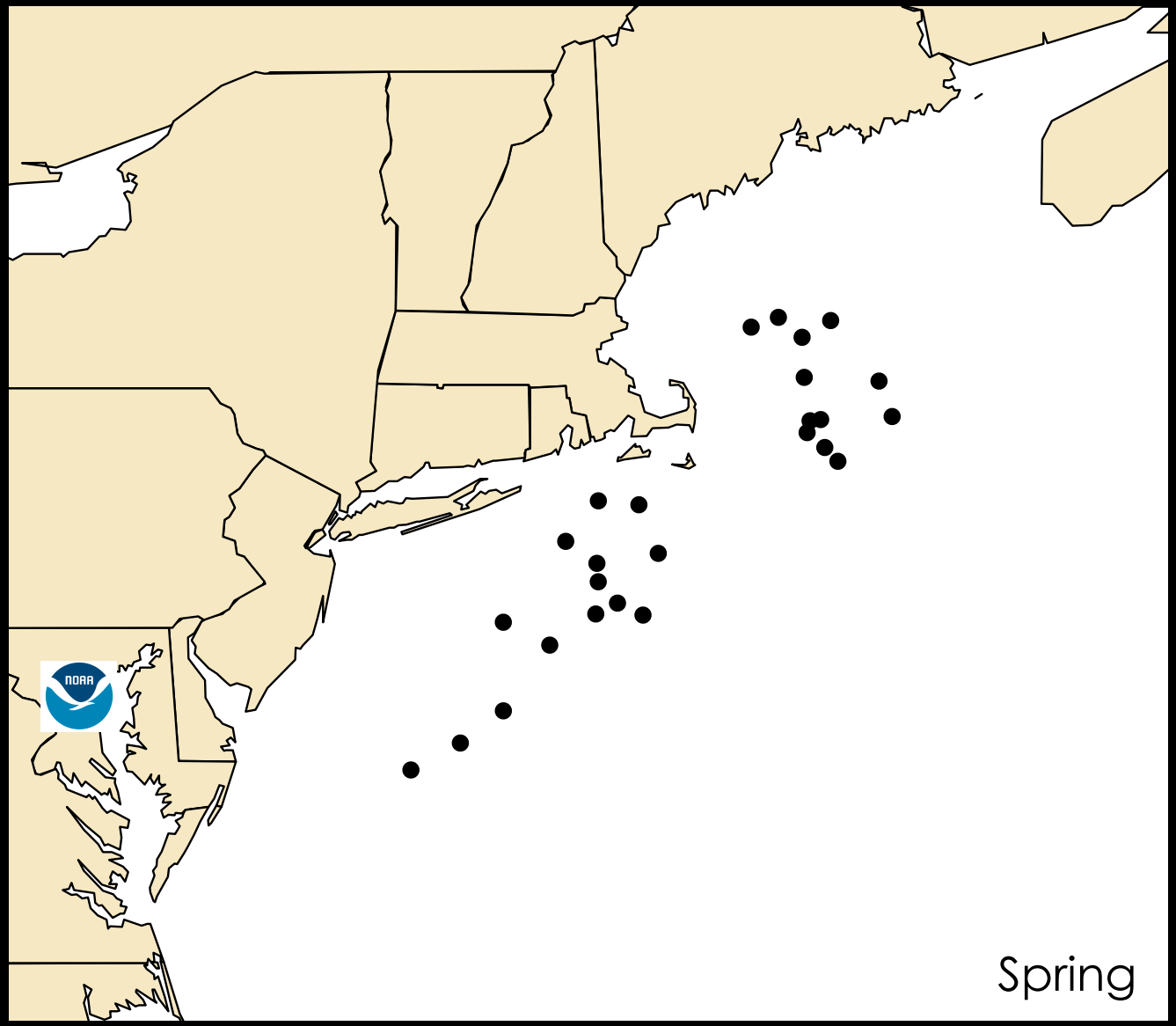
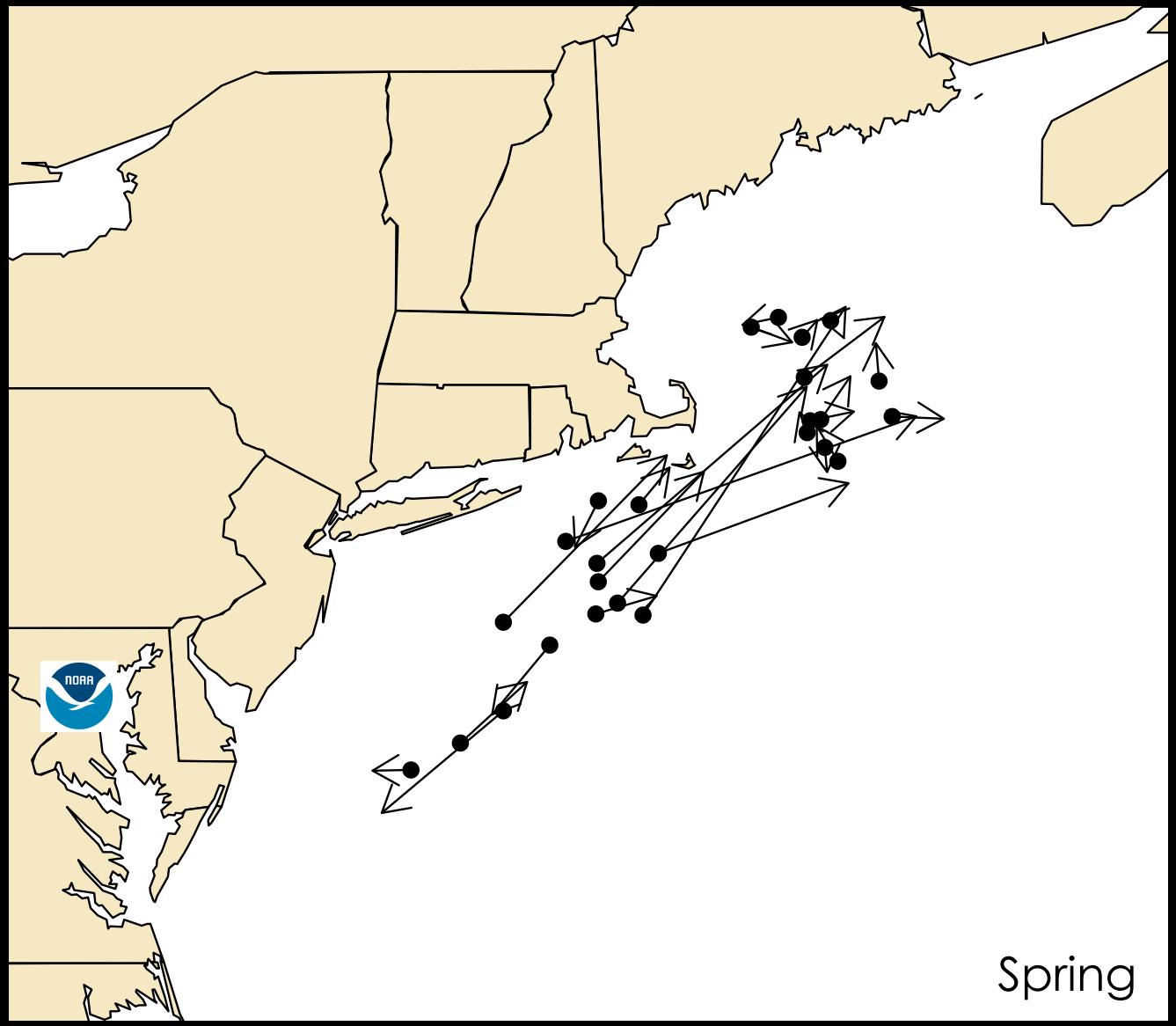




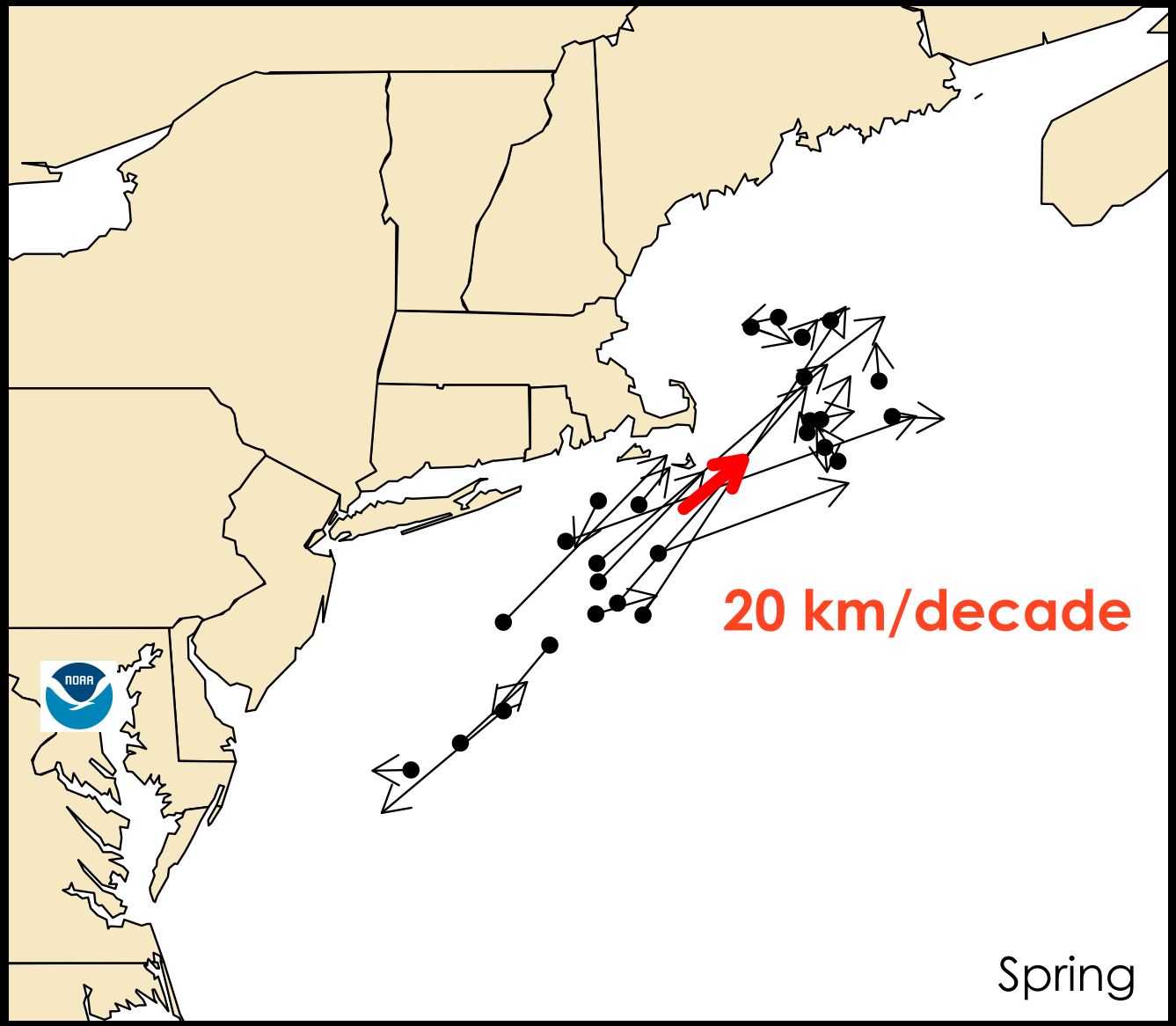
Centers of species' ranges: 1968



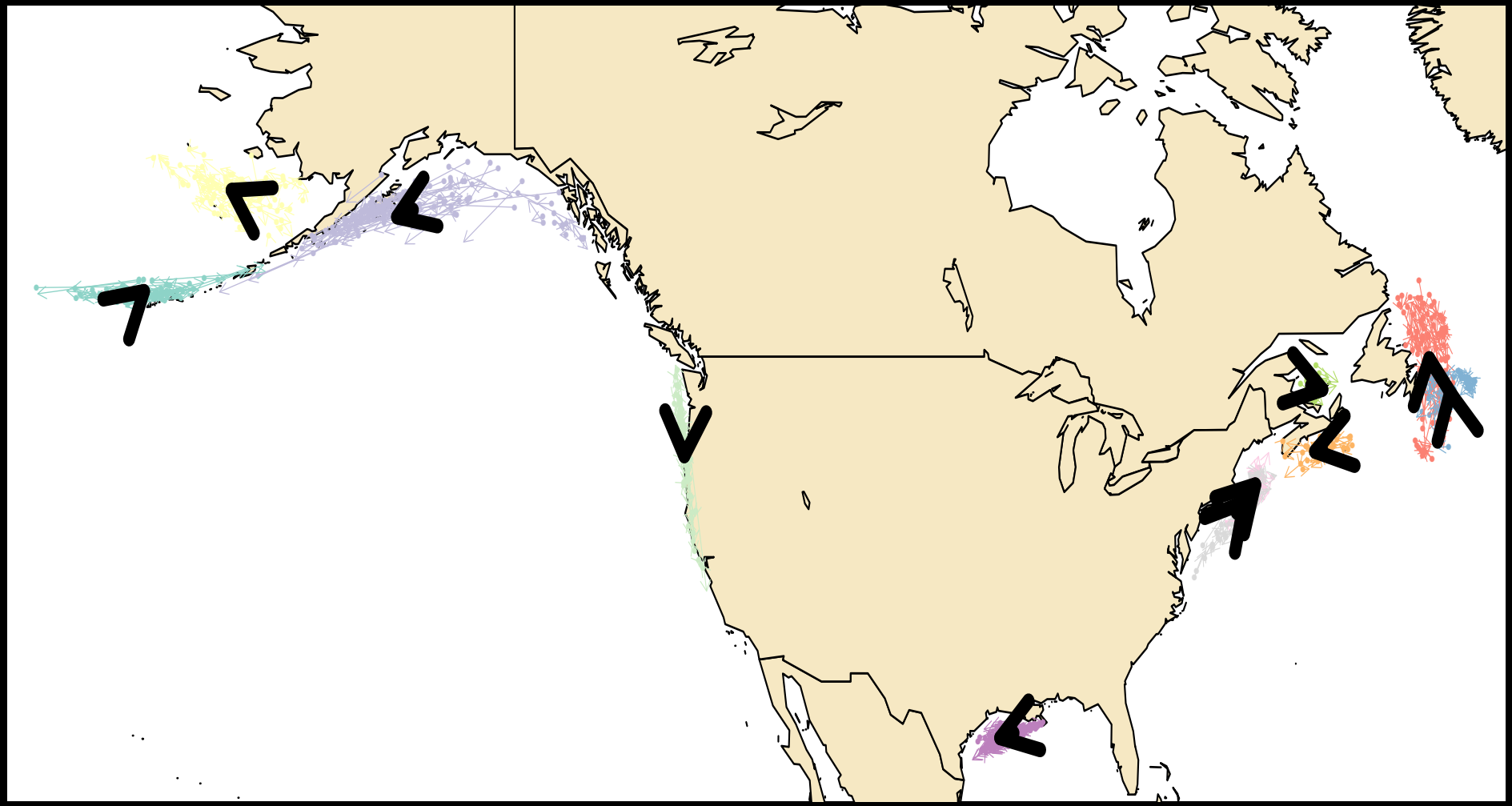
Shifts in centers of species' ranges: 1968-2008



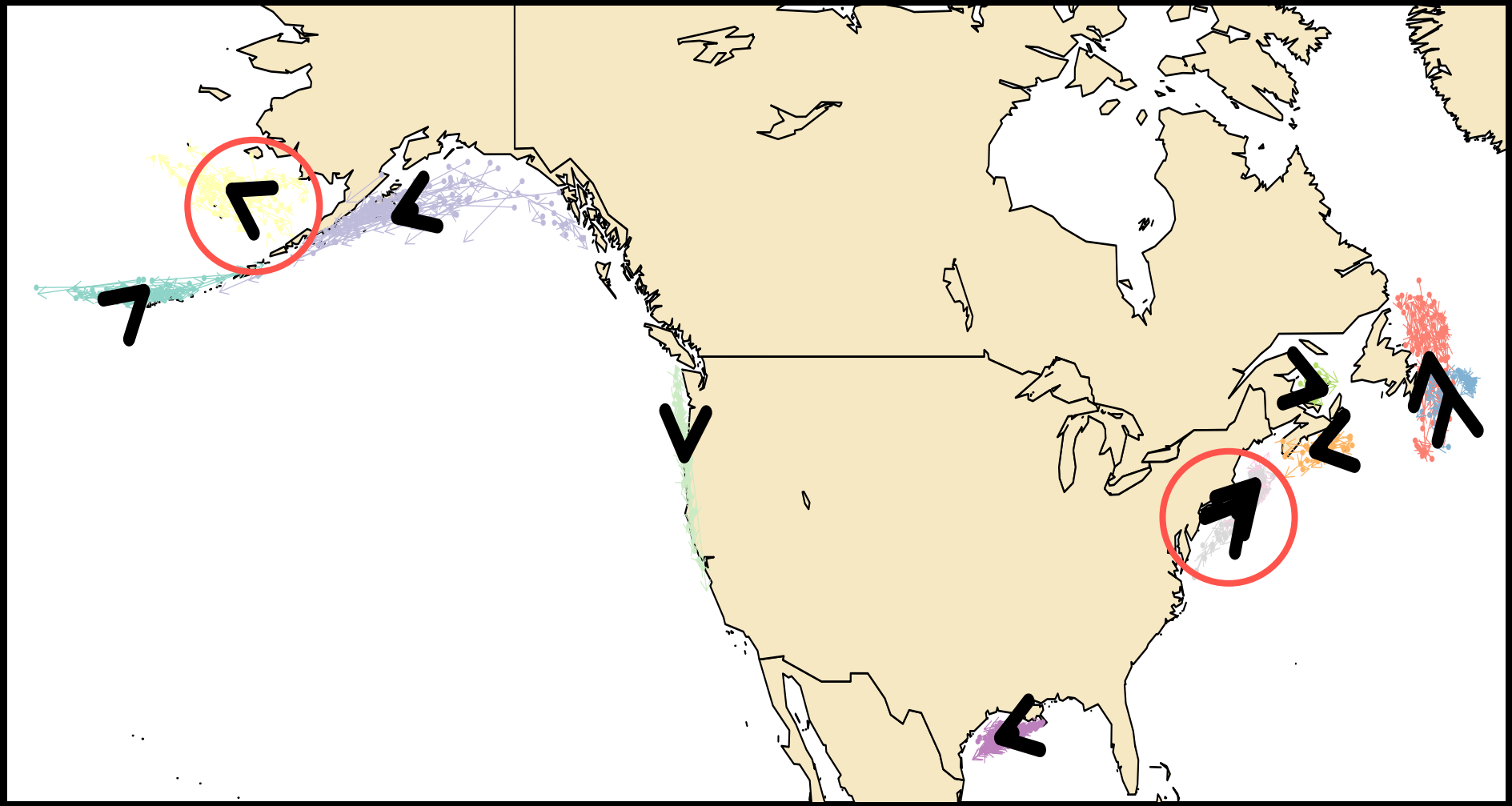
Average shift to the northeast



Wide variation in range shifts

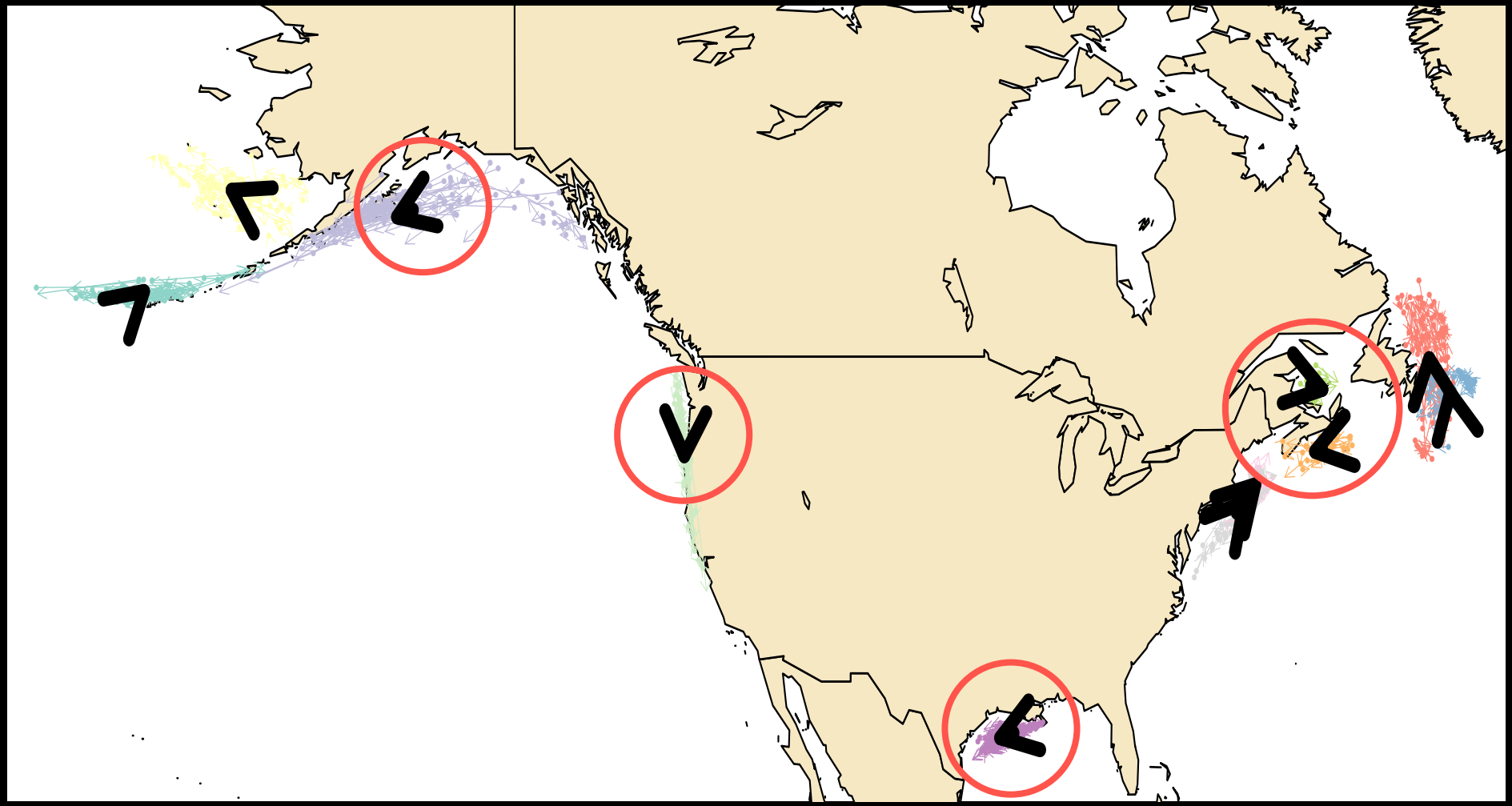


Previously known poleward shifts

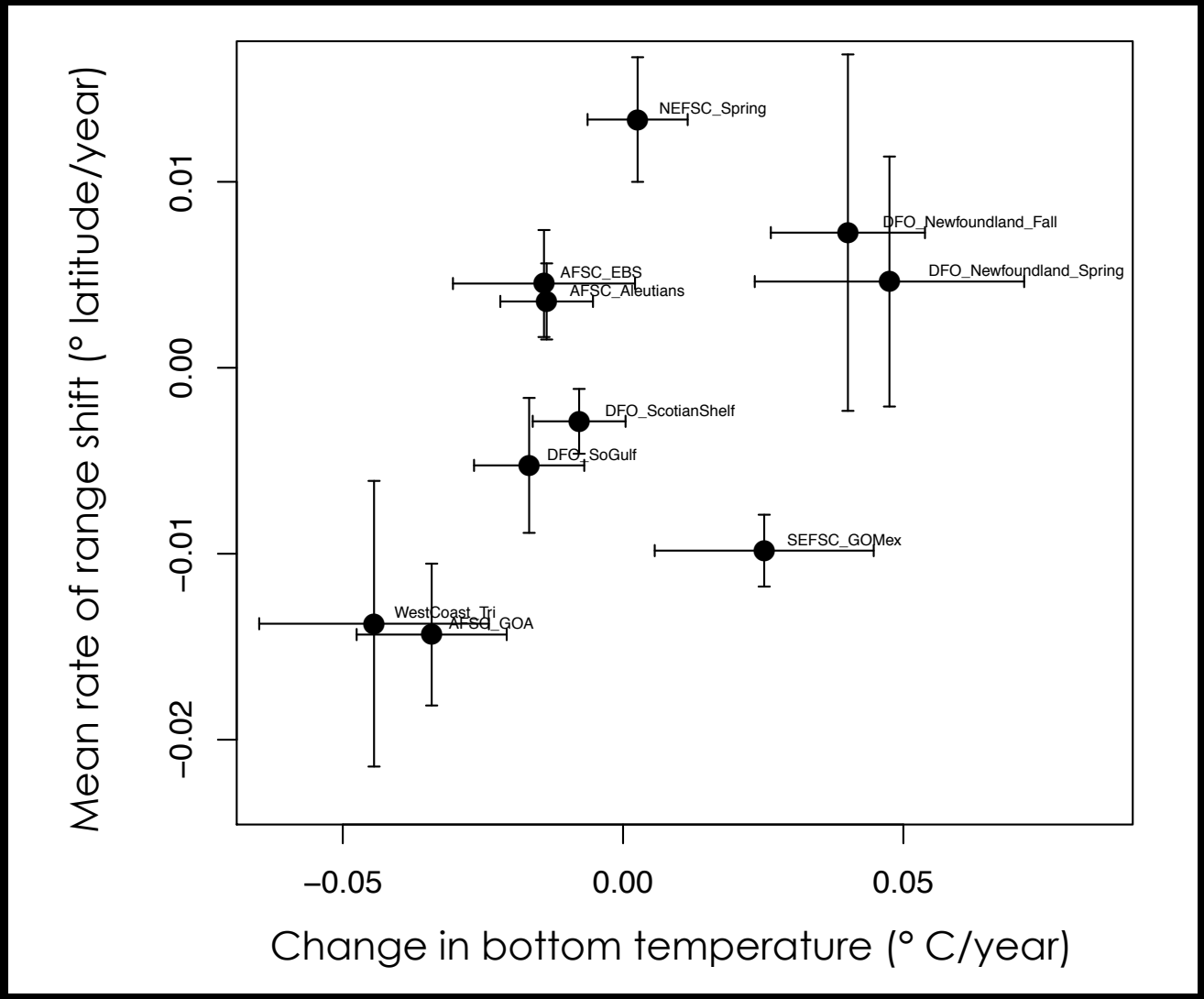


Mueter & Litzow 2008 *Ecol Appl*; Nye *et al.* 2009 *MEPS*

Many regions shifting south



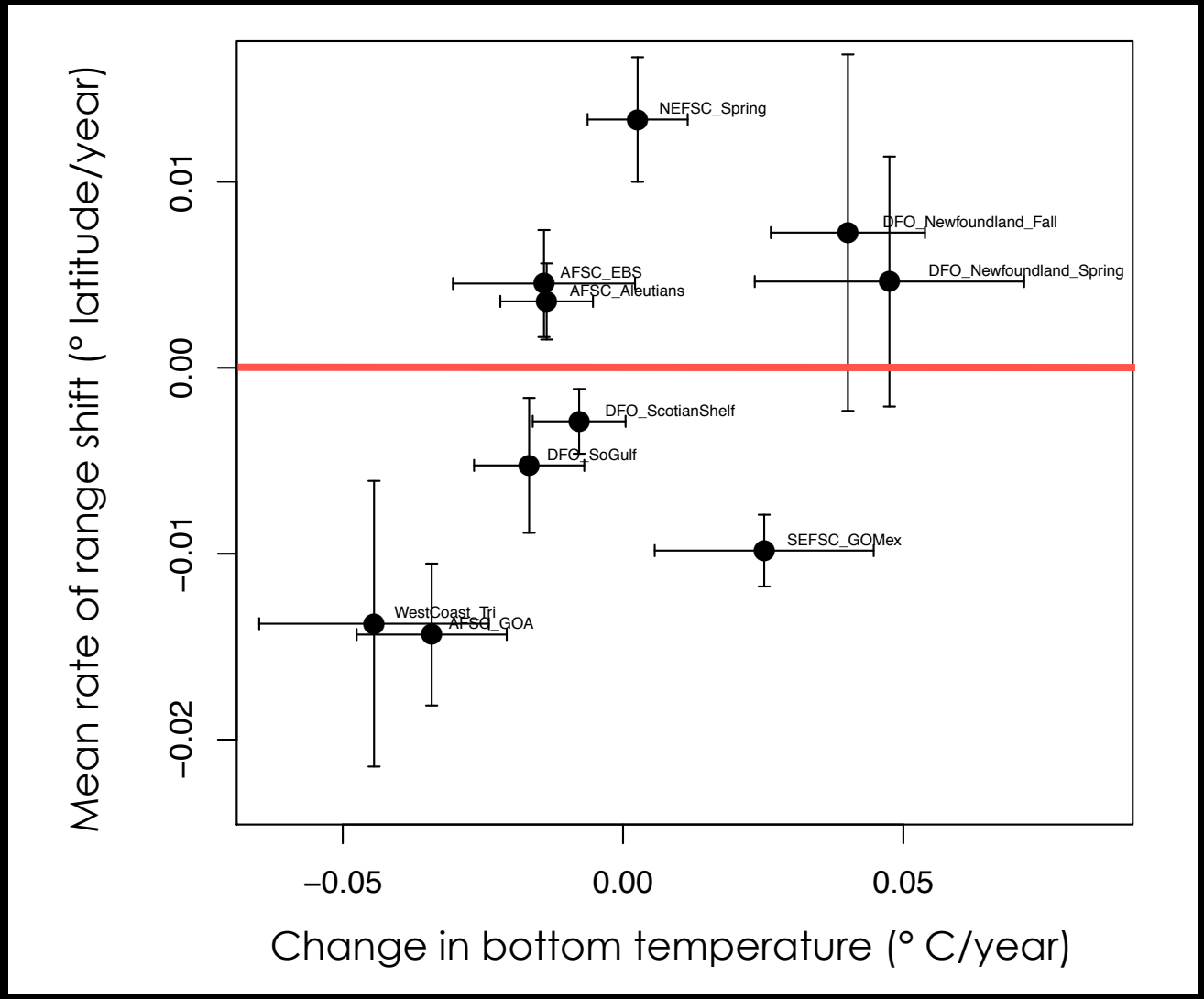
Bottom temperature and regional shifts



Bottom temperature and regional shifts

North

South



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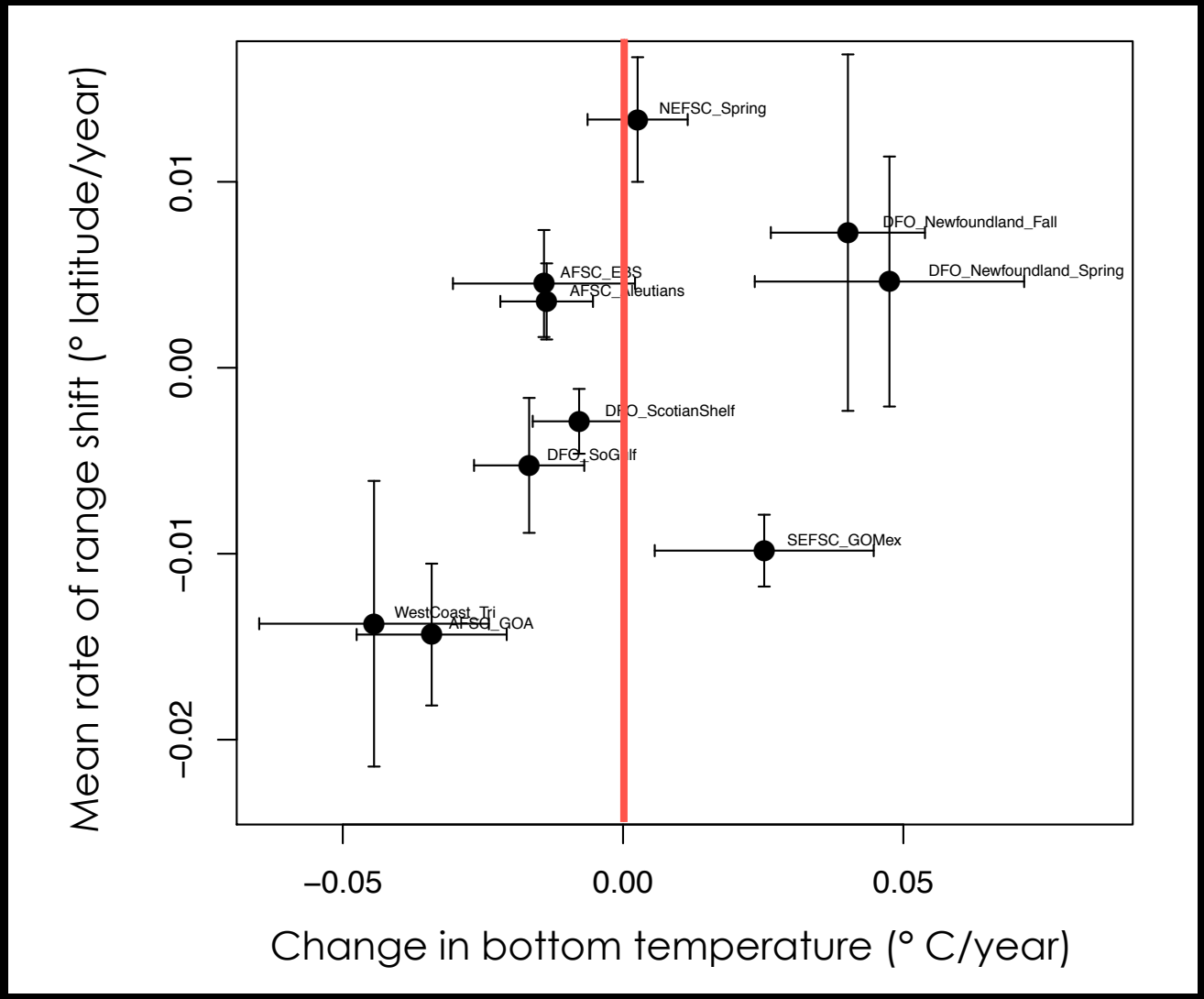
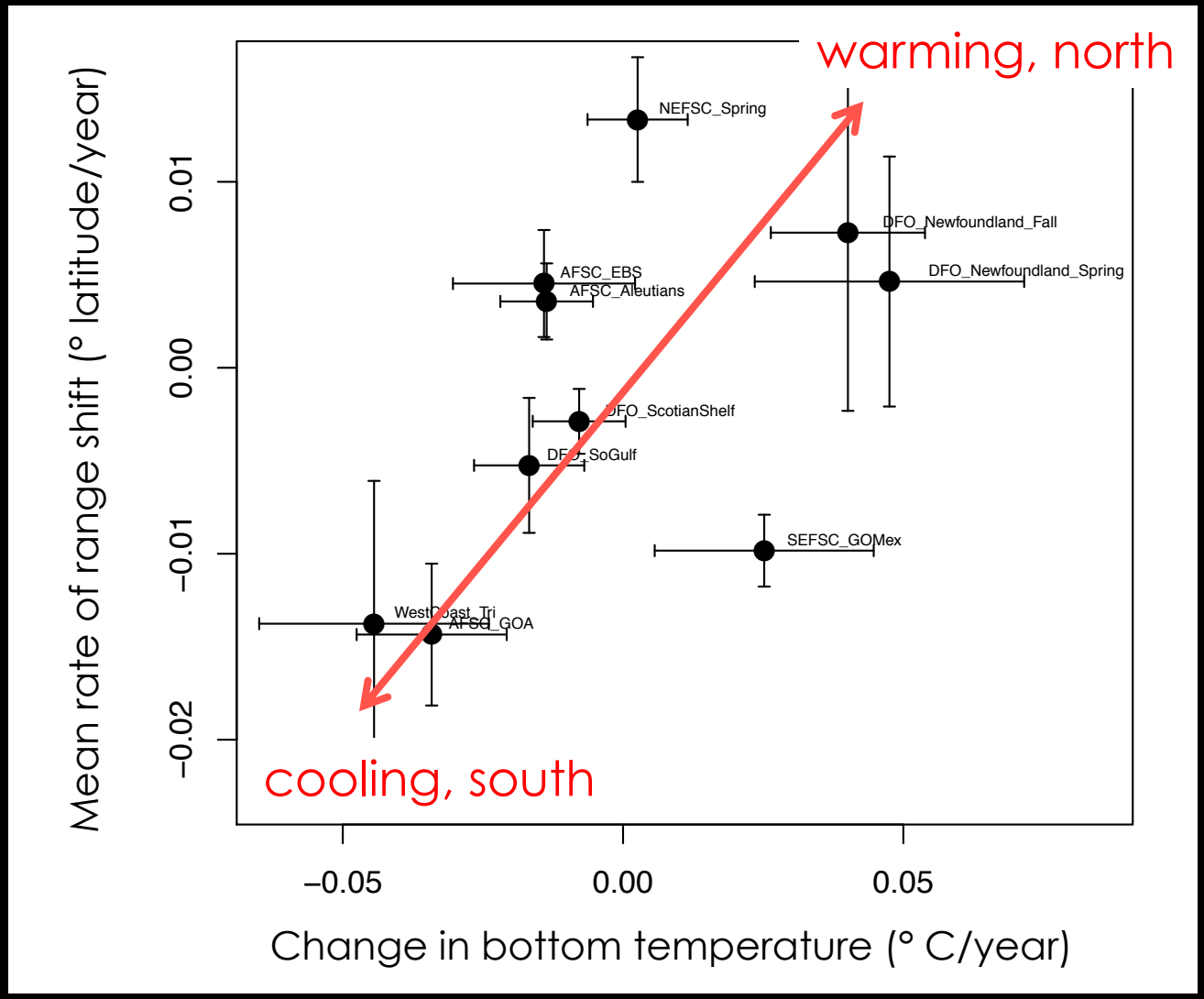


Colder

Warmer

Bottom temperature and regional shifts



Colder

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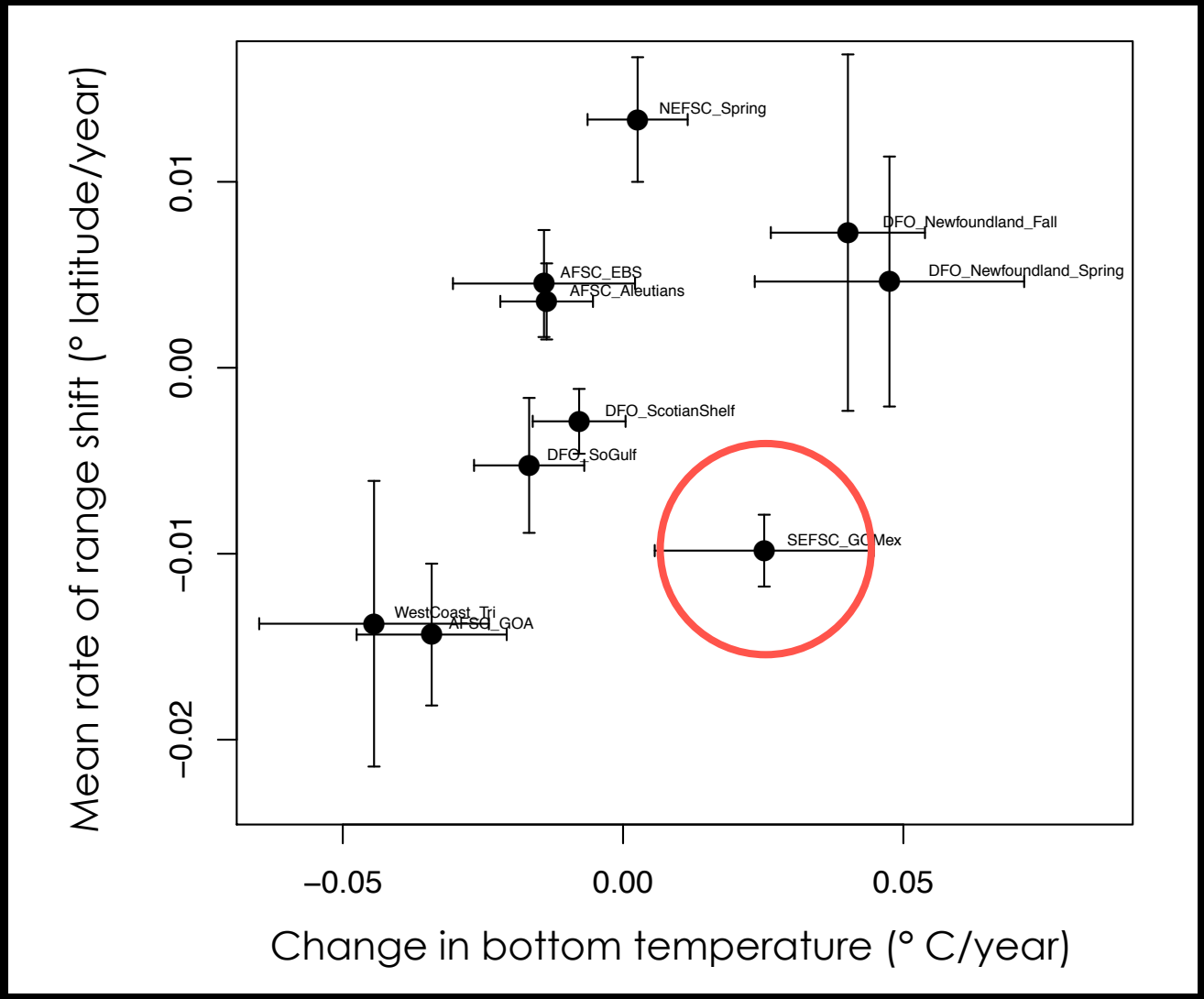
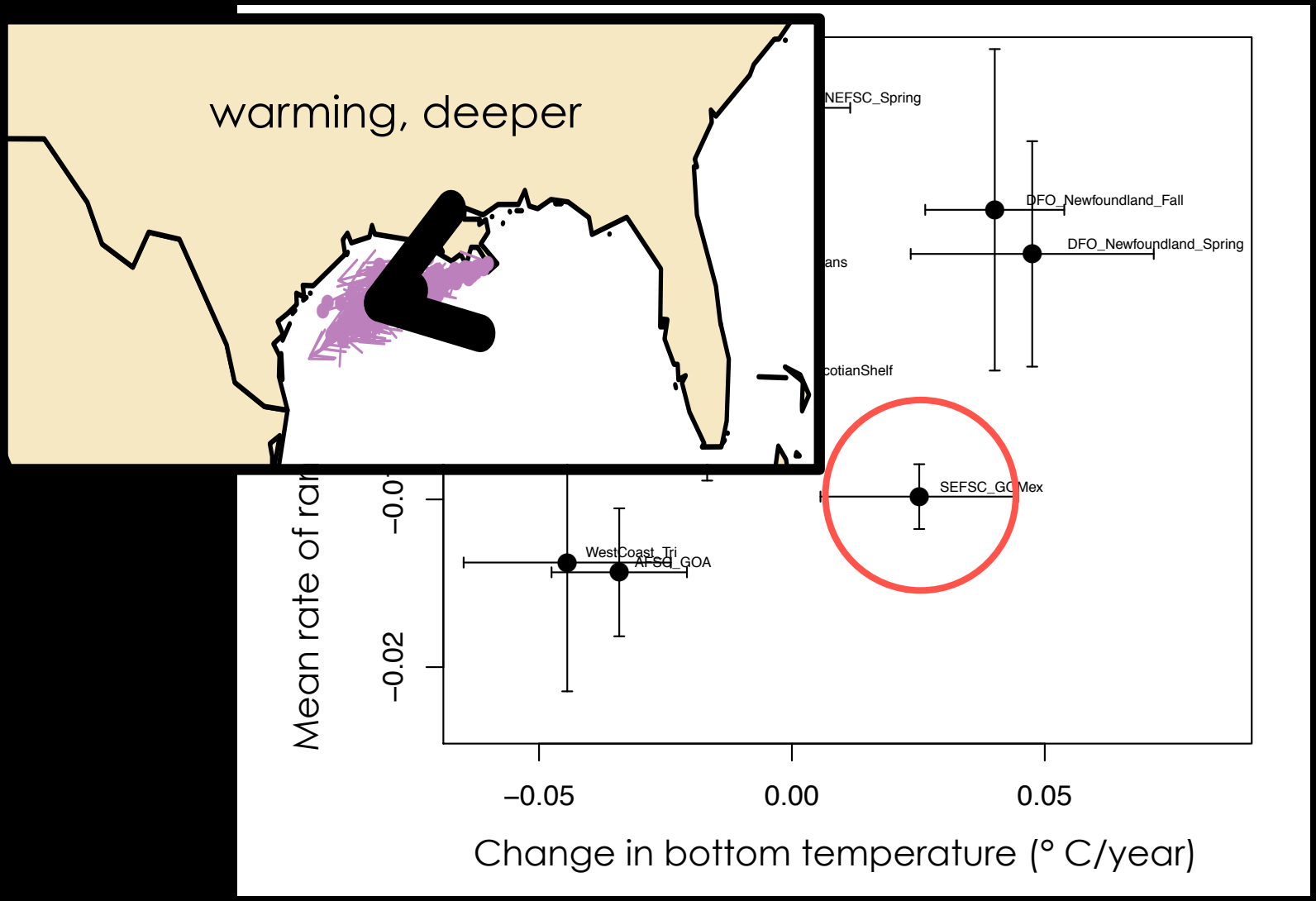
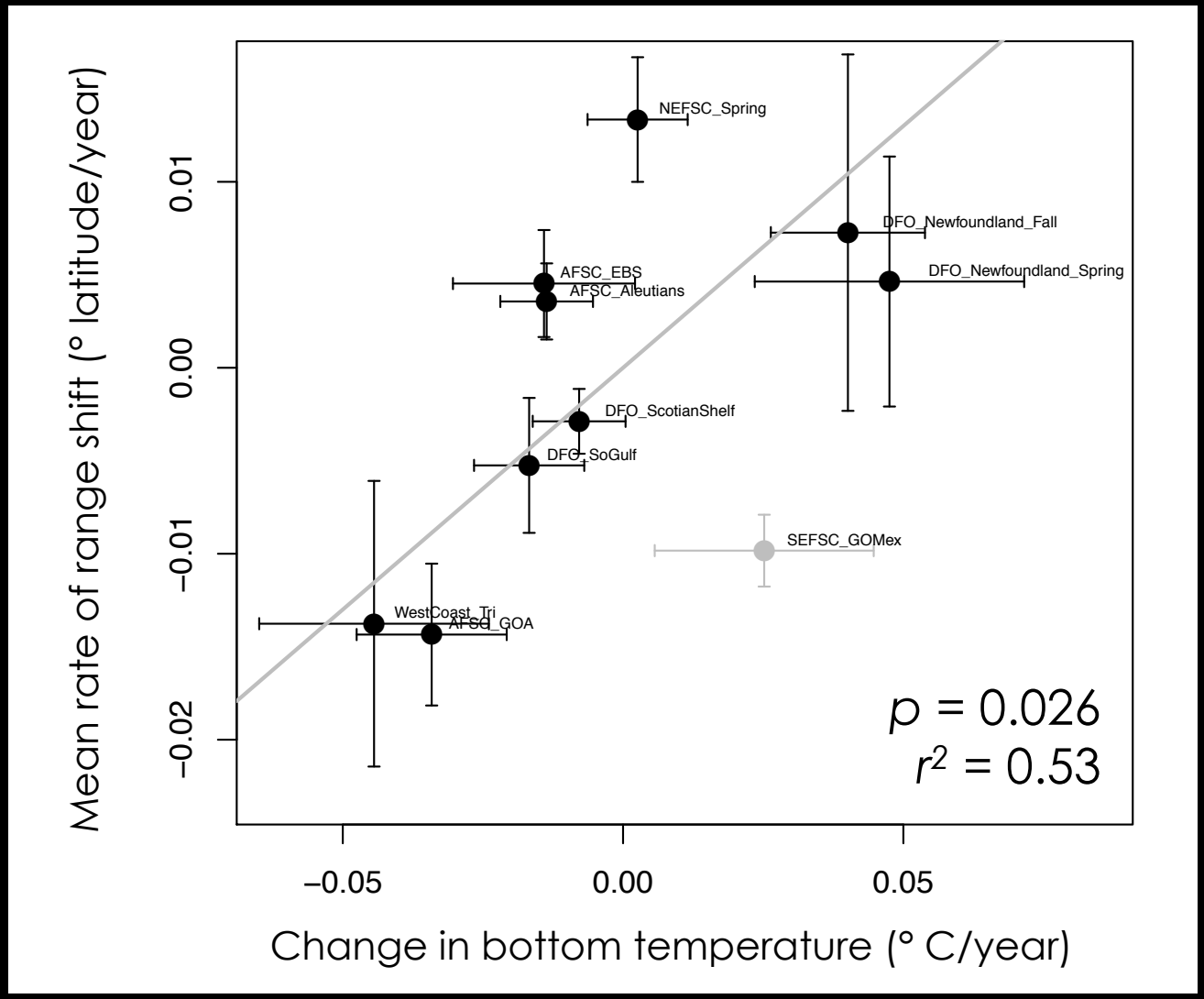
Gulf of Mexico



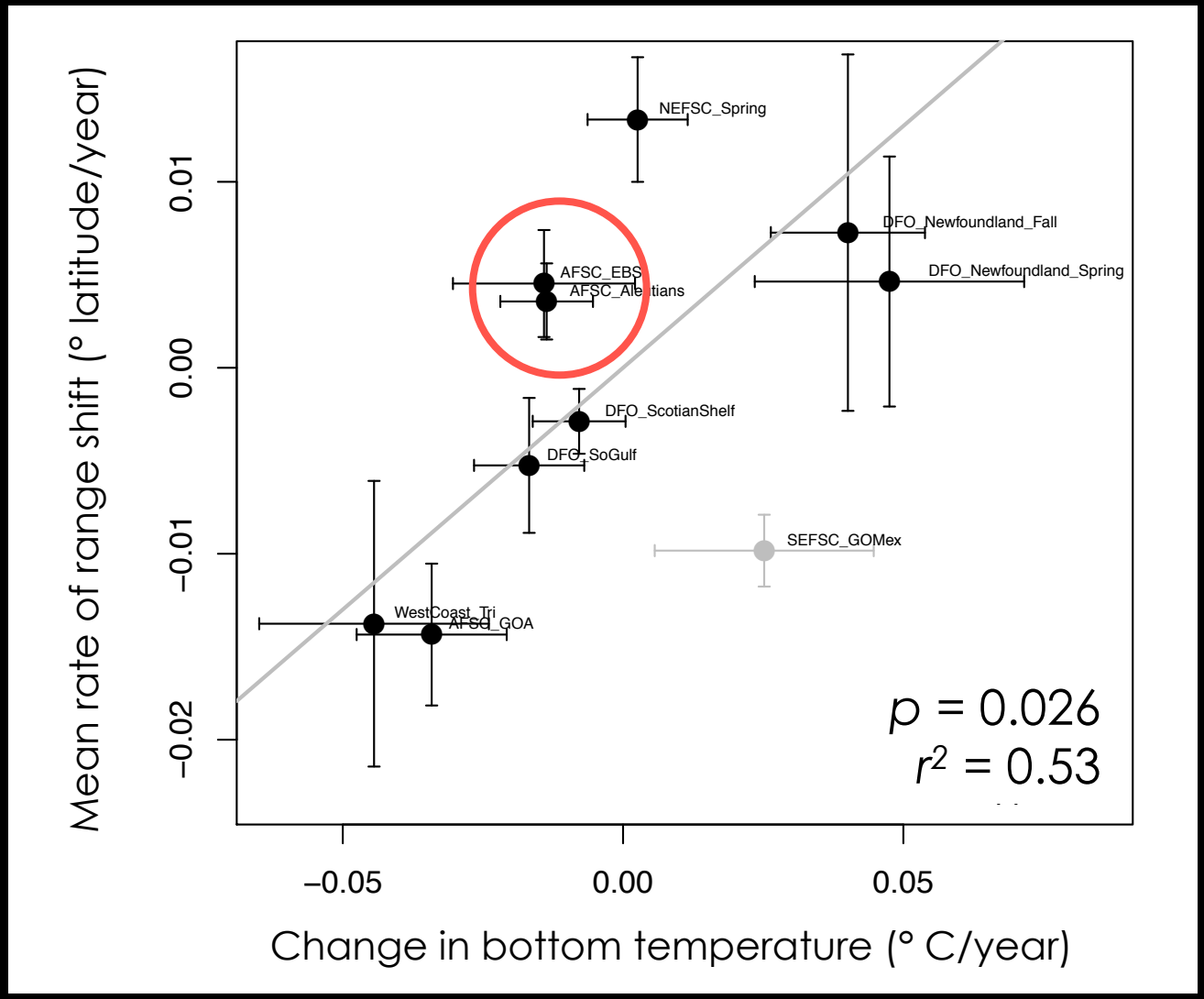
Gulf of Mexico: constrained by geography



Bottom temperature explains regional shifts



Eastern Bering Sea



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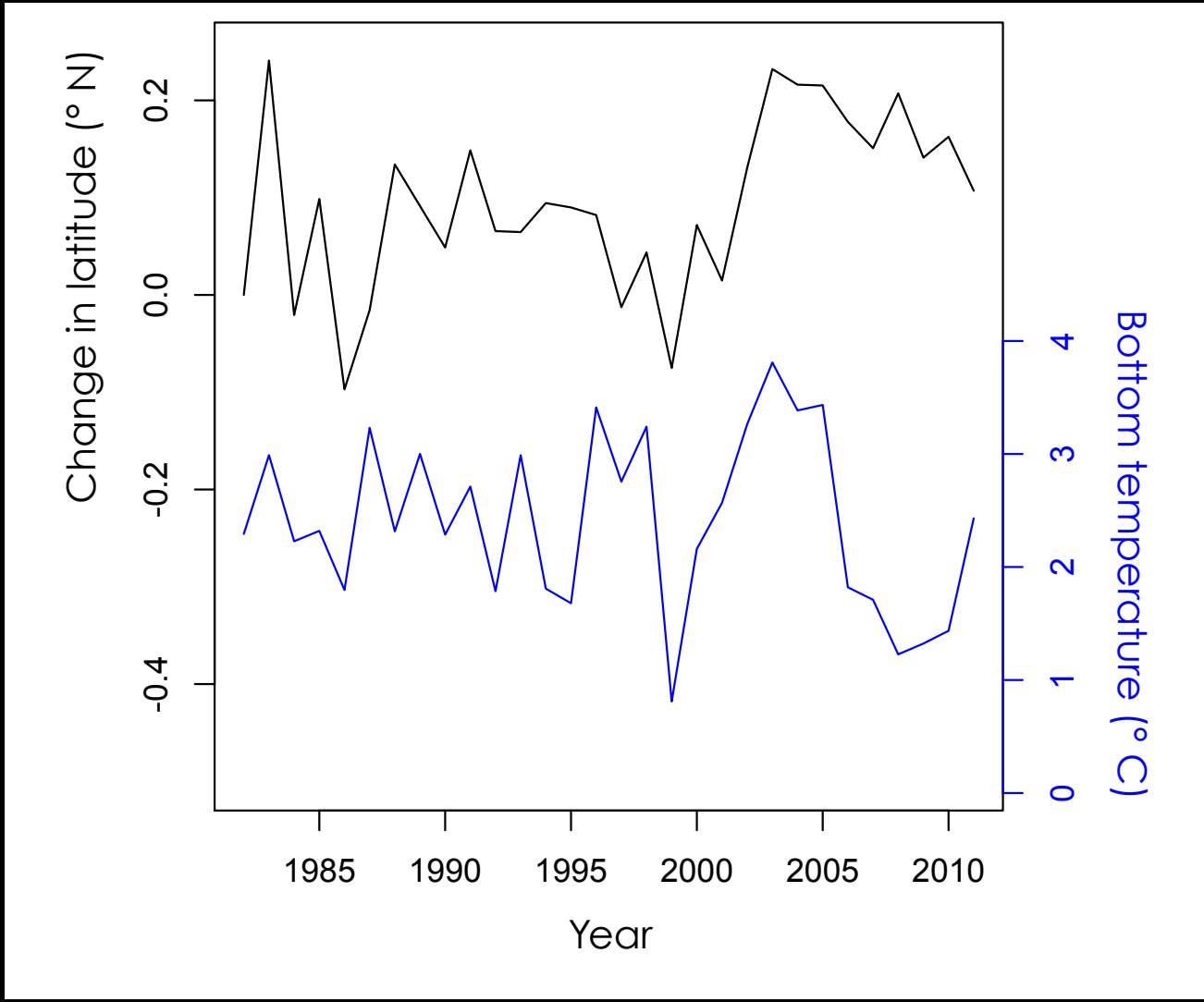

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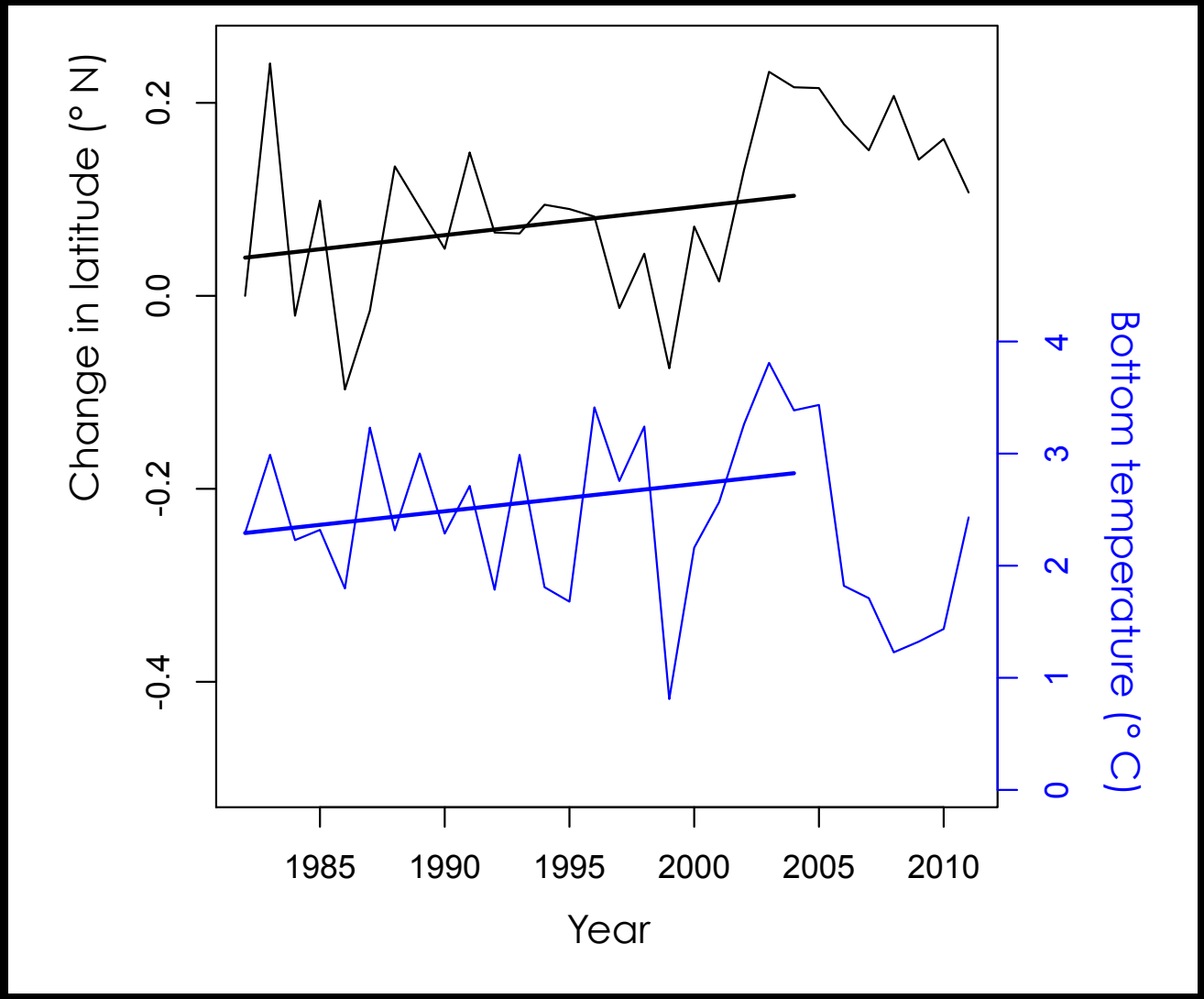
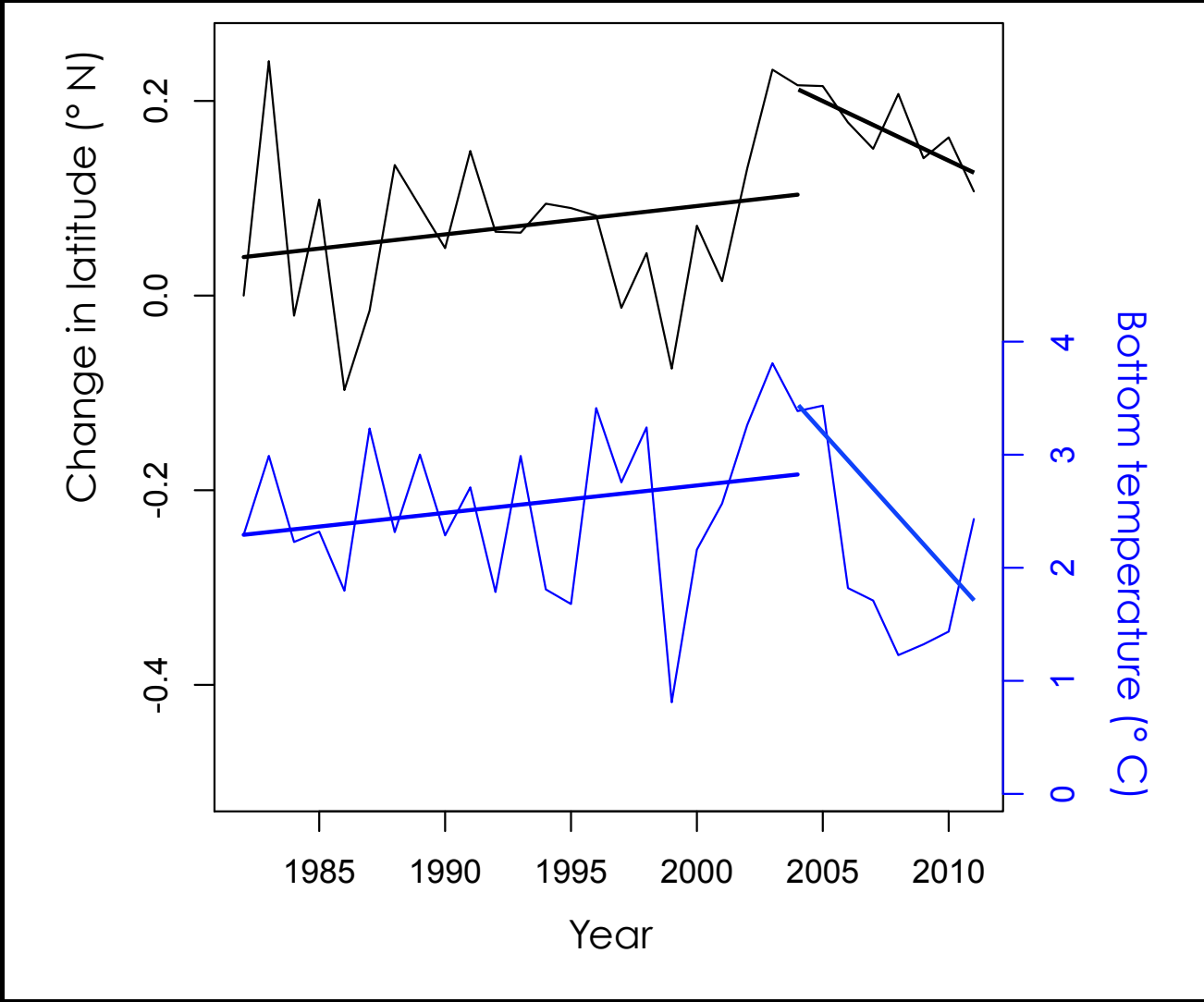


Eastern Bering Sea: lagged response



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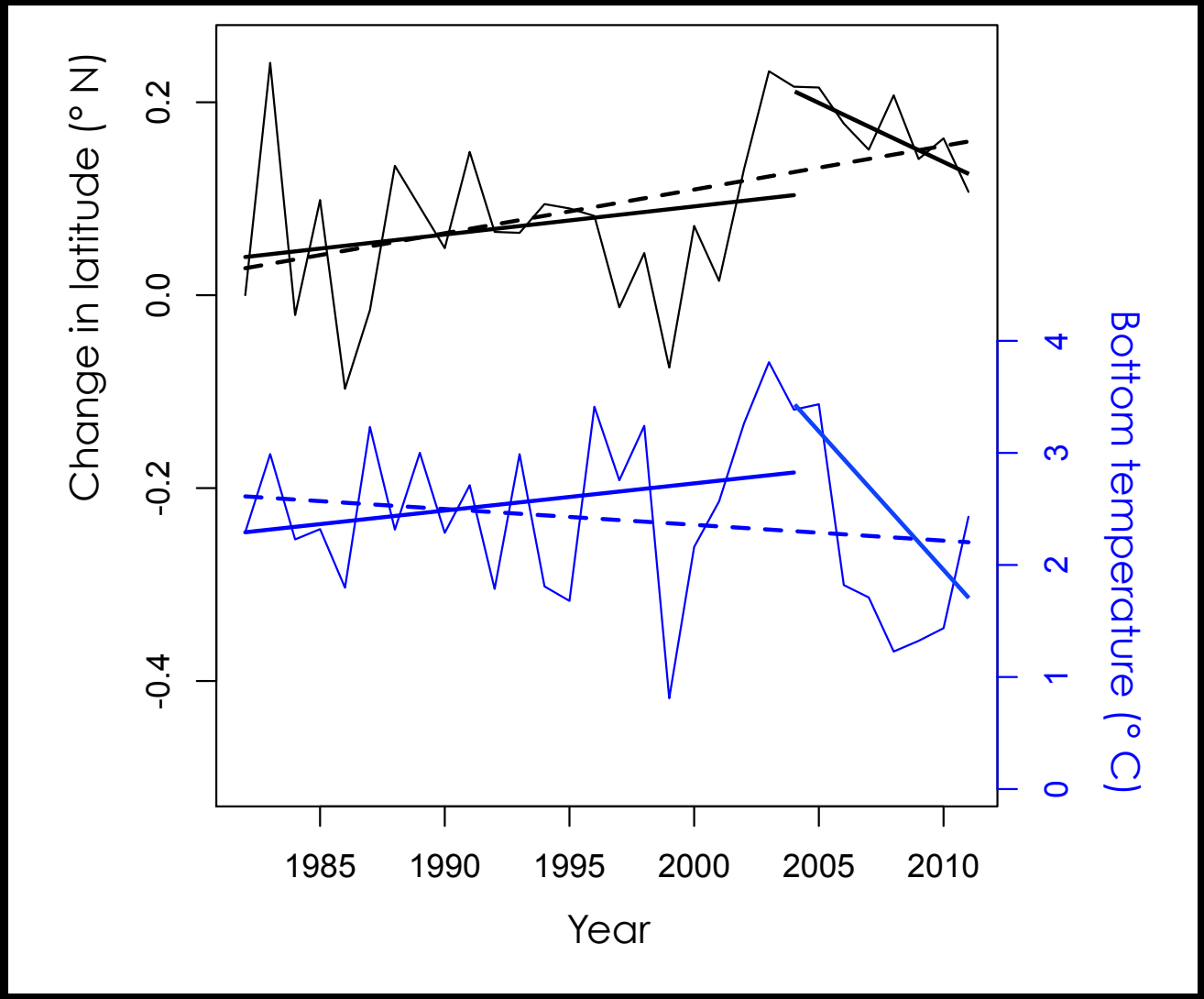
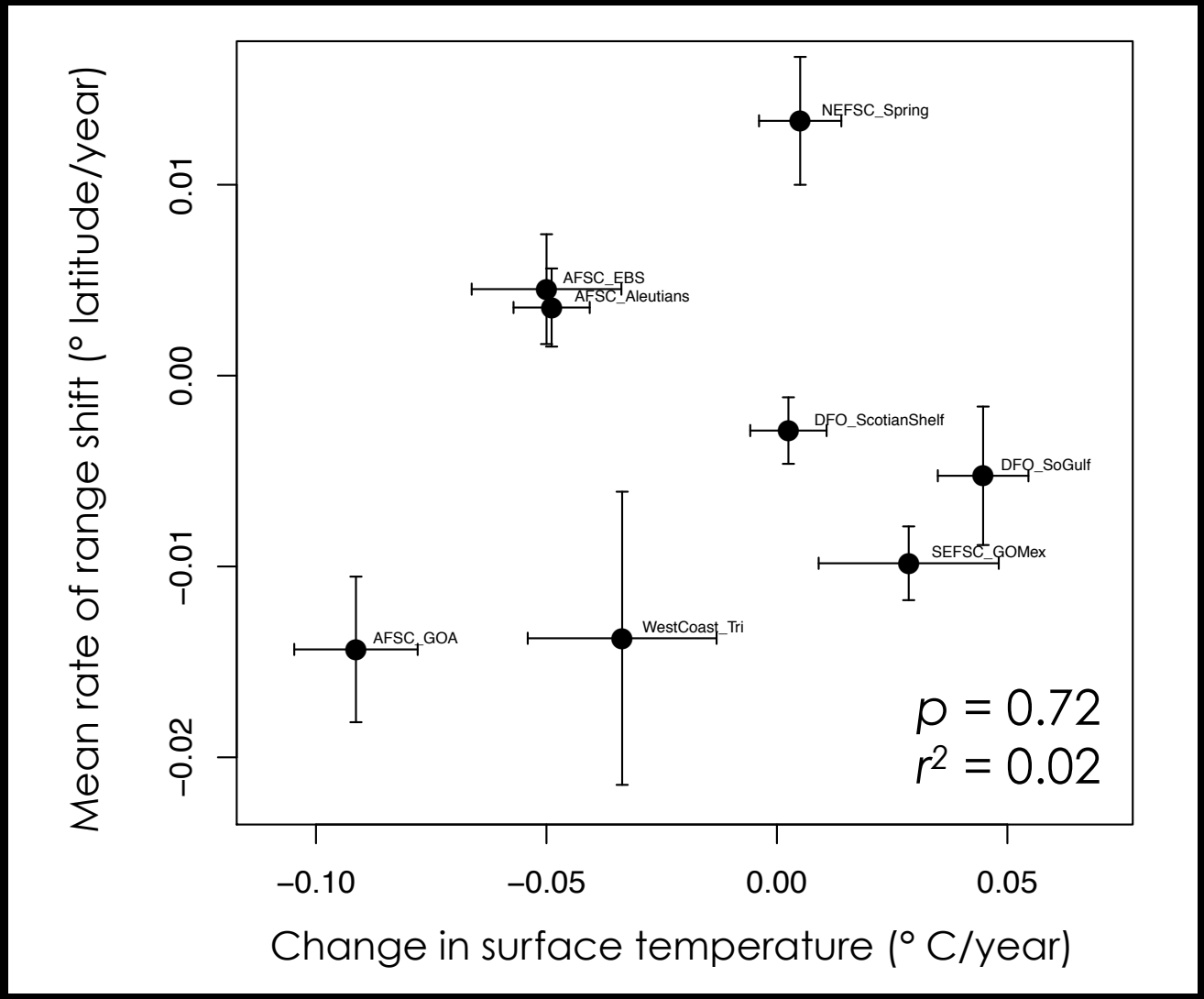
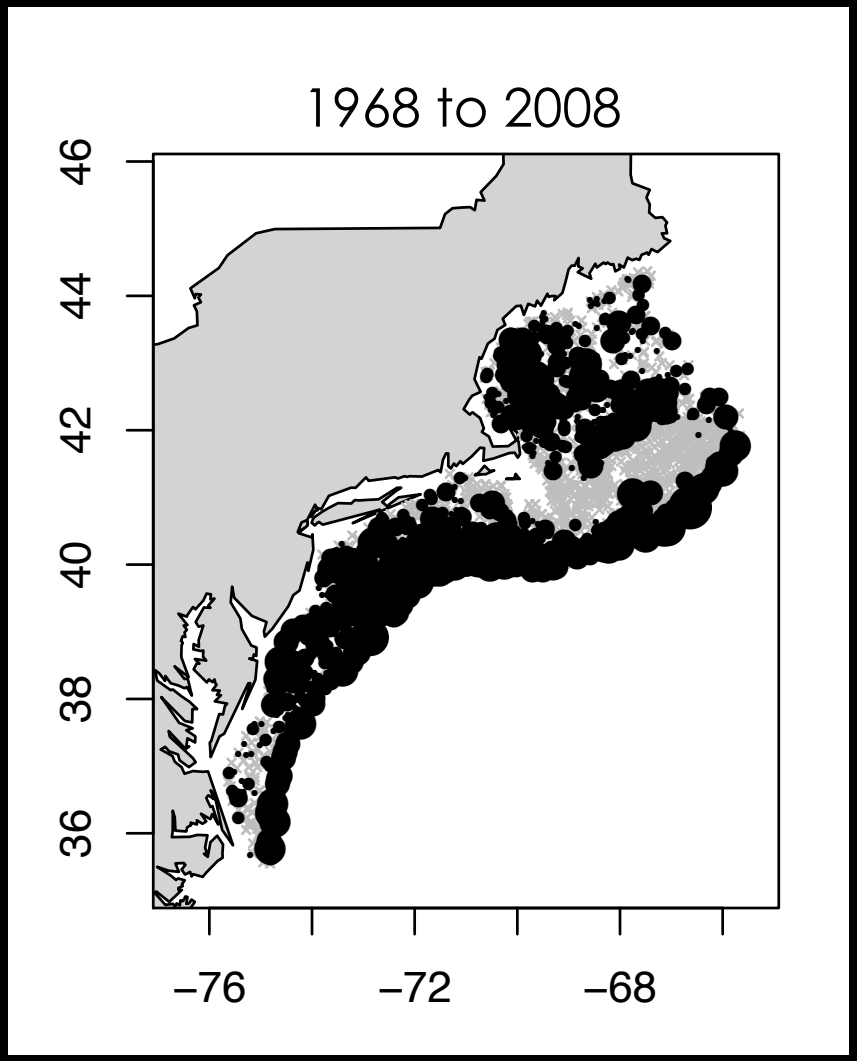


Sea surface temperature: no relation



Assemblages track multi-decadal bottom temperature trends

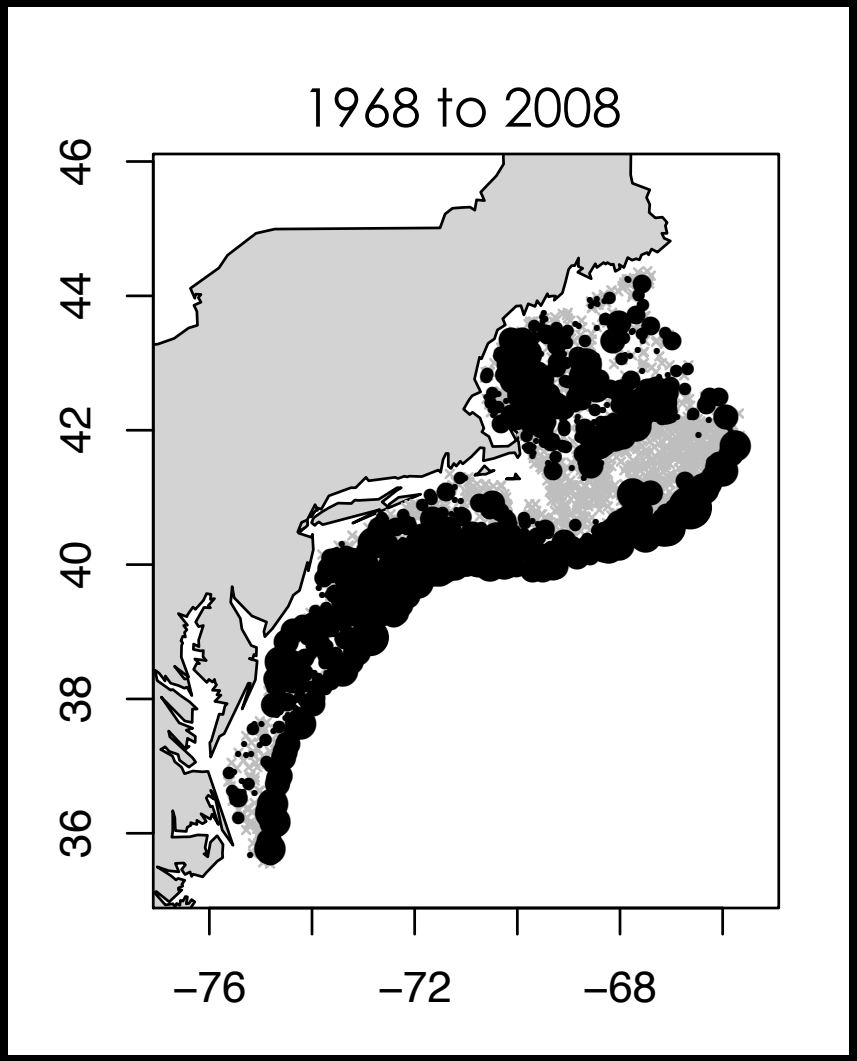
Distribution of Silver hake (*Merluccius bilinearis*)

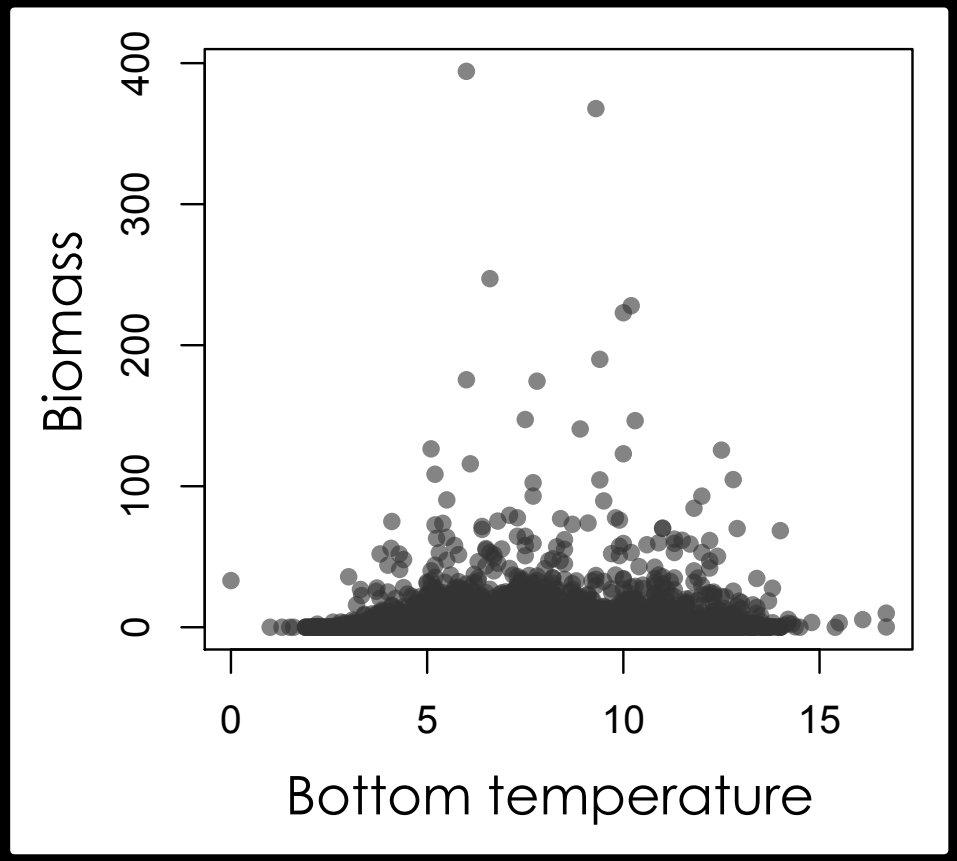


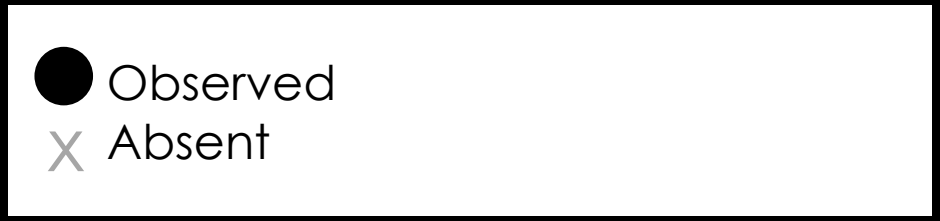
Observed

Absent

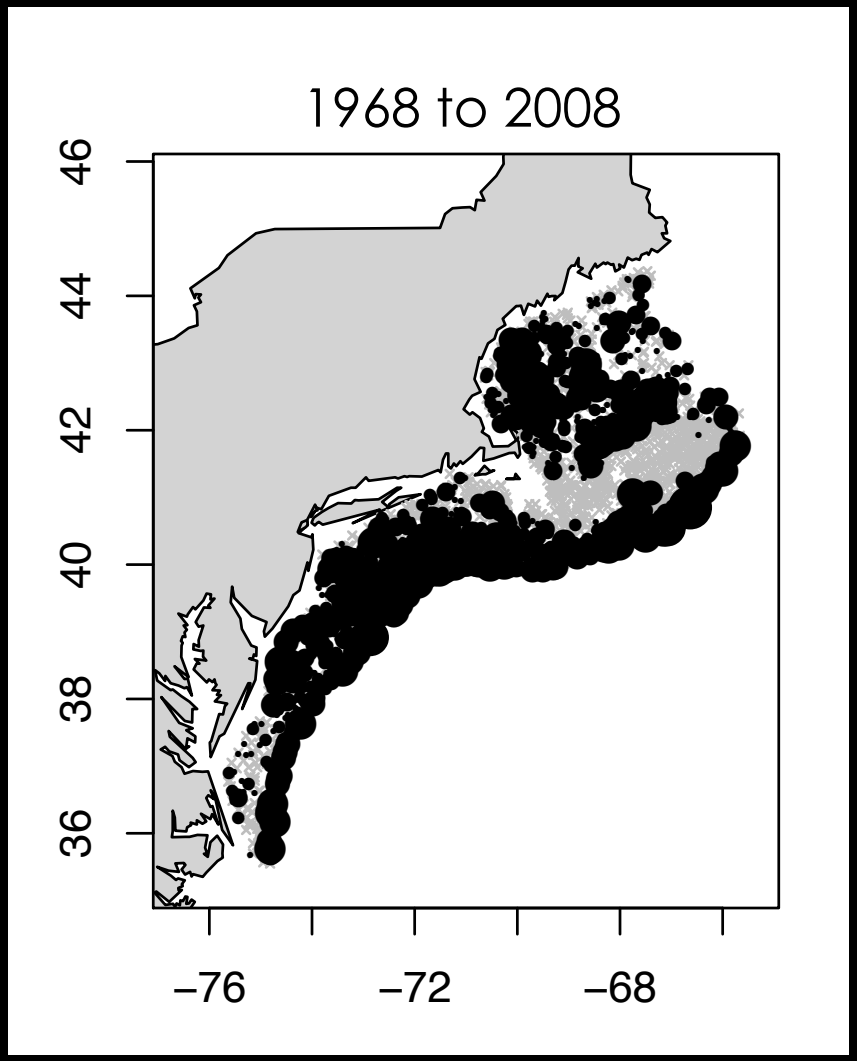
Biomass relative to temperature

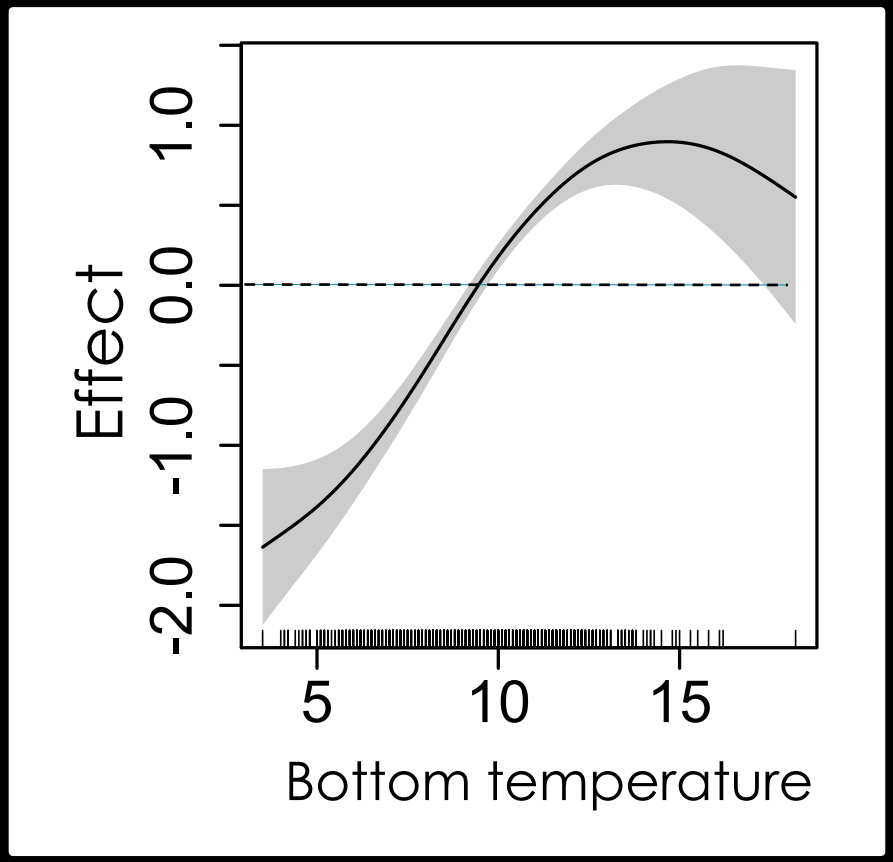






Thermal envelope from Generalized Additive Models





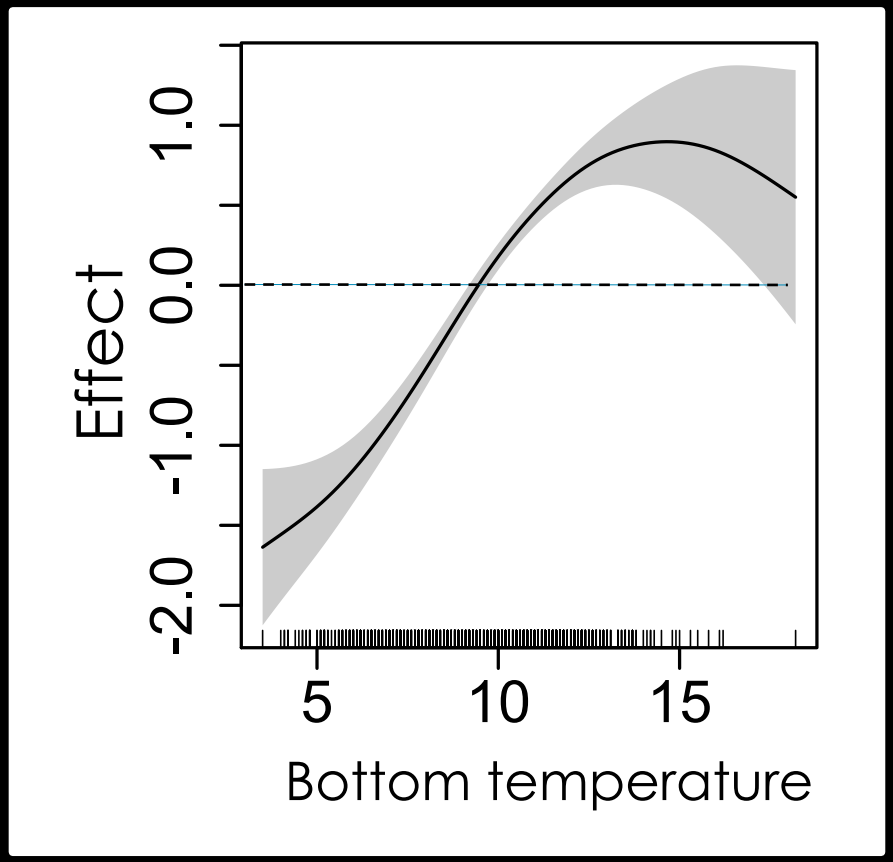
Observed

Absent

Thermal envelope from Generalized Additive Models

p(Present) ~

s(Bottom temperature)

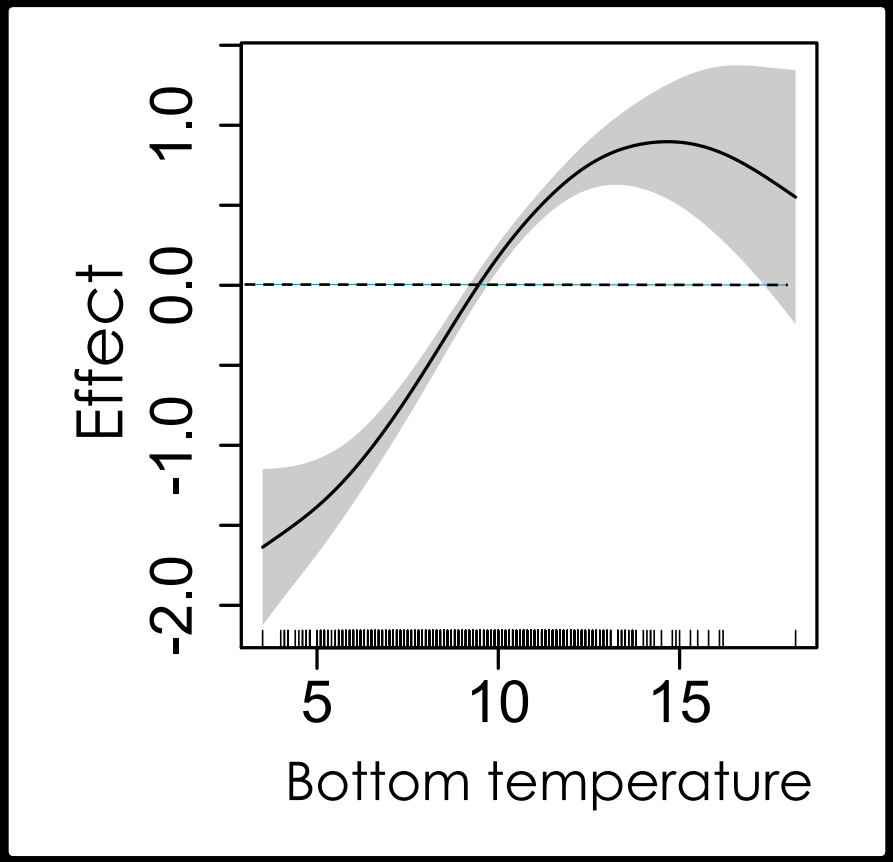


Thermal envelope from Generalized Additive Models

p(Present) ~

s(Bottom temperature) +

s(Surface temperature)



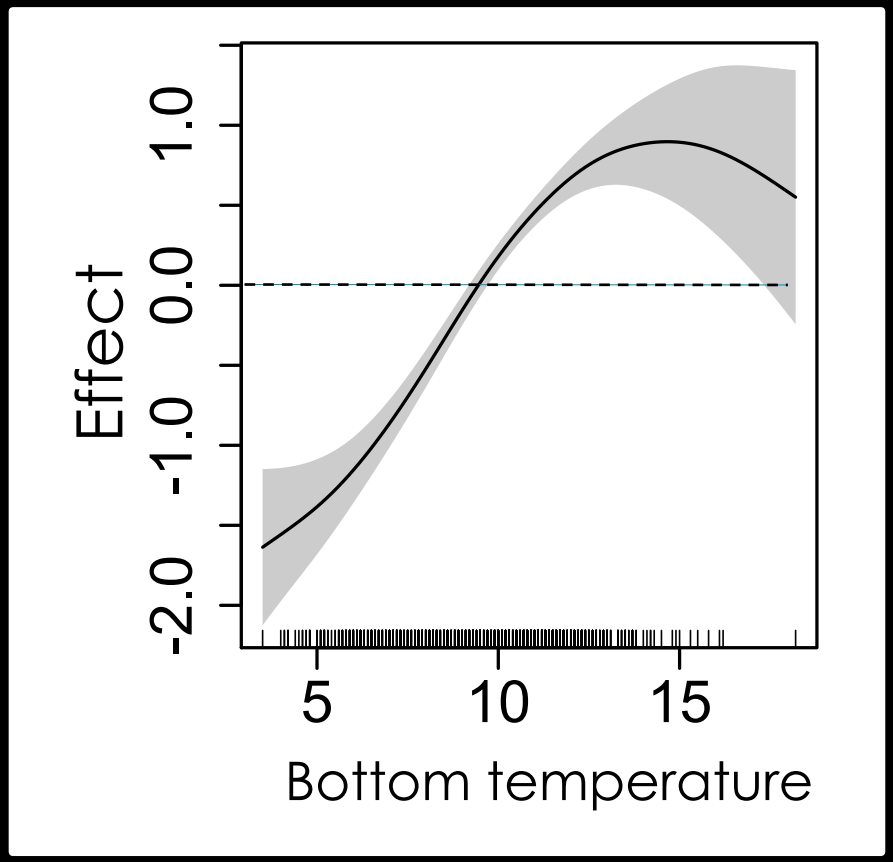
Thermal envelope from Generalized Additive Models

p(Present) ~

s(Bottom temperature) +

s(Surface temperature) +

stratum



Thermal envelope from Generalized Additive Models

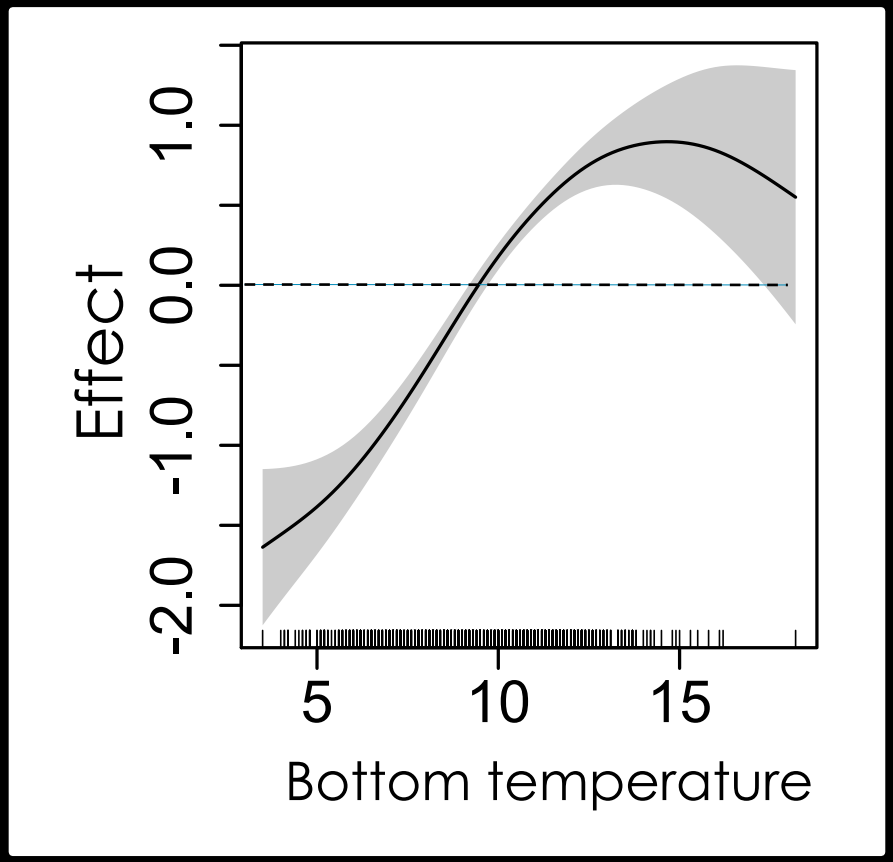
p(Present) ~

s(Bottom temperature) +

s(Surface temperature) +

stratum +

mean biomass



Thermal envelope from Generalized Additive Models

p(Present) ~

s(Bottom temperature) +

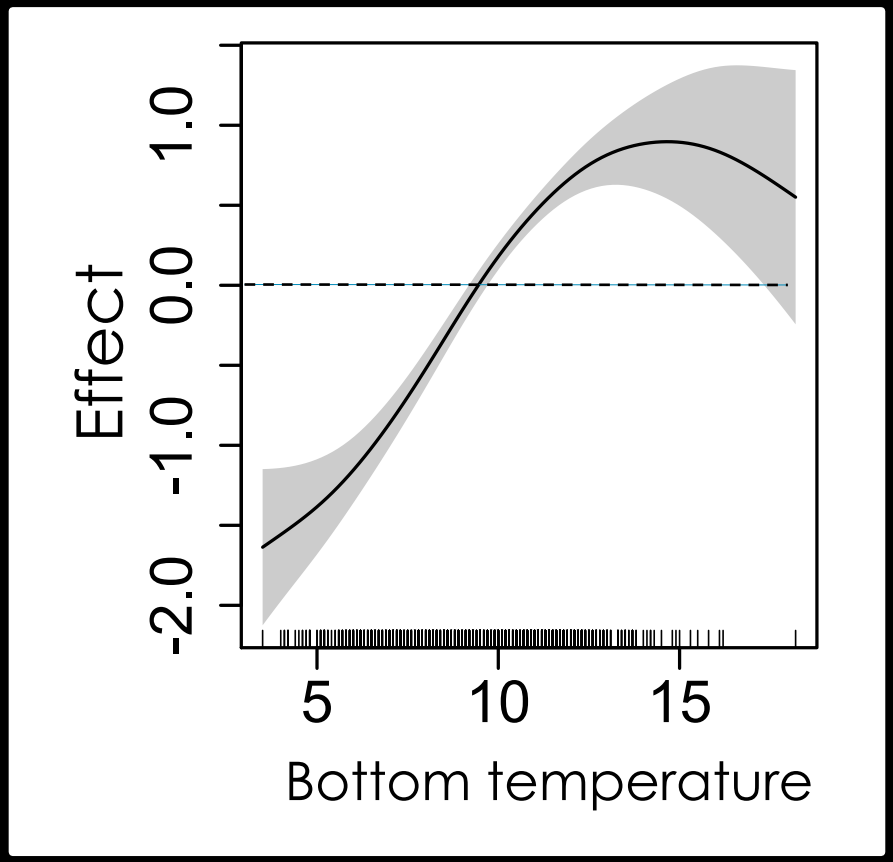
s(Surface temperature) +

stratum +

mean biomass +

e

e ~ Binomial(n,p)



Thermal envelope from Generalized Additive Models

E(log(Biomass) | Present) ~

s(Bottom temperature) +

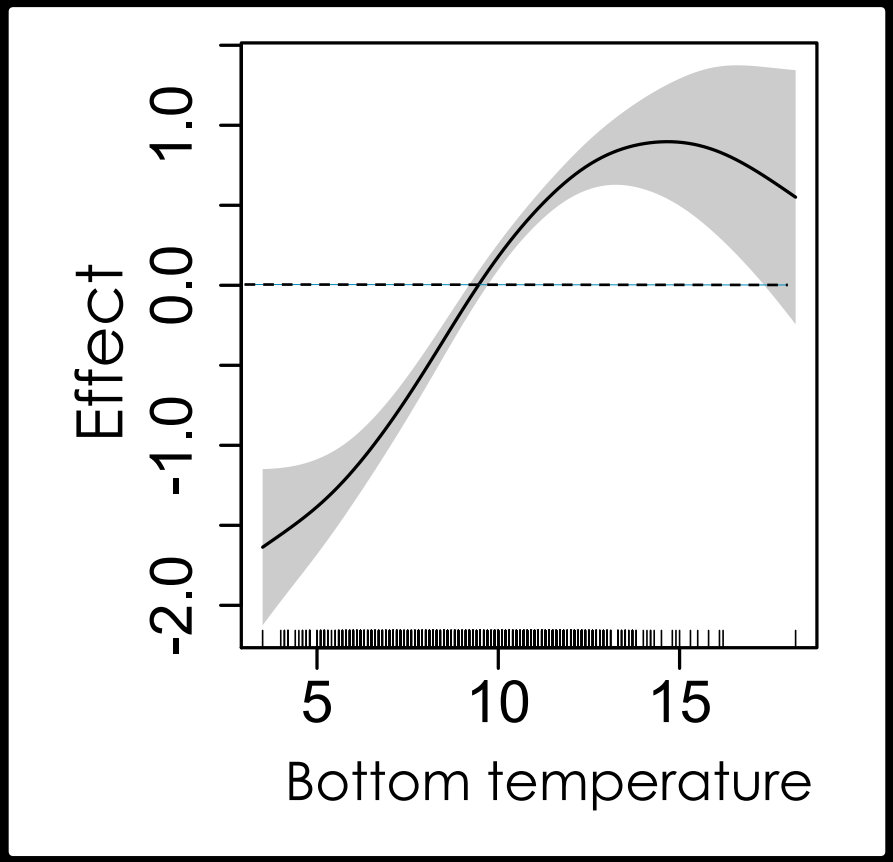
s(Surface temperature) +

stratum +

mean biomass +

e

e ~ Gaussian()



Thermal envelope from Generalized Additive Models

E(log(Biomass) | Present) ~

s(Bottom temperature) +

s(Surface temperature) +

stratum +

mean biomass +

e

P(presence) x E(biomass | present)

Thermal envelope from Generalized Additive Models

E(log(Biomass) | Present) ~

s(Bottom temperature) +

s(Surface temperature) +

stratum +

mean biomass +

e

static through time

Thermal envelope from Generalized Additive Models

E(log(Biomass) | Present) ~

s(Bottom temperature) +

s(Surface temperature) +

stratum + static through time

mean biomass + static through space

e

Thermal envelope from Generalized Additive Models

E(log(Biomass) | Present) ~

s(Bottom temperature) +

s(Surface temperature) +

stratum +

mean biomass +

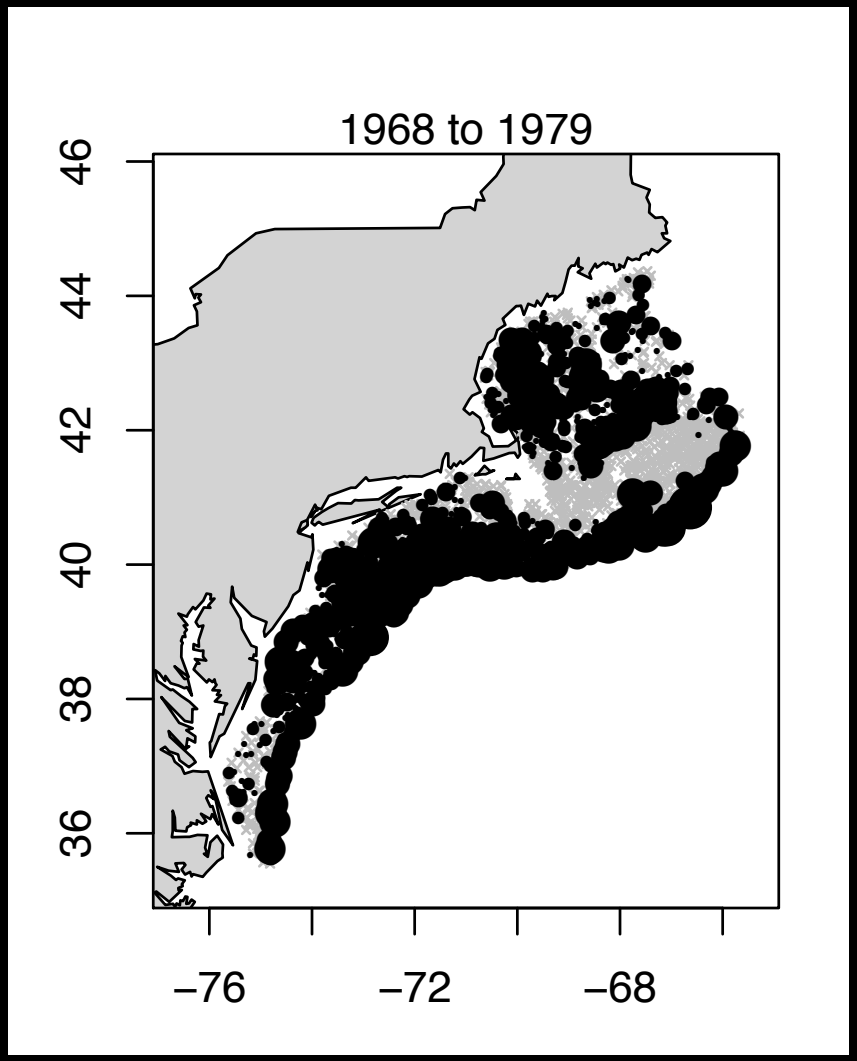
e

range shifts?

static through time

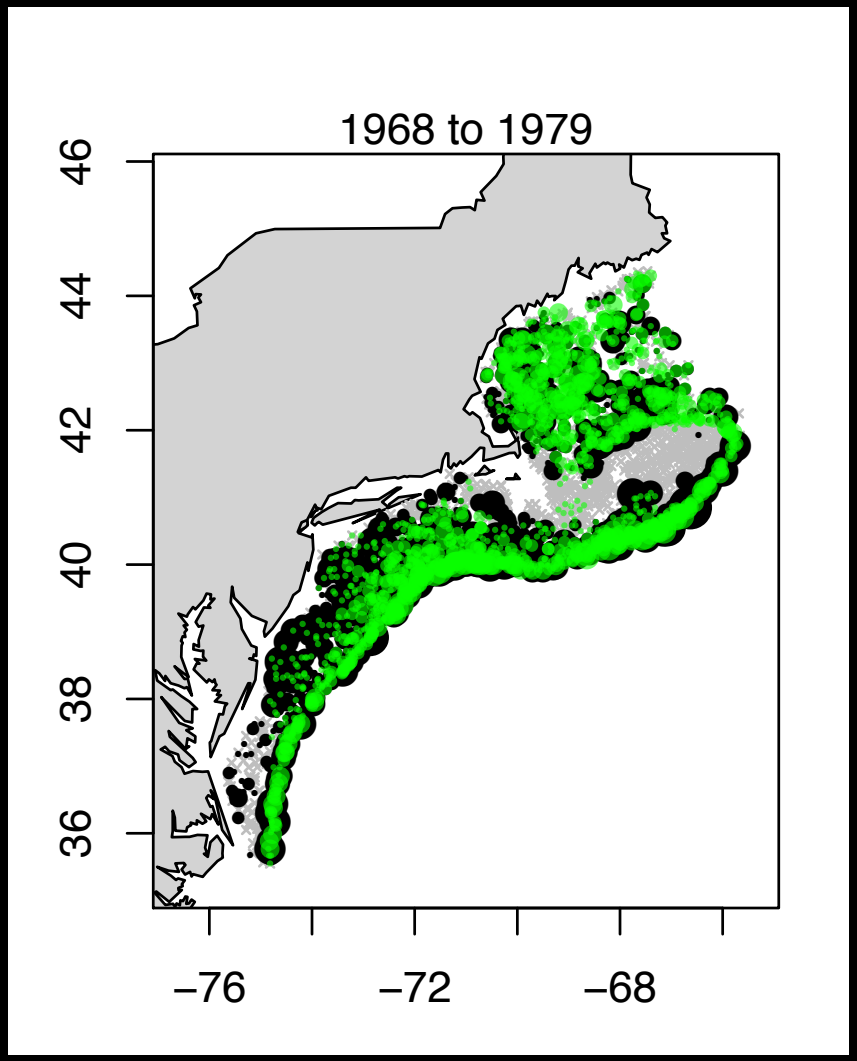
static through space

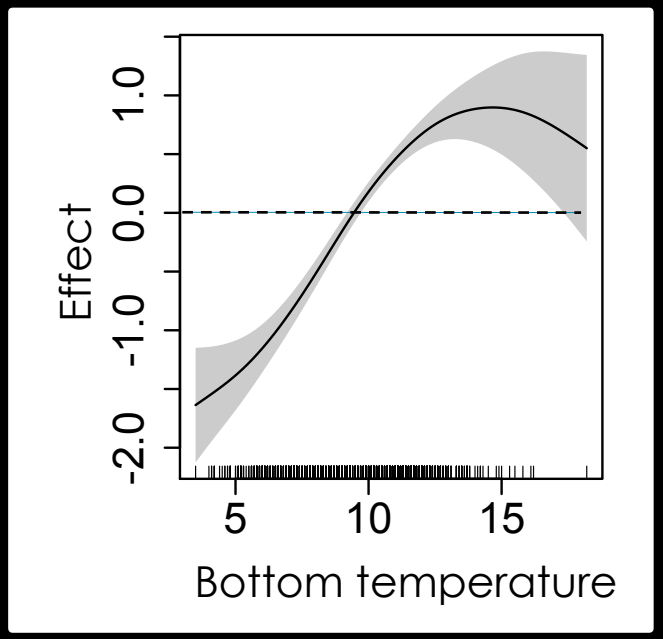
Distribution of Silver hake (*Merluccius bilinearis*)



Observed
Absent

Predicted distribution of Silver hake



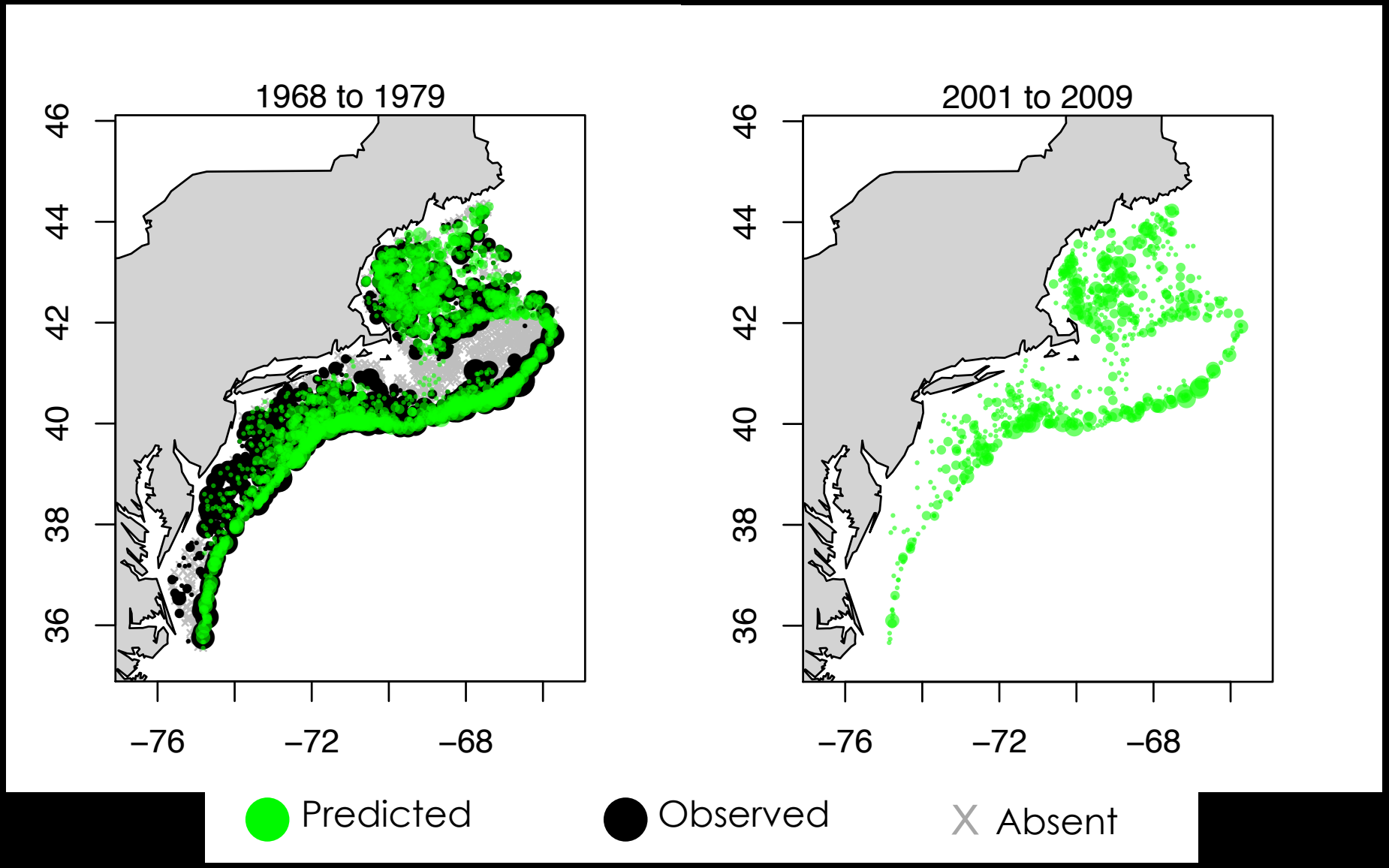


Observed

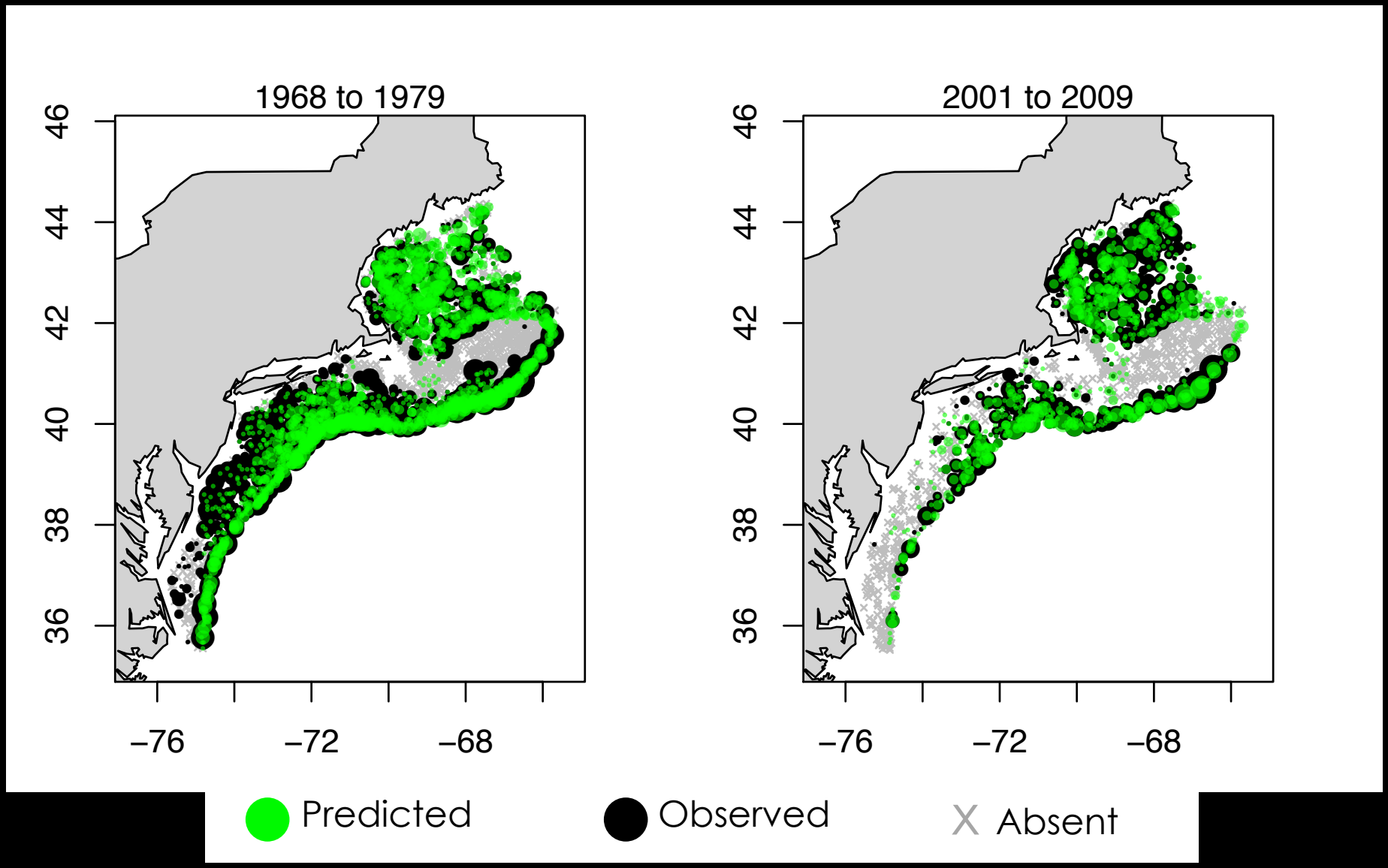
Absent

Predicted

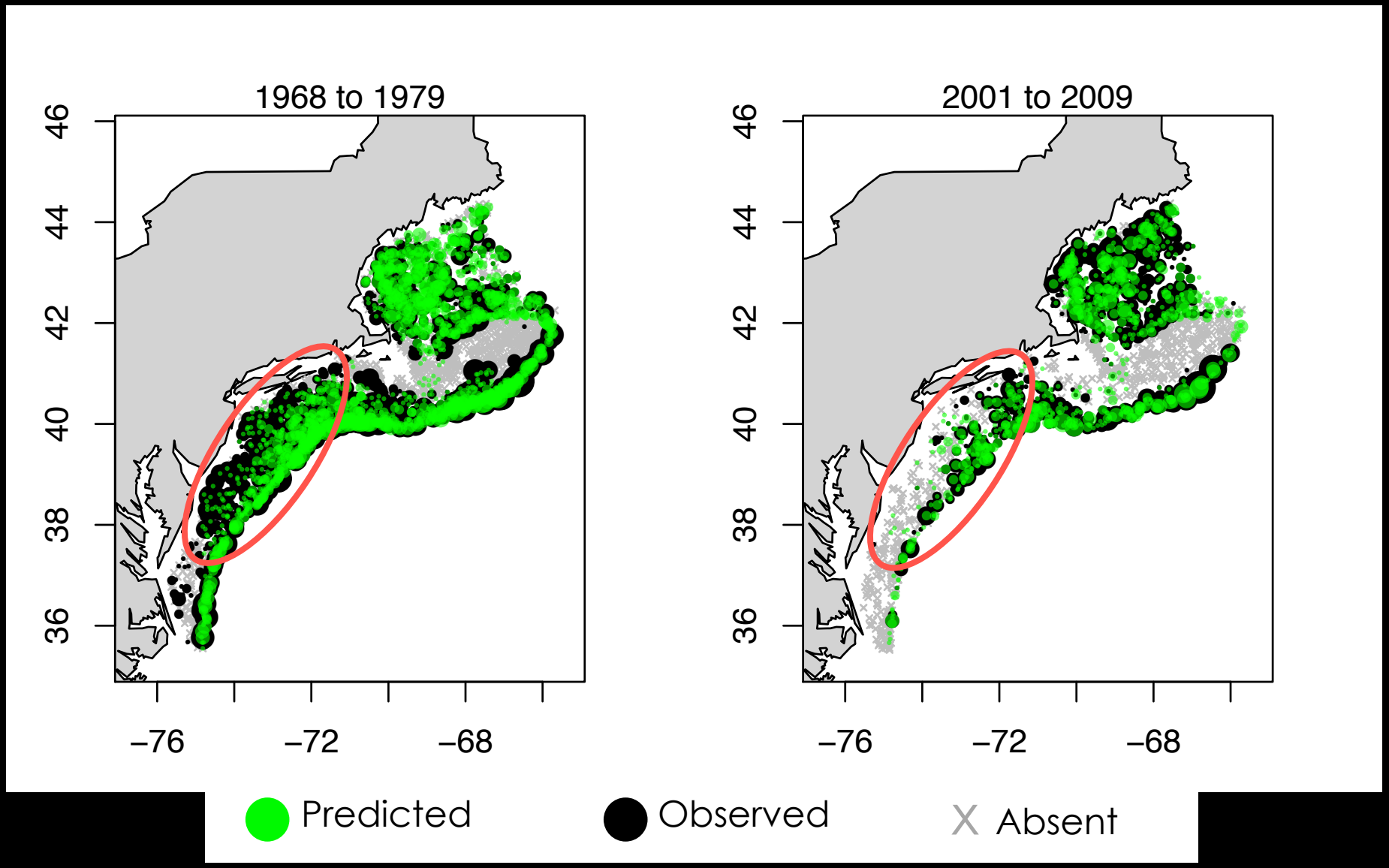
Predicted distribution



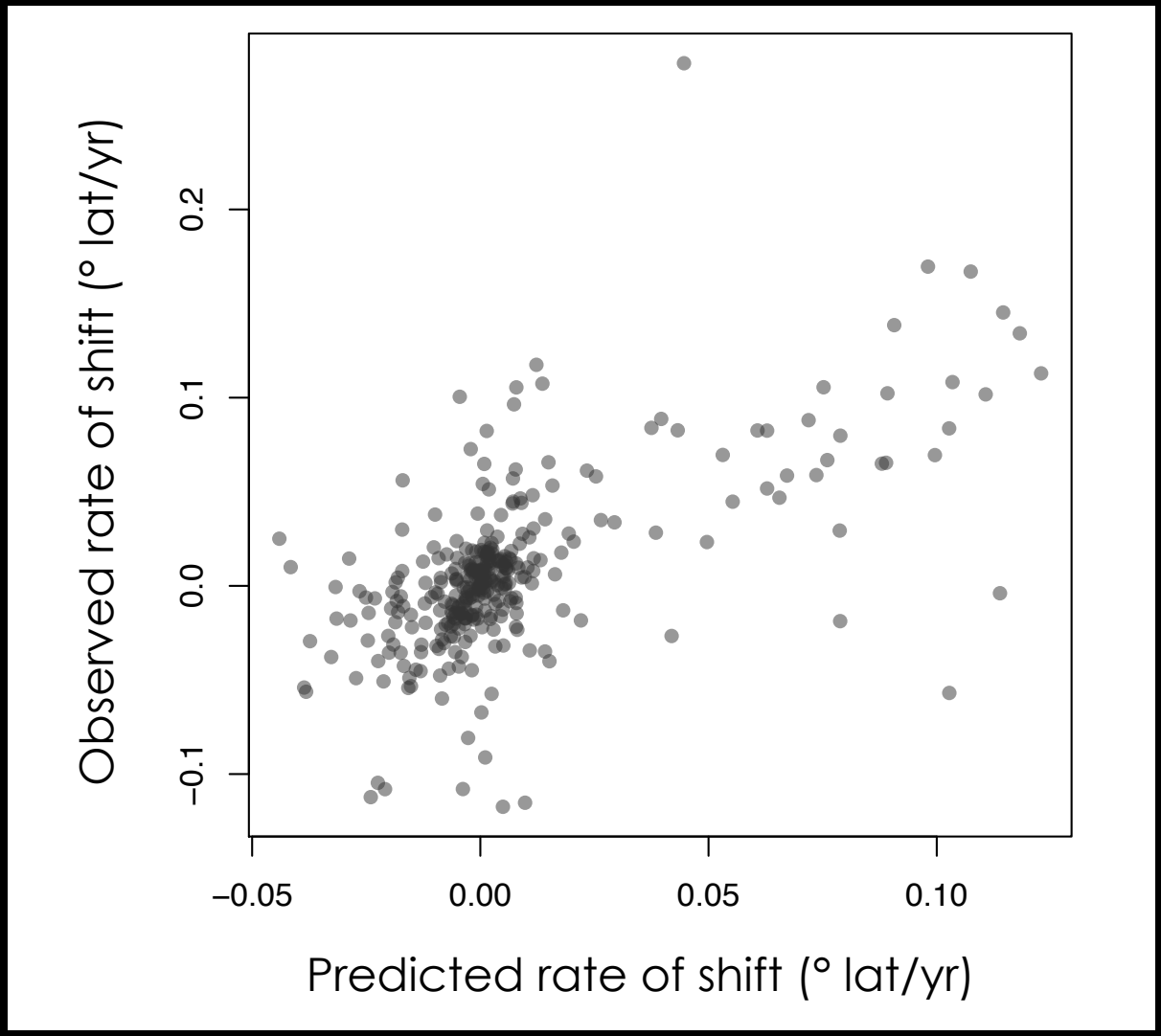
Predicted distribution



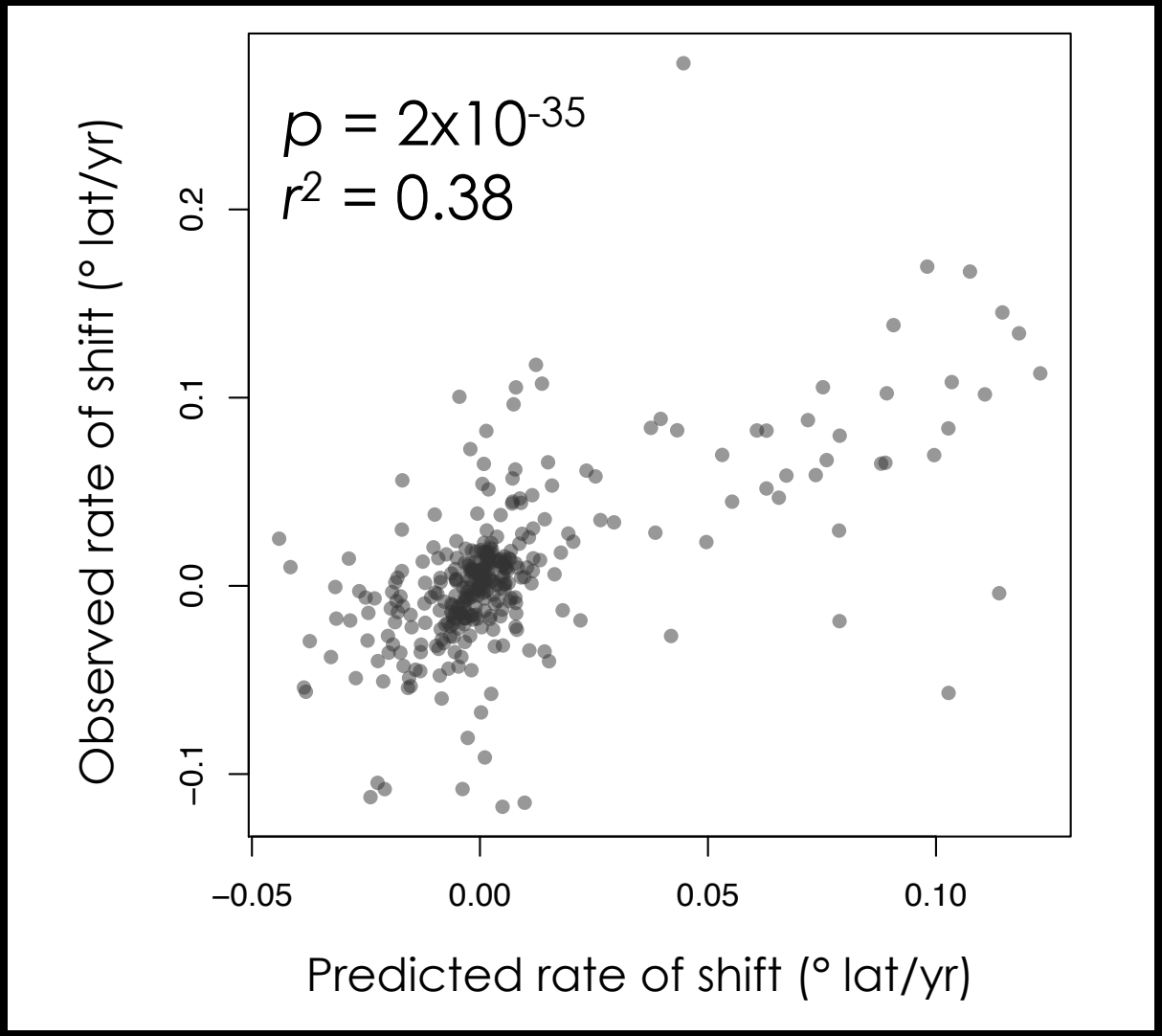
Temperature explains range contractions



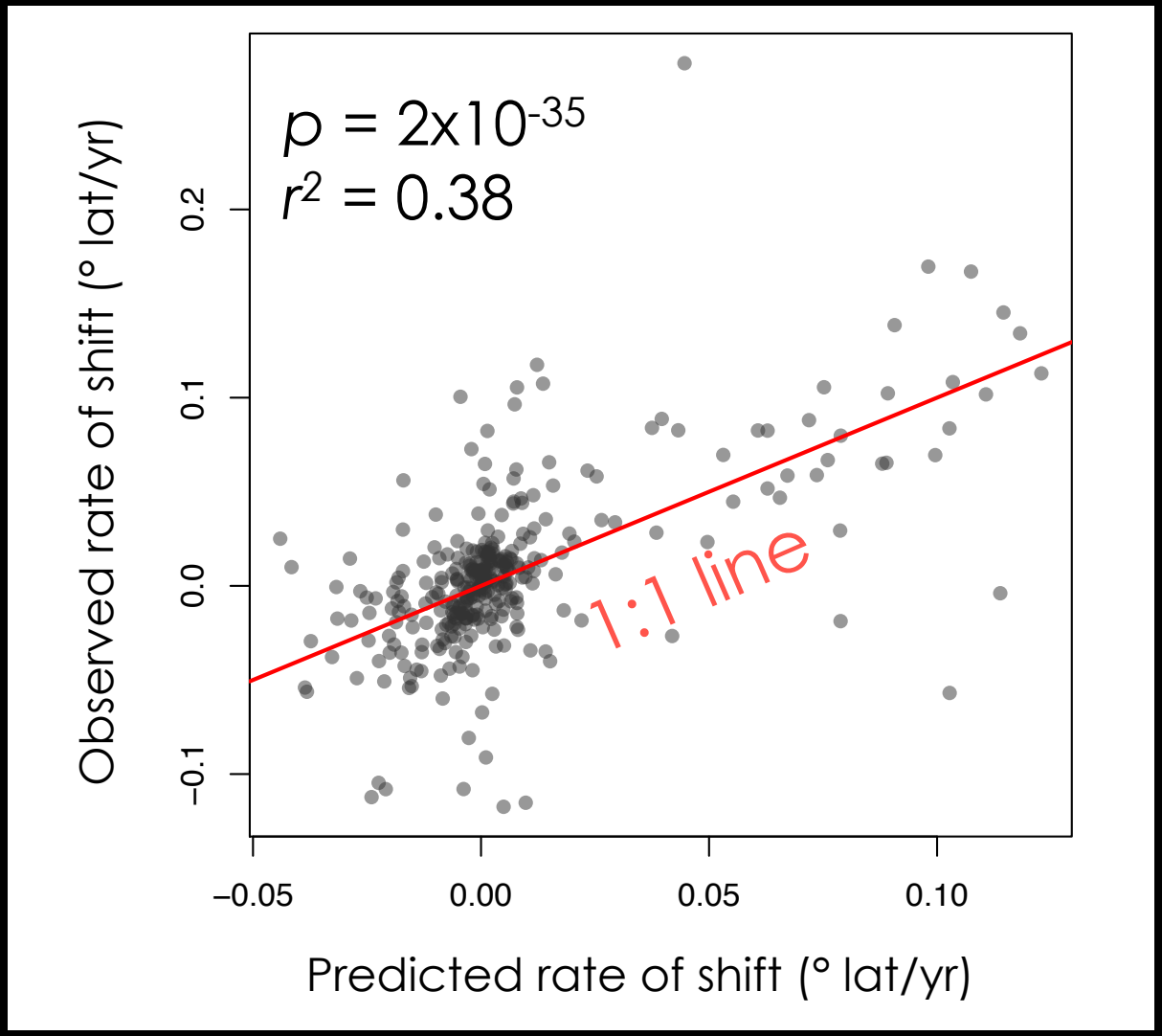
Across 325 populations



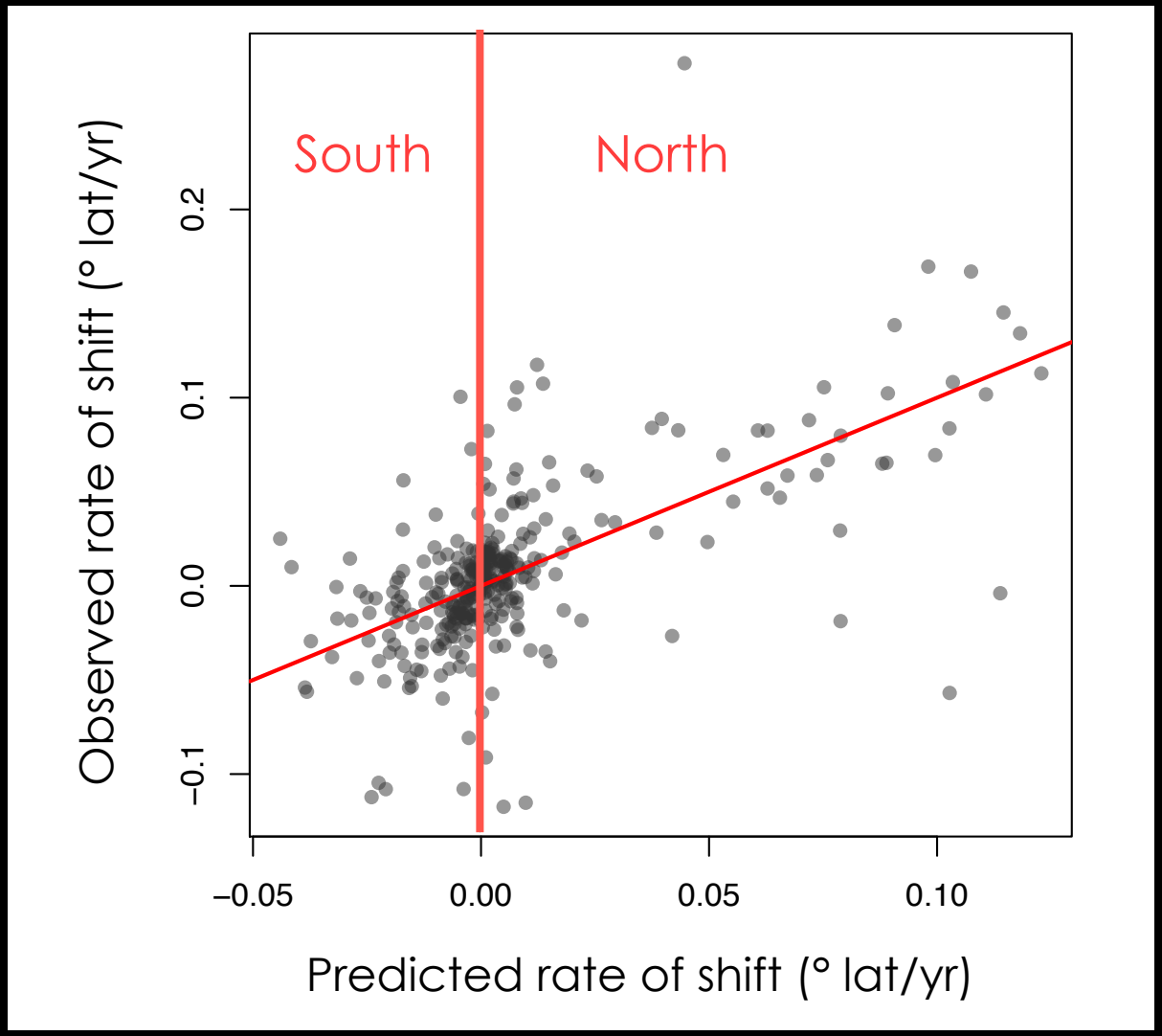
Climate velocity explains shifts



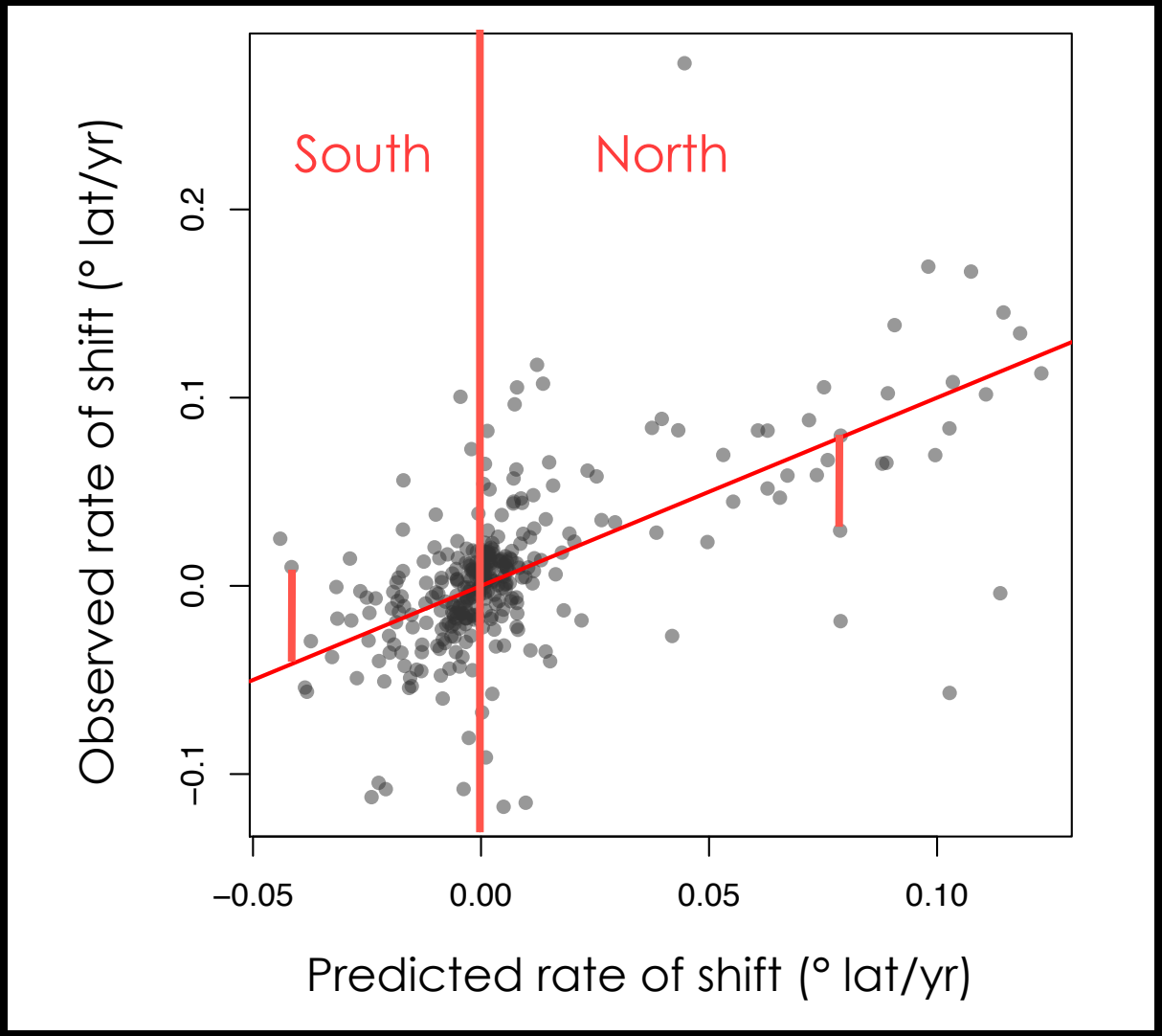
Do populations lag climate velocity?



Do populations lag climate velocity?

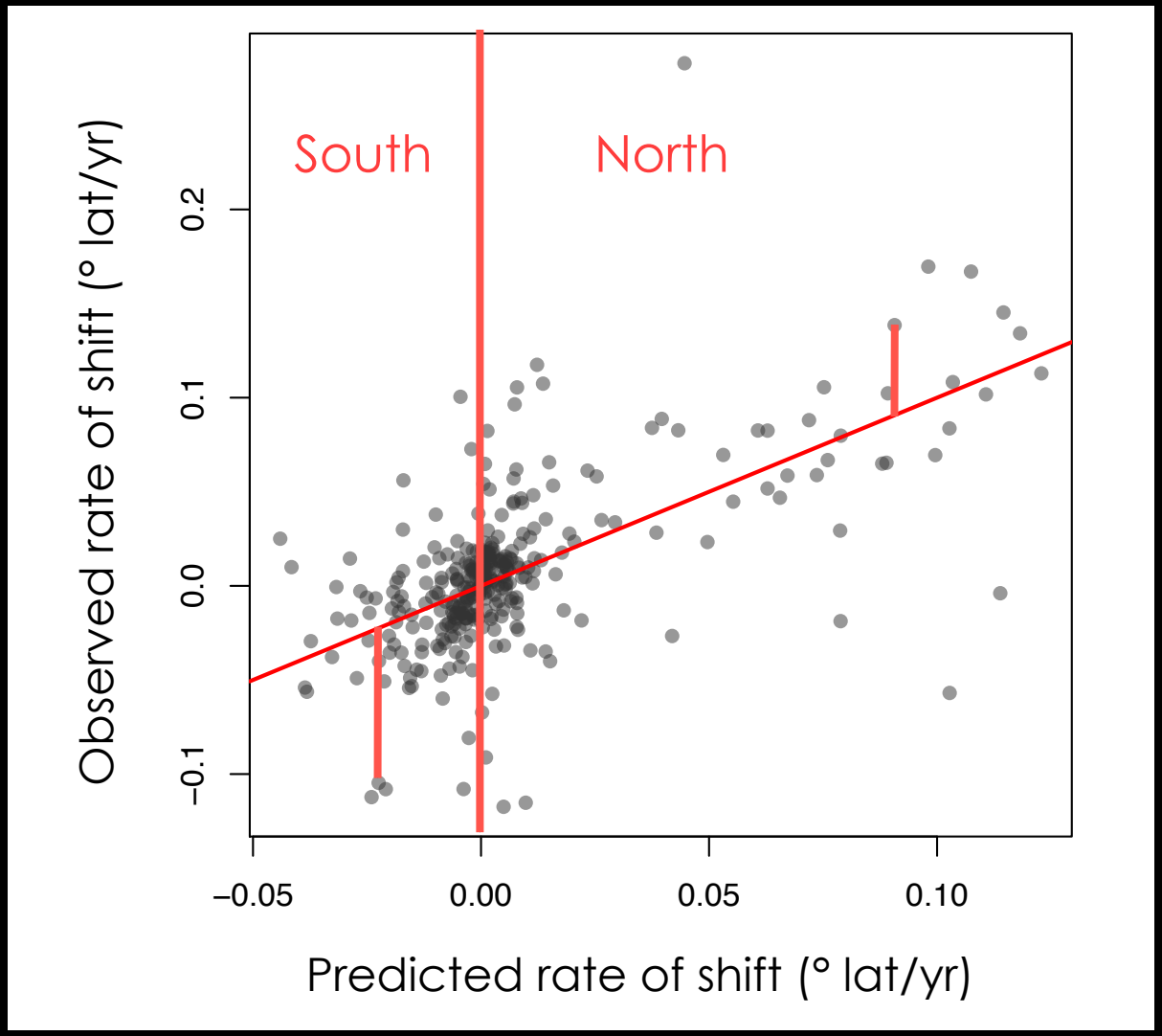


Do populations lag climate velocity?



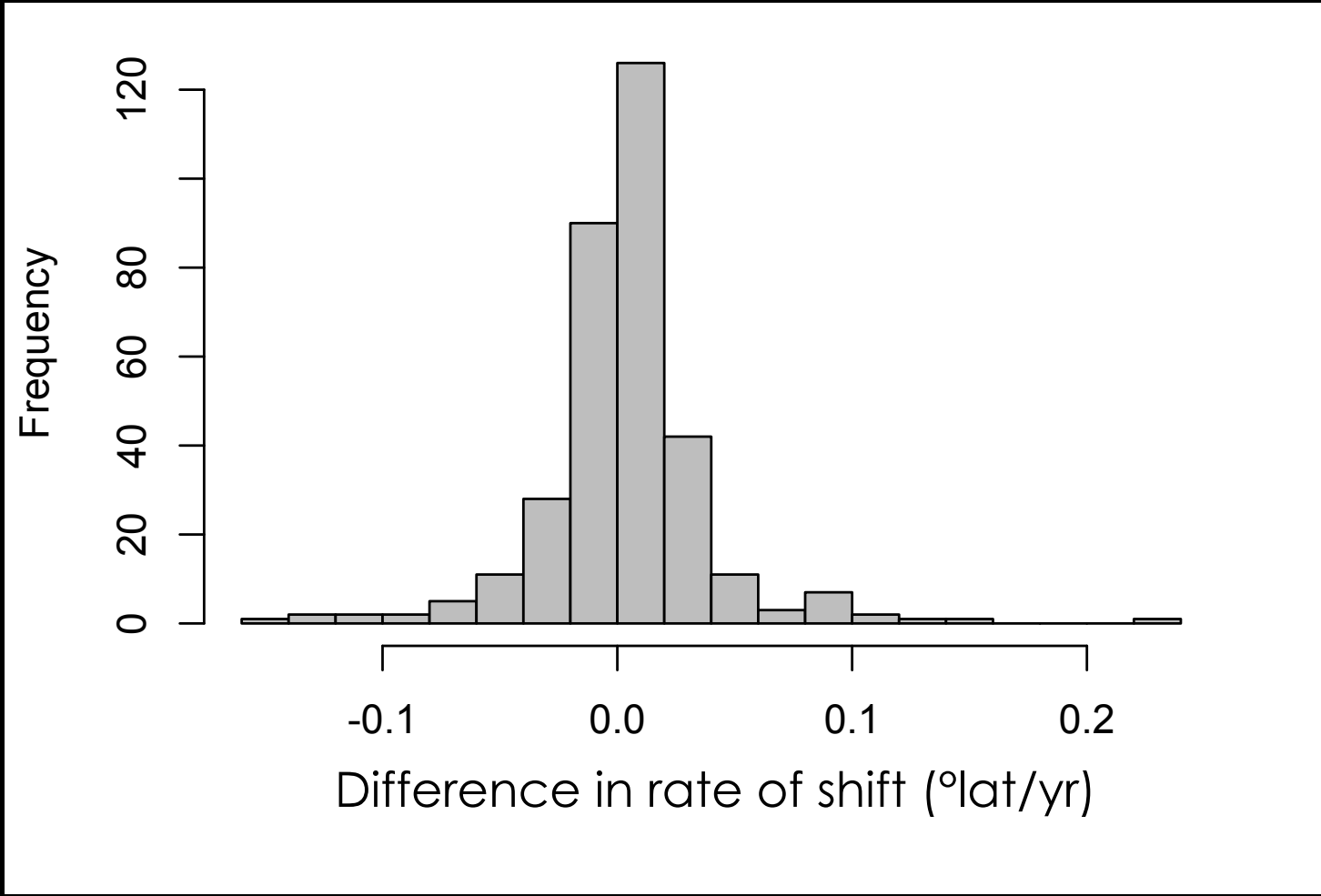
Lagging behind

Do populations lag climate velocity?

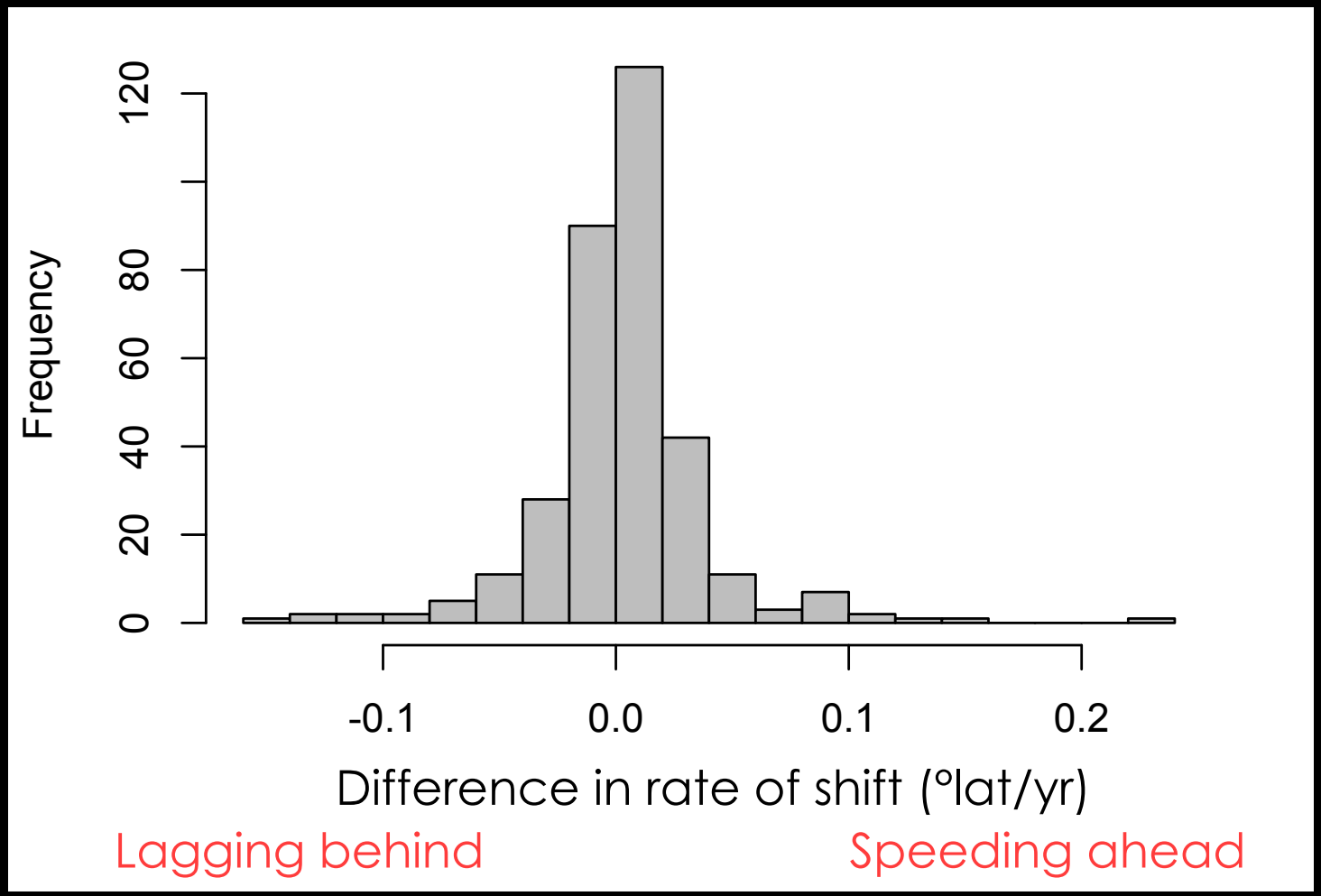


Speeding ahead

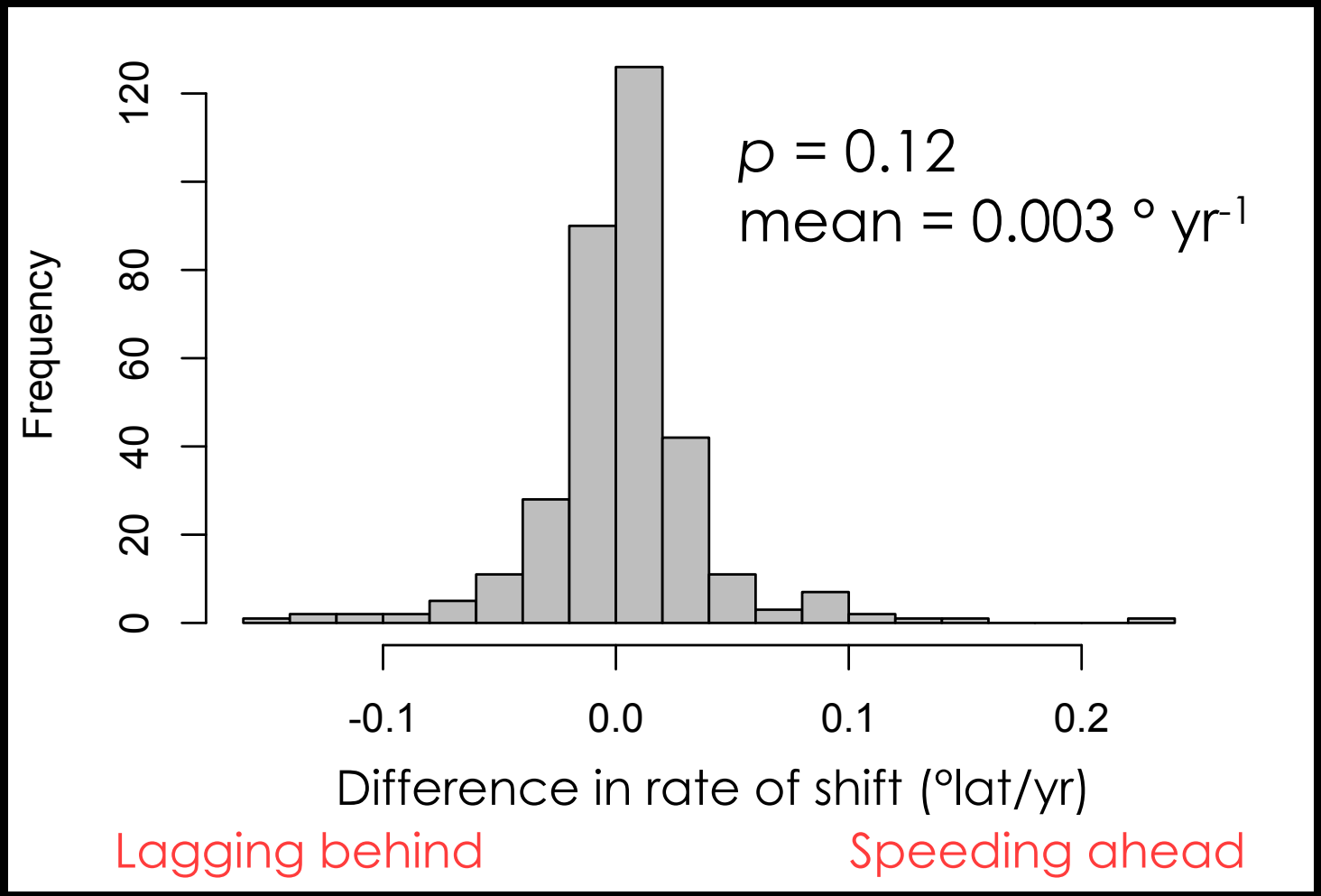
Do populations lag climate velocity?



Do populations lag climate velocity?



No evidence for an overall lag



Outline

- Assemblages and species follow local climate velocities
- Why do some species lag behind?
- How does fishing affect range shifts?
- Do fisheries follow range shifts?

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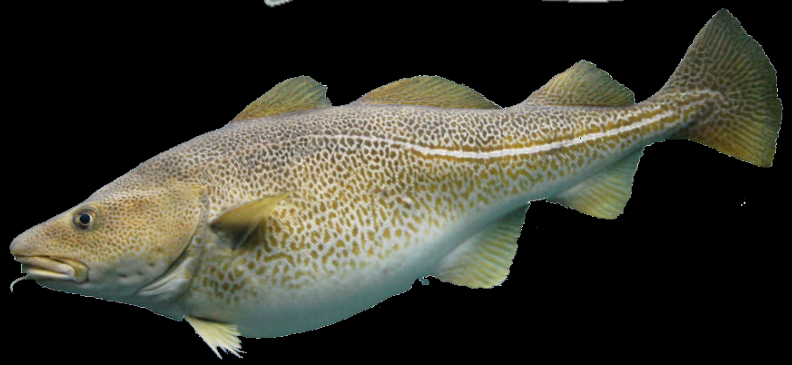
Can we explain different rates?

Observed rate of shift (° lat/yr)

163 fishes and 58 invertebrates



Can we explain different rates?

Observed rate of shift (° lat/yr) ~

Climate velocity

Can we explain different rates?

Observed rate of shift (° lat/yr) ~

- Climate velocity
- Demersal/pelagic

Can we explain different rates?

Observed rate of shift (° lat/yr) ~

- Climate velocity
- Demersal/pelagic
- Commercially fished/not

Can we explain different rates?

Observed rate of shift (° lat/yr) ~

- Climate velocity
- Demersal/pelagic
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- Biomass trend

Can we explain different rates?

Observed rate of shift (° lat/yr) ~

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- Commercially fished/not
- Biomass trend
- Fish/invertebrate

Can we explain different rates?

Observed rate of shift (° lat/yr) ~

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- Fish/invertebrate

Multiple linear regression, simplified by AIC

Lags in fished, demersal species

Observed shift =

+ Climate velocity

+ 0.005 x Unfished

+ 0.012 x Pelagic

$r^2 = 0.32$

$p < 1\text{x}10^{-10}$

Lags in fished, demersal species

Observed shift =

+ Climate velocity

+ 0.005 x Unfished

+ 0.012 x Pelagic

Fished species shift slower

$r^2 = 0.32$

$p < 1 \times 10^{-10}$

Lags in fished, demersal species

Observed shift =

+ Climate velocity

+ 0.005 x Unfished

+ 0.012 x Pelagic

Fished species shift slower

Demersal species shift slower

$r^2 = 0.32$

$p < 1 \times 10^{-10}$

Lags in fished, demersal species

Observed shift =

+ Climate velocity

+ 0.005 x Unfished

+ 0.012 x Pelagic

$r^2 = 0.31$

$r^2 = 0.32$

$p < 1 \times 10^{-10}$

Lags in fished, demersal species

Observed shift =

+ Climate velocity

+ 0.005 x Unfished

+ 0.012 x Pelagic

$r^2 = 0.31$

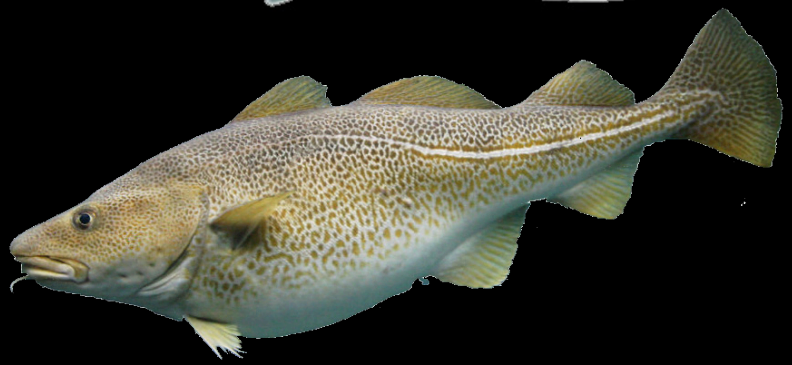
$r^2 = 0.32$

$p < 1 \times 10^{-10}$

Can we explain rates for fishes?

Observed rate of shift (° lat/yr)

163 fishes



Can we explain rates for fishes?

Observed rate of shift (° lat/yr) ~

- Climate velocity
- Demersal/pelagic
- Commercially fished/not
- Biomass trend

Can we explain rates for fishes?

Observed rate of shift (° lat/yr) ~

- Climate velocity
- Demersal/pelagic
- Commercially fished/not
- Biomass trend
- Maximum length

Can we explain rates for fishes?

Observed rate of shift (° lat/yr) ~

- Climate velocity
- Demersal/pelagic
- Commercially fished/not
- Biomass trend
- Maximum length
- Trophic level

Can we explain rates for fishes?

Observed rate of shift (° lat/yr) ~

- Climate velocity
- Demersal/pelagic
- Commercially fished/not
- Biomass trend
- Maximum length
- Trophic level
- Growth rate

Can we explain rates for fishes?

Observed rate of shift (° lat/yr) ~

- Climate velocity
- Demersal/pelagic
- Commercially fished/not
- Biomass trend
- Maximum length
- Trophic level
- Growth rate
- Lifespan

Lags in fished, demersal fishes

Observed shift =

+ Climate velocity

+ 0.012 x Unfished

+ 0.028 x Pelagic

$r^2 = 0.50$

$p < 1 \times 10^{-10}$

Lags in fished, demersal fishes

Observed shift =

+ Climate velocity

+ 0.012 x Unfished

+ 0.028 x Pelagic

$r^2 = 0.44$

$r^2 = 0.50$

$p < 1 \times 10^{-10}$

Outline

- Assemblages and species follow local climate velocities
- Fished, demersal species shift slightly slower
- Does fishing affect range shifts?
- Do fisheries follow range shifts?

Outline

- Assemblages and species follow local climate velocities
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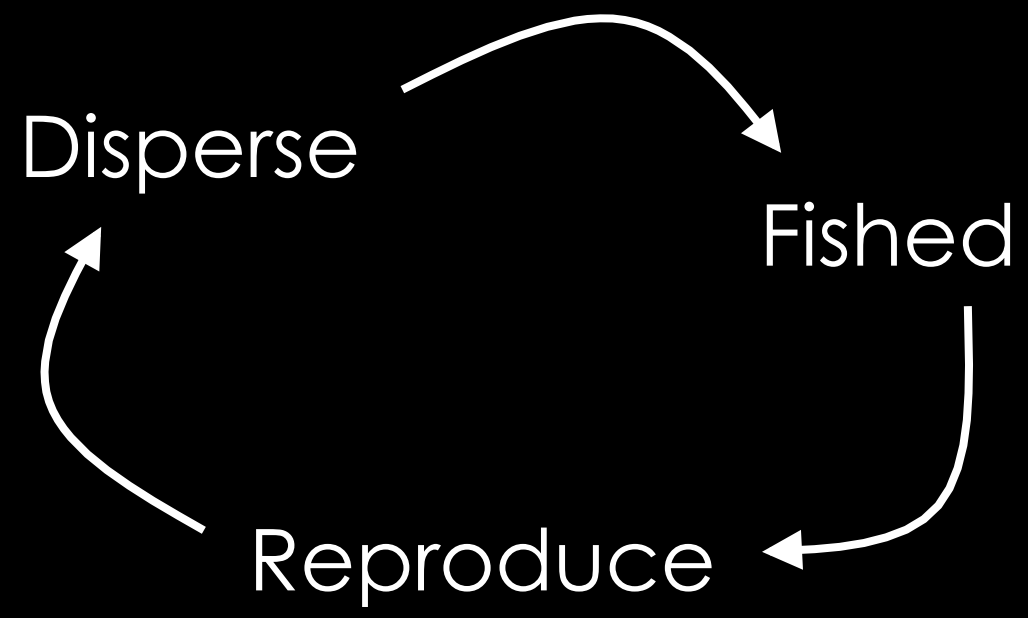
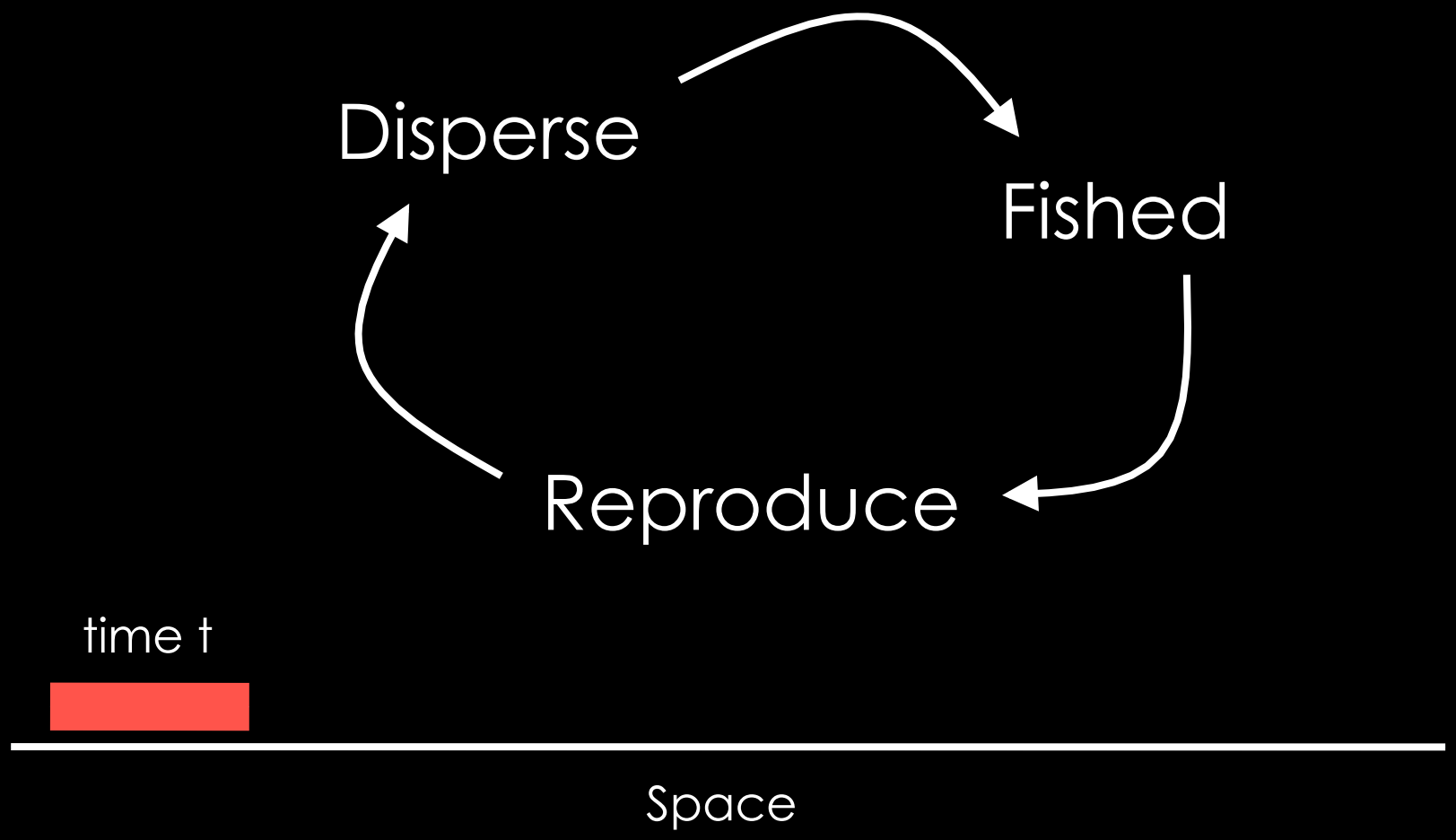
Model for a species' range



with Emma Fuller & Eleanor Brush

Model for a species' range



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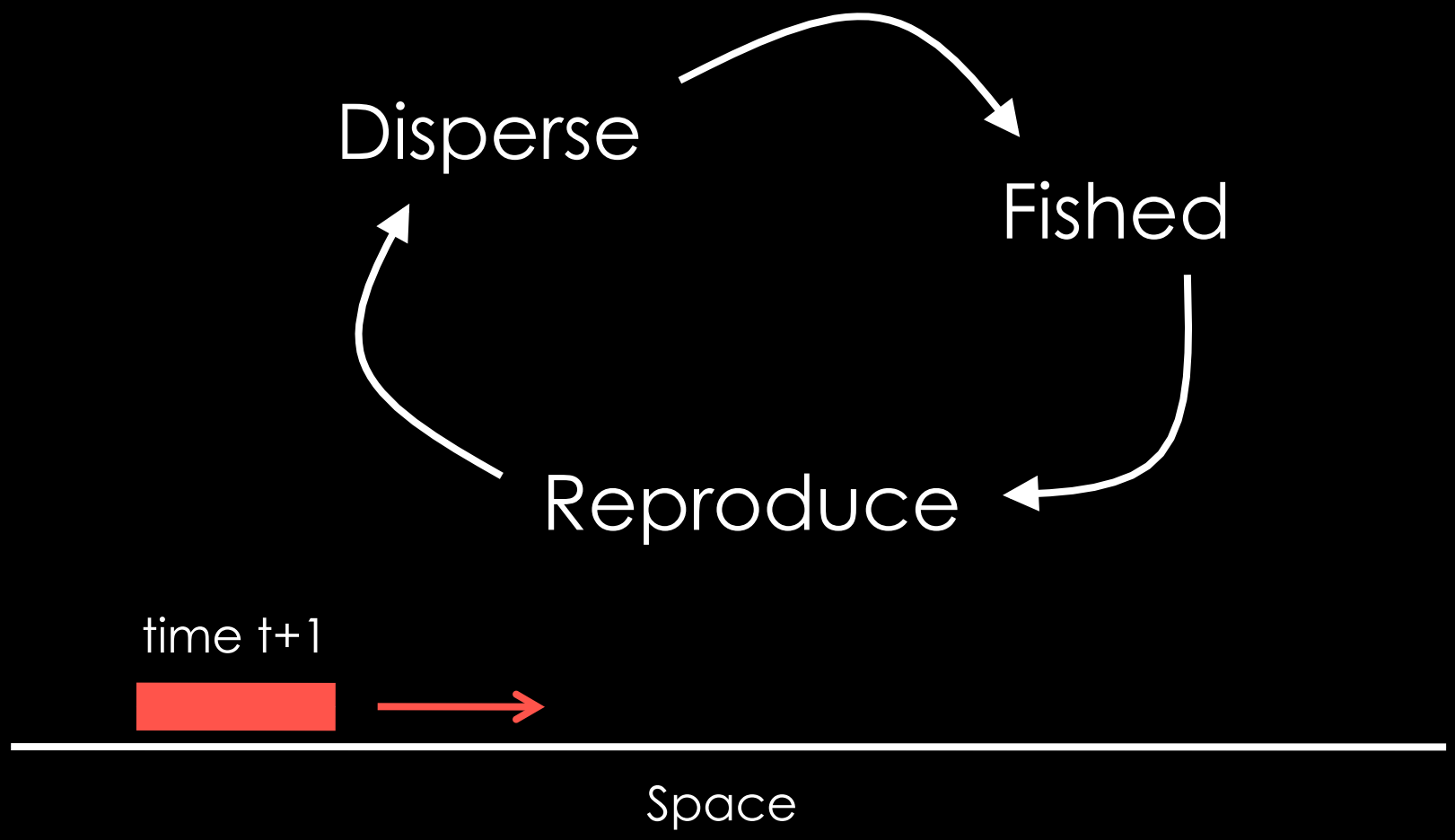

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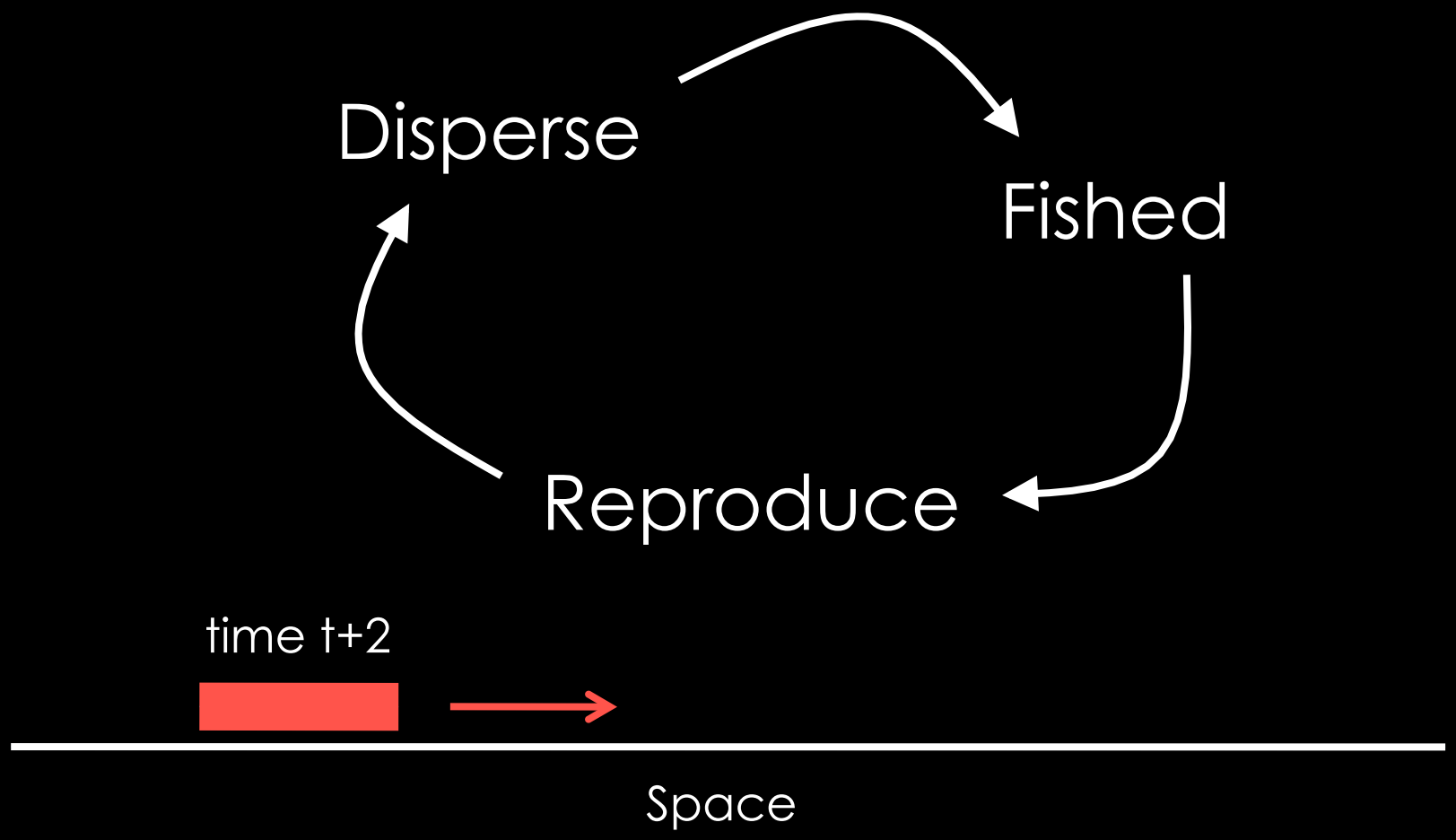
Model for a species' range



with Emma Fuller & Eleanor Brush

Model for a species' range

$$n_{t+1}(x) =$$

offspring

with Emma Fuller & Eleanor Brush

Model for a species' range

$$n_{t+1}(x) = f(a_t(y))$$

offspring

reproduction

with Emma Fuller & Eleanor Brush

Model for a species' range

adults

$$n_{t+1}(x) = f(a_t(y))$$

offspring

reproduction

with Emma Fuller & Eleanor Brush

Model for a species' range

adults

$$n_{t+1}(x) = k(x-y)f(a_t(y))$$

offspring

dispersal

reproduction

with Emma Fuller & Eleanor Brush

Model for a species' range

adults

$$n_{t+1}(x) = \int_{-L/2+ct}^{L/2+ct} k(x-y) f(a_t(y)) dy$$

offspring habitat dispersal reproduction

with Emma Fuller & Eleanor Brush

Model for a species' range

adults

$$n_{t+1}(x) = \int_{-L/2+ct}^{L/2+ct} k(x-y) f(a_t(y)) dy$$

adults

$$a_t(y) =$$

with Emma Fuller & Eleanor Brush

Model for a species' range

adults

$$n_{t+1}(x) = \int_{-L/2+ct}^{L/2+ct} k(x-y) f(a_t(y)) dy$$

adults offspring

$$a_t(y) = n_t(y)$$

with Emma Fuller & Eleanor Brush

Model for a species' range

adults

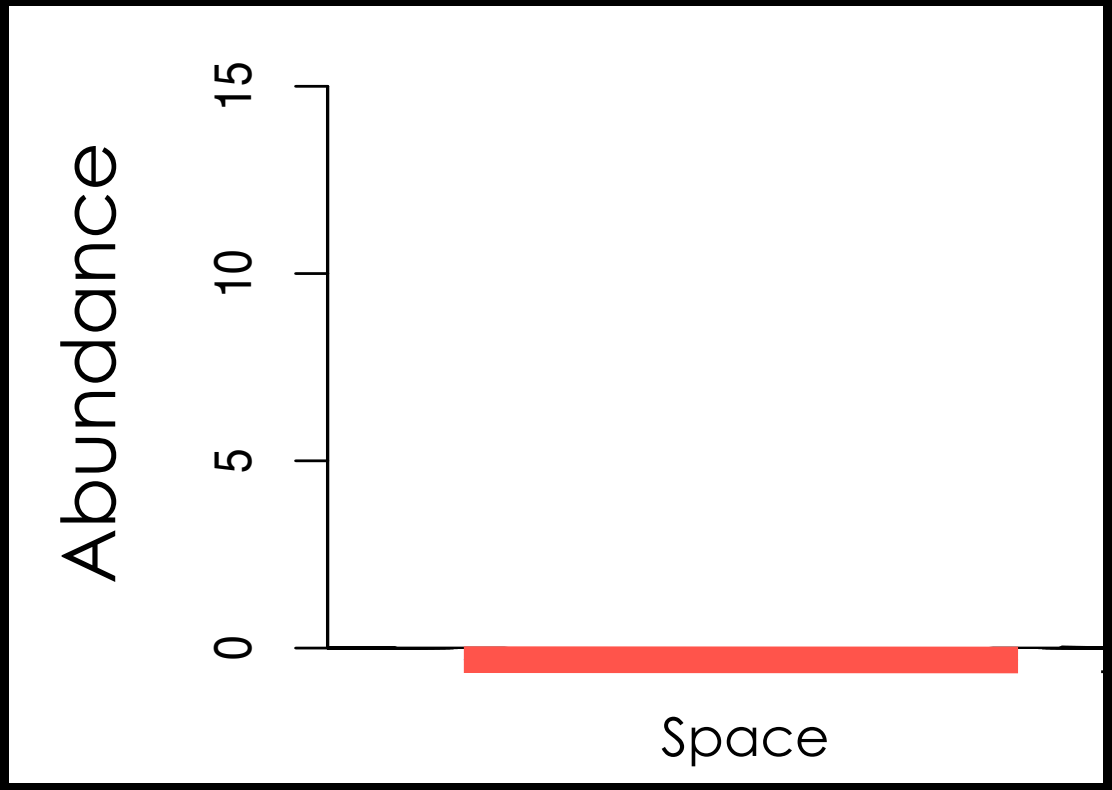
$$n_{t+1}(x) = \int_{-L/2+ct}^{L/2+ct} k(x-y) f(a_t(y)) dy$$

adults offspring harvest

$$a_t(y) = n_t(y) - h(n_t(y))$$

with Emma Fuller & Eleanor Brush

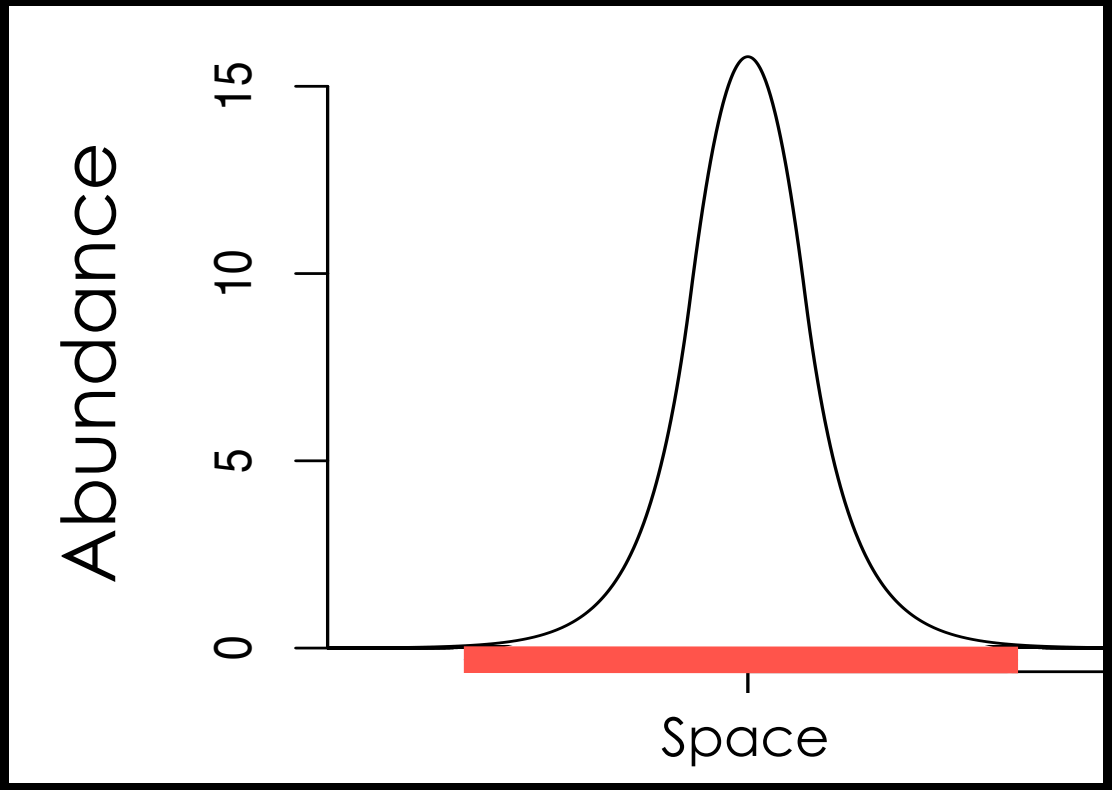
Idealized species range



Habitable environment

with Emma Fuller & Eleanor Brush

Idealized species range

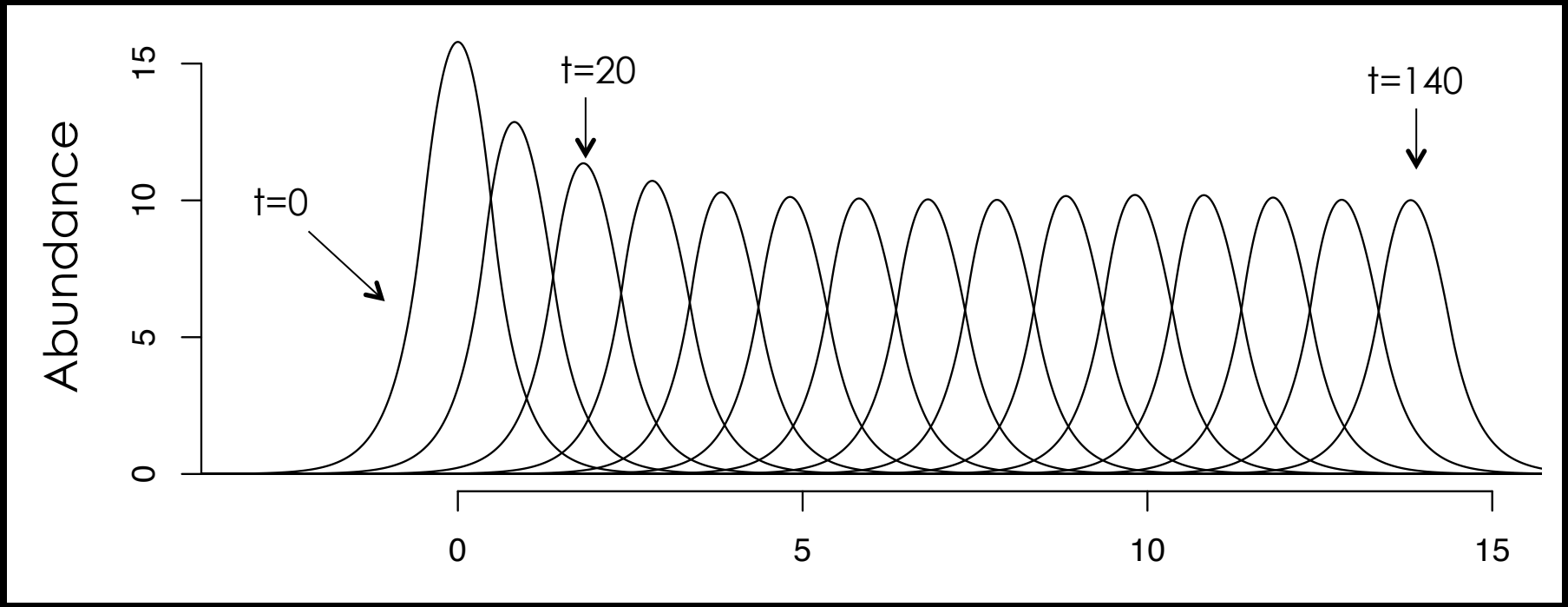


Habitable environment

with Emma Fuller & Eleanor Brush

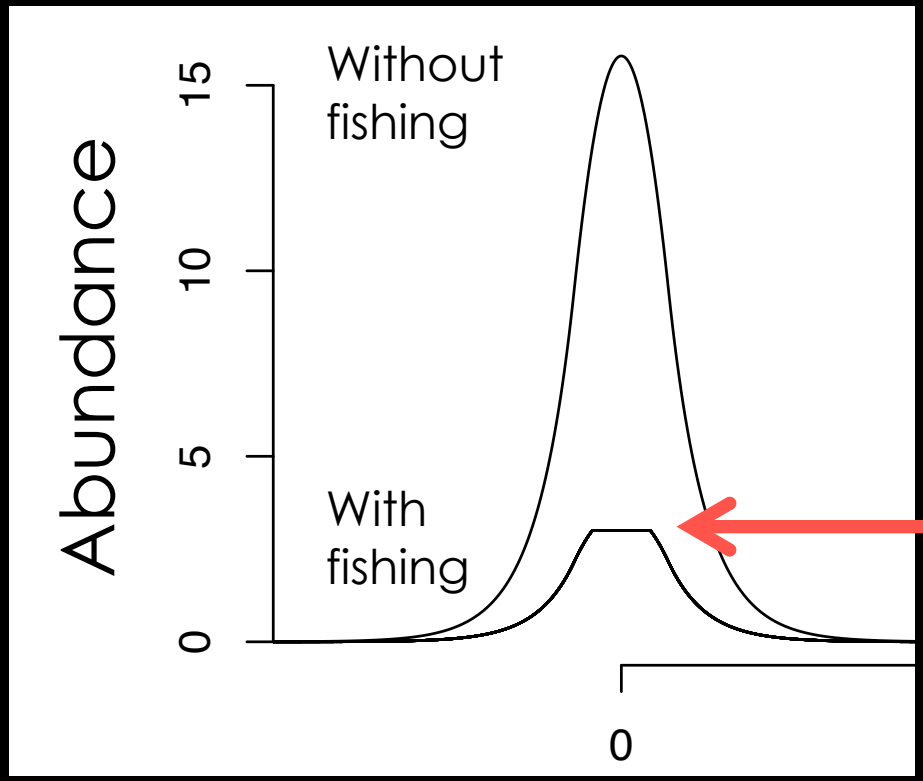
With climate: no fishing

Population shifts with climate



with Emma Fuller & Eleanor Brush

Fishing: constant escapement



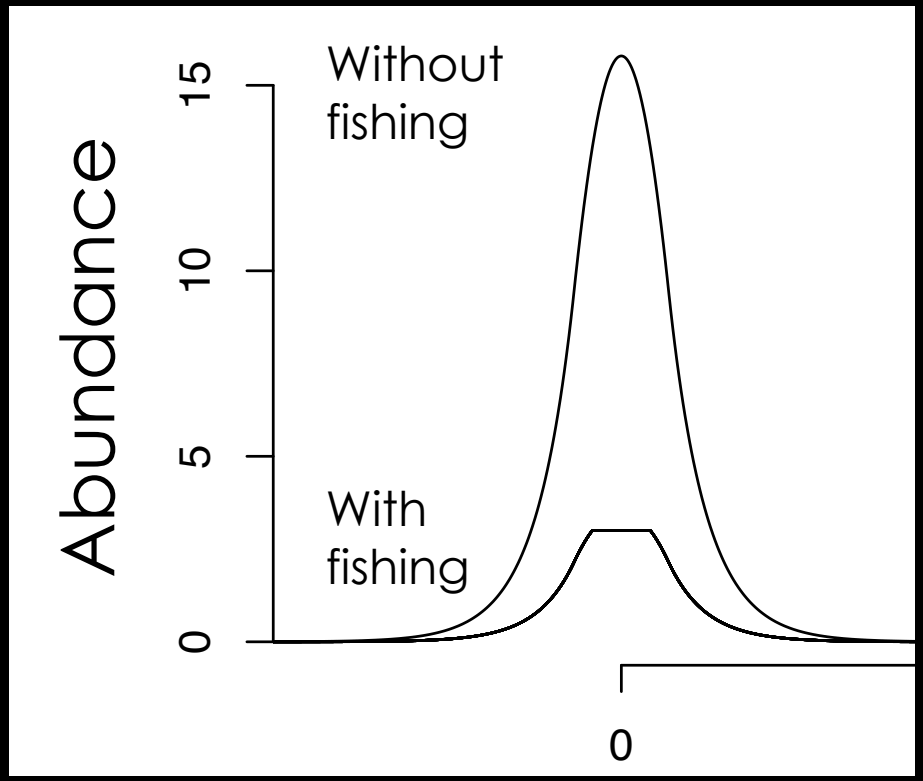
Harvest all fish above a threshold density

Threshold

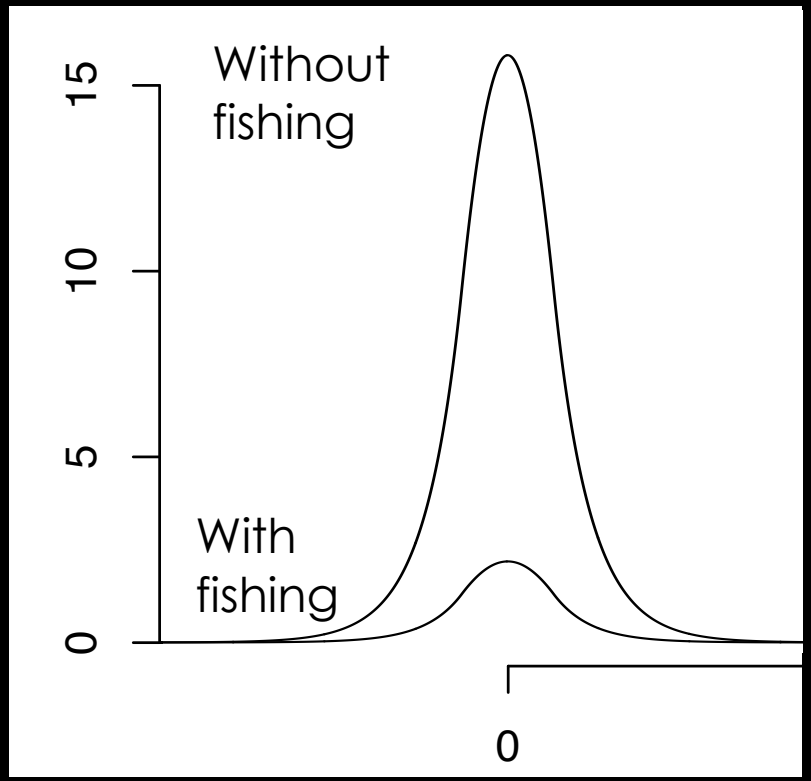
with Emma Fuller & Eleanor Brush

Fishing: constant harvest rate

Constant Escapement



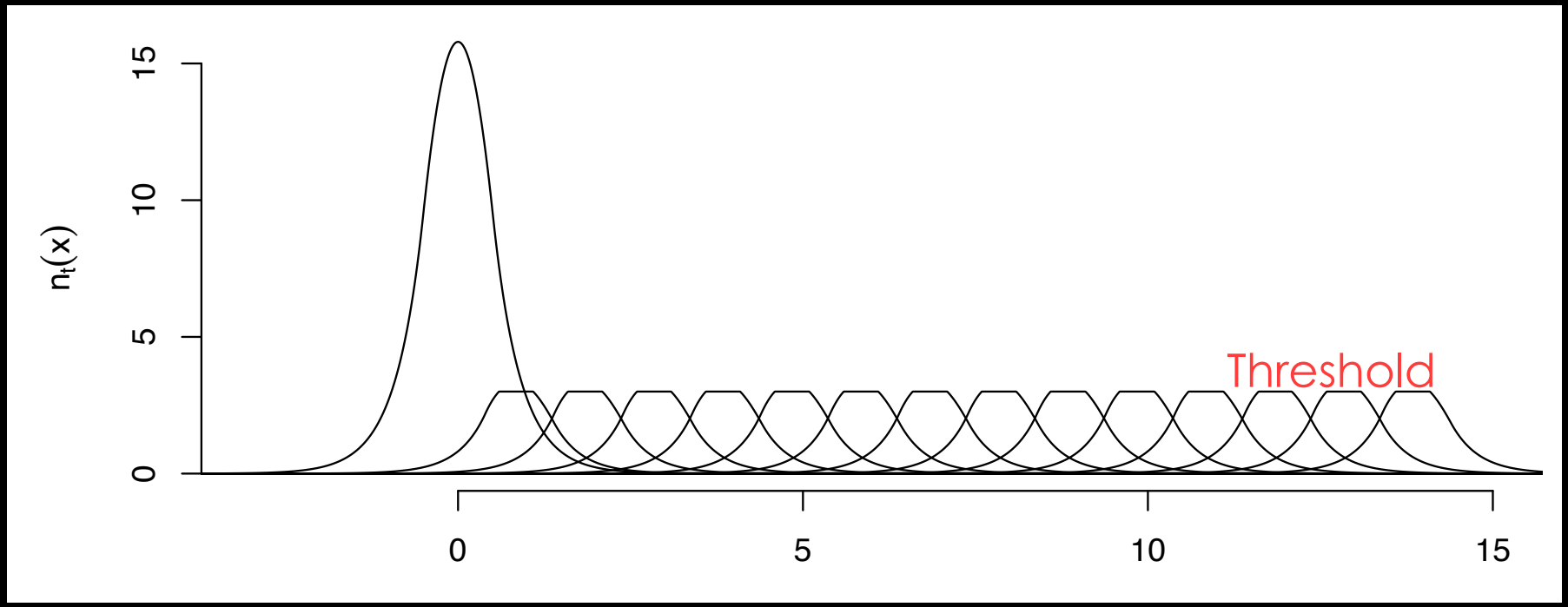
Constant Harvest



with Emma Fuller & Eleanor Brush

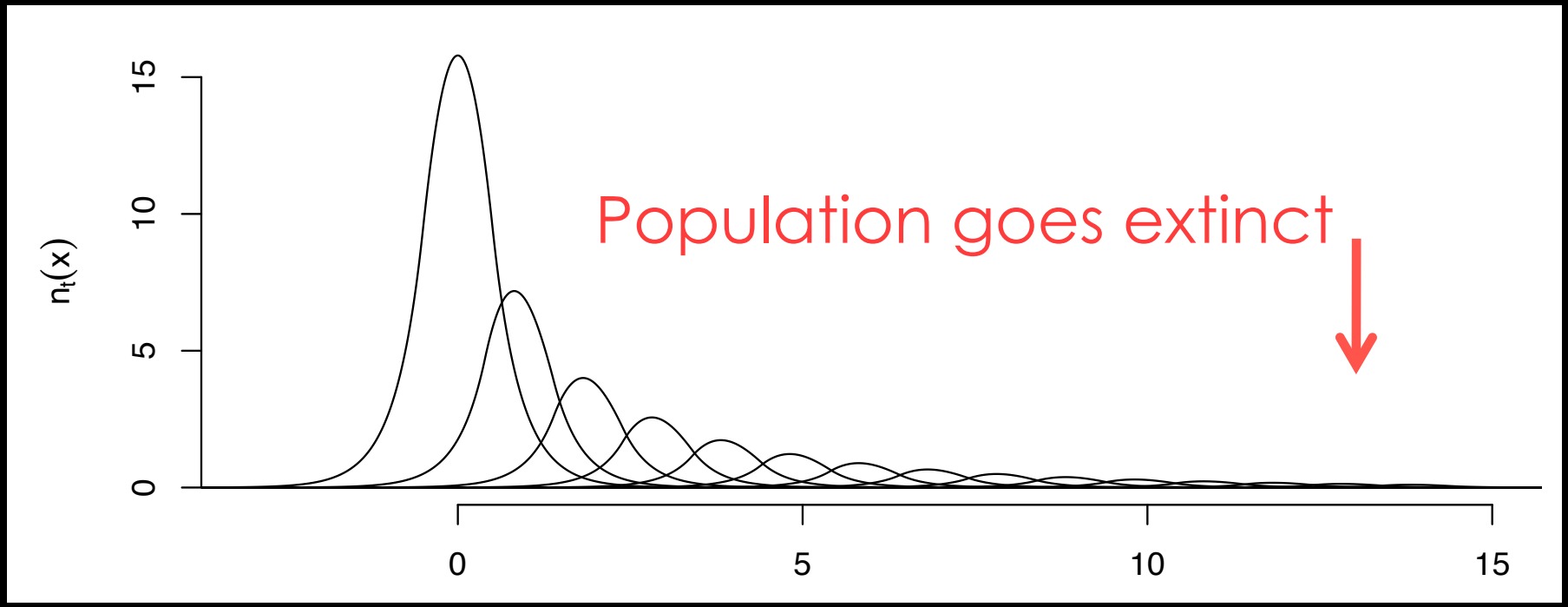
With climate: constant escapement

Population shifts and survives



with Emma Fuller & Eleanor Brush

With climate: constant harvest



with Emma Fuller & Eleanor Brush

Outline

- Assemblages and species follow local climate velocities
- Fished, demersal species shift slightly slower
- Fishing at leading edge slows range shift
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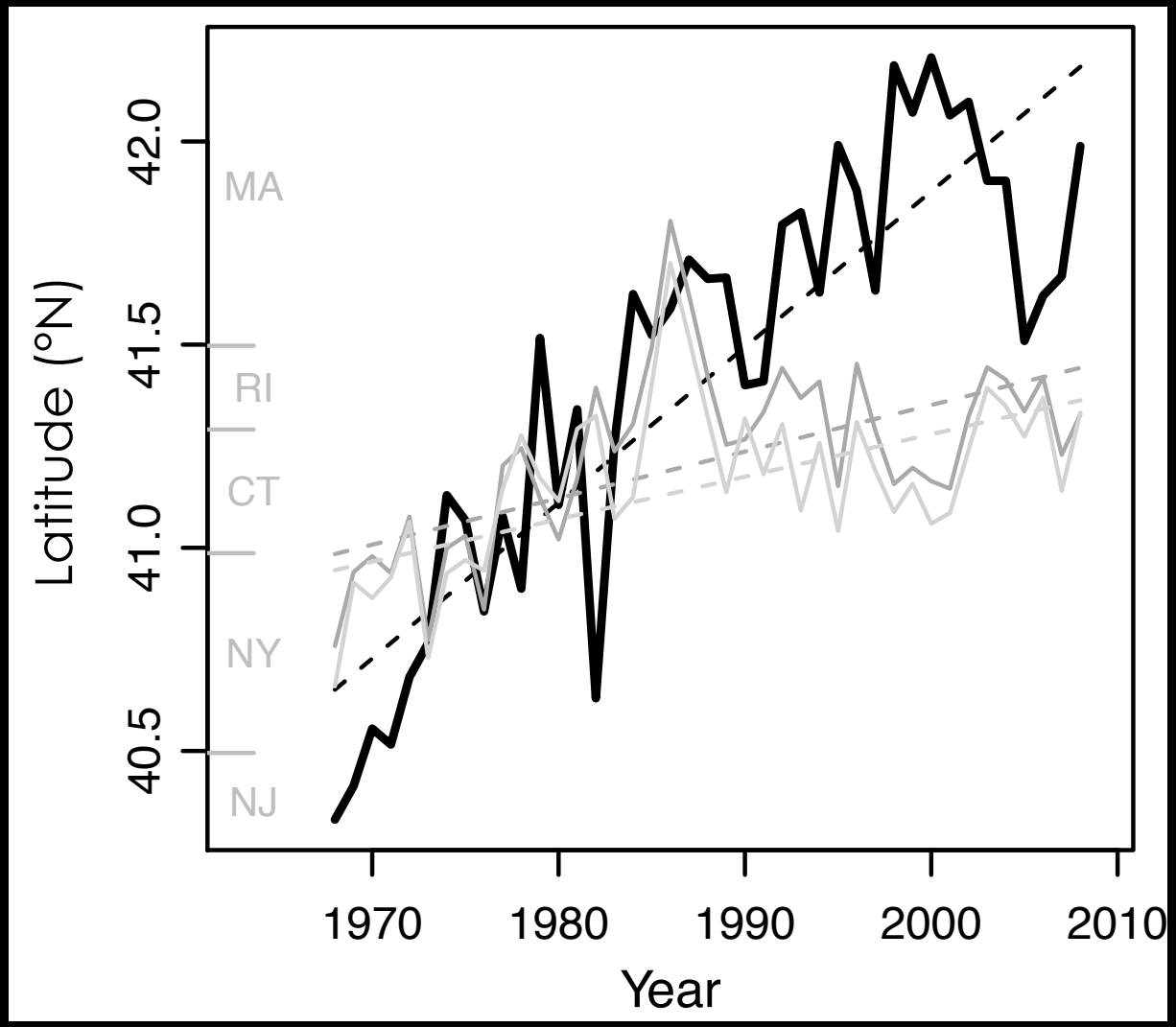
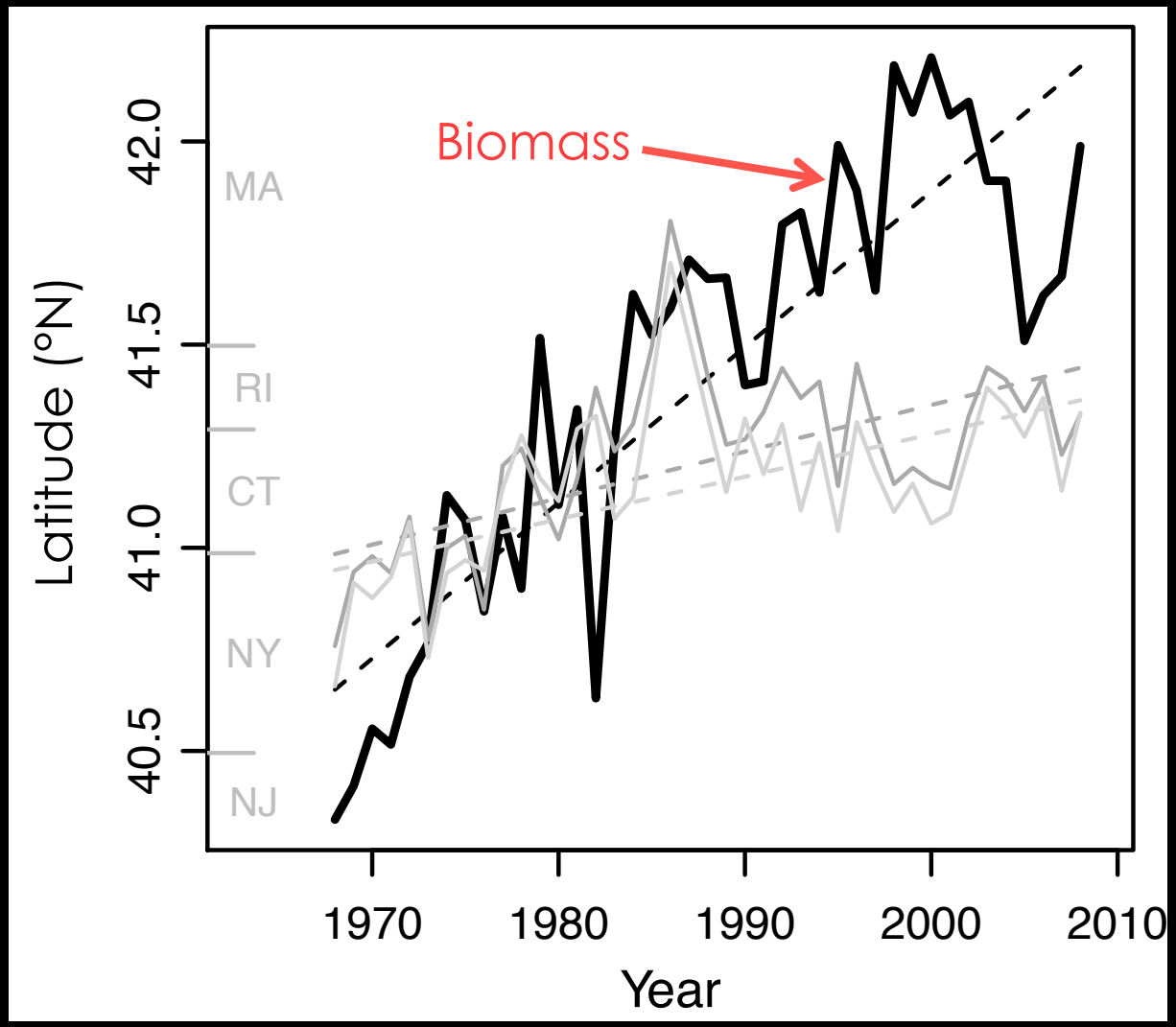
Fisheries lag behind fish



Red hake
(*Urophycis chuss*)

Pinsky & Fogarty *in review*

Fisheries lag behind fish



Red hake
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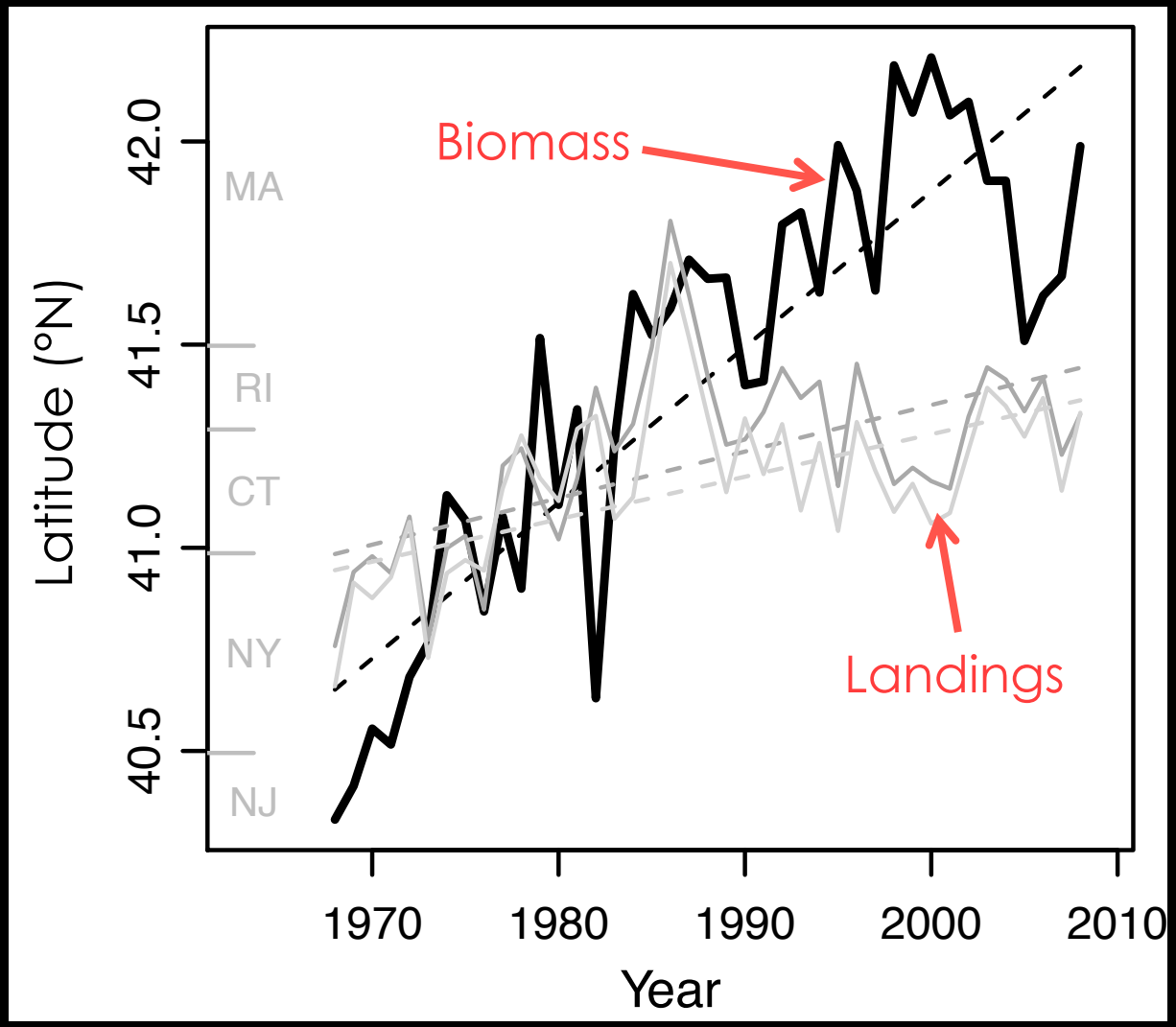
Pinsky & Fogarty *in review*

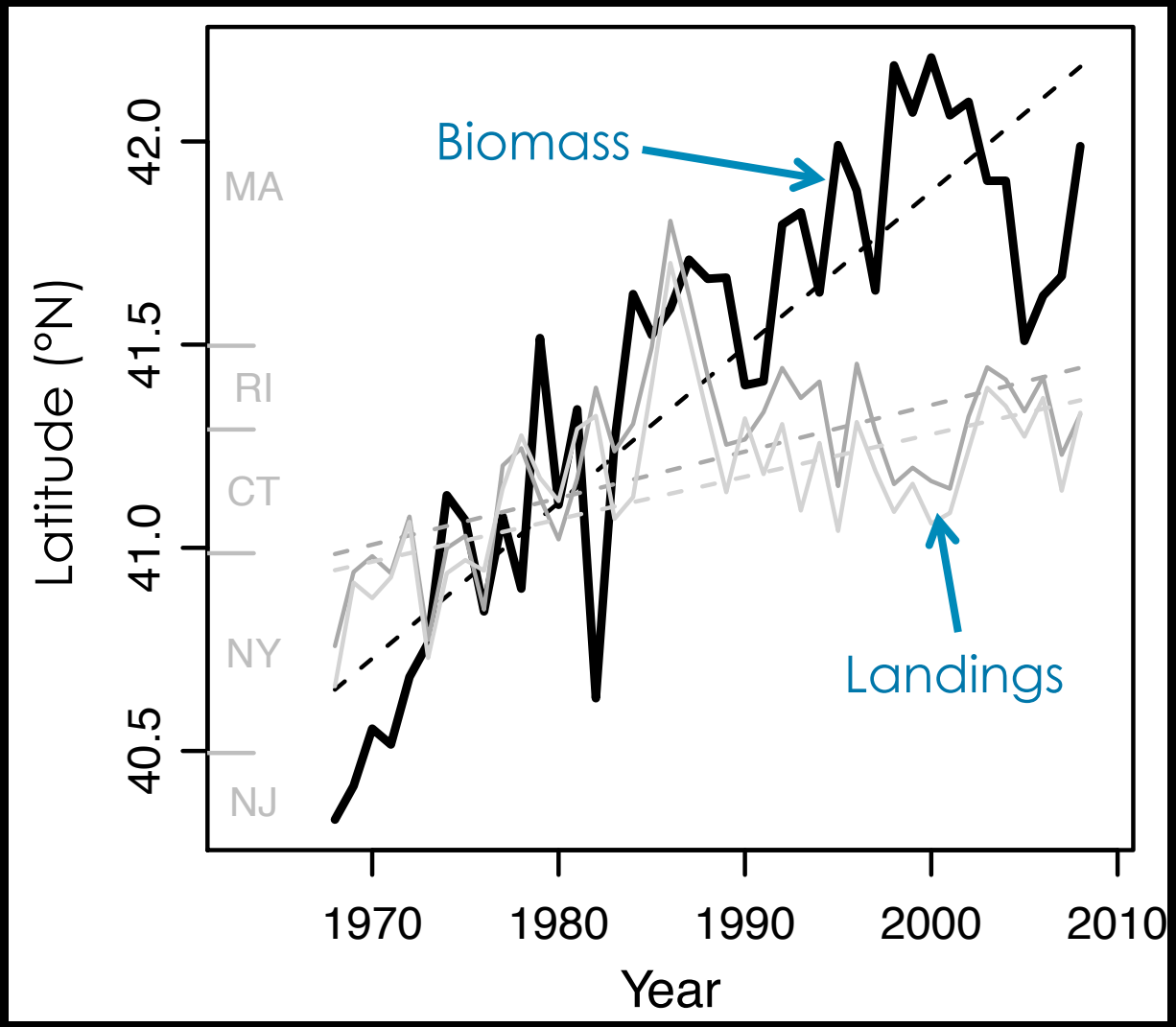
Fisheries lag behind fish



Red hake
(*Urophycis chuss*)

Pinsky & Fogarty *in review*

Fisheries lag behind fish



Red hake
(*Urophycis chuss*)

Landings
75%
slower

Pinsky & Fogarty *in review*

Fisheries lag behind fish

Red hake	75% slower
American lobster	87% slower
Yellowtail flounder	85% slower
Summer flounder	68% slower

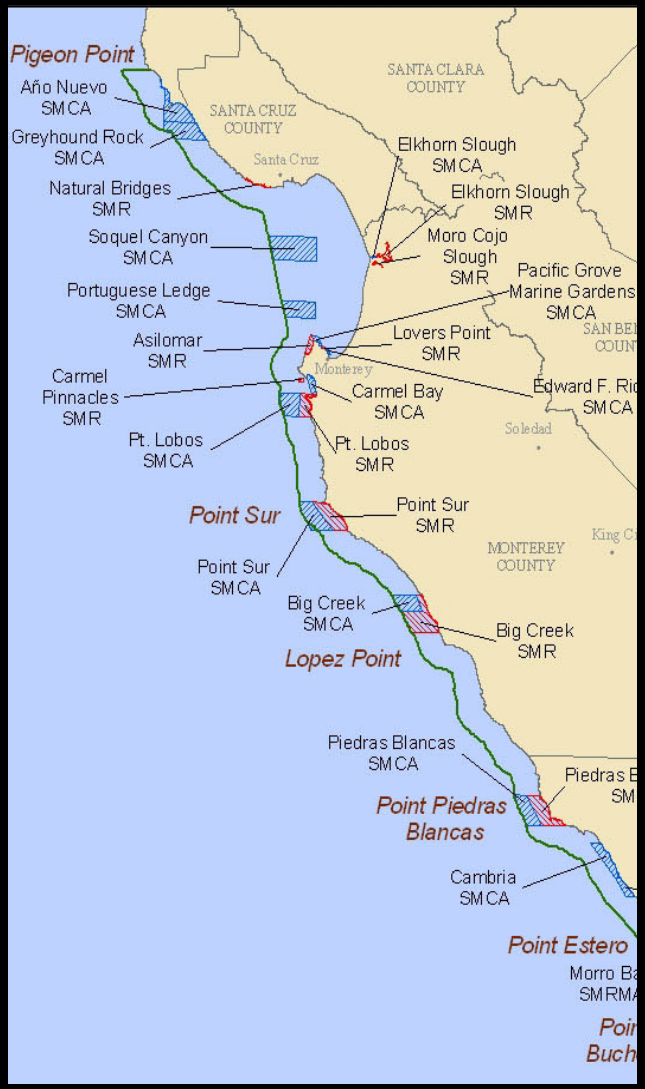
Pinsky & Fogarty *in review*

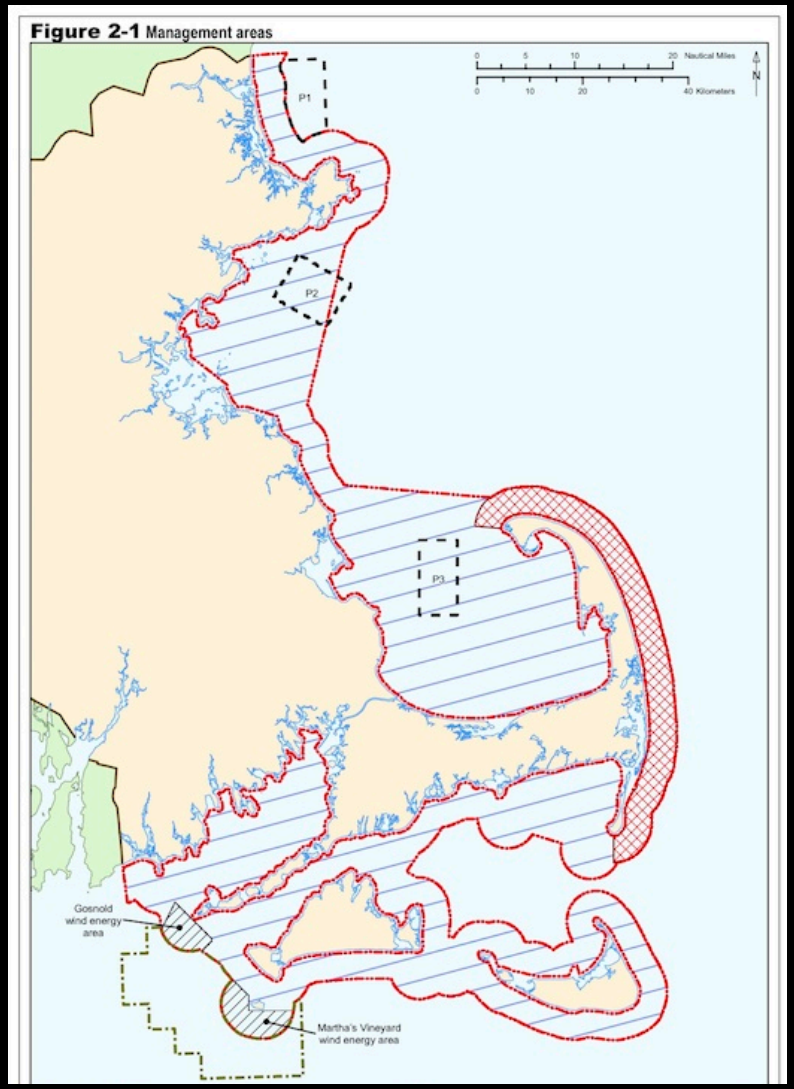
Outline

- Assemblages and species follow local climate velocities
- Fished, demersal species shift slightly slower
- Fishing at leading edge slows range shift
- Fisheries lag behind range shifts

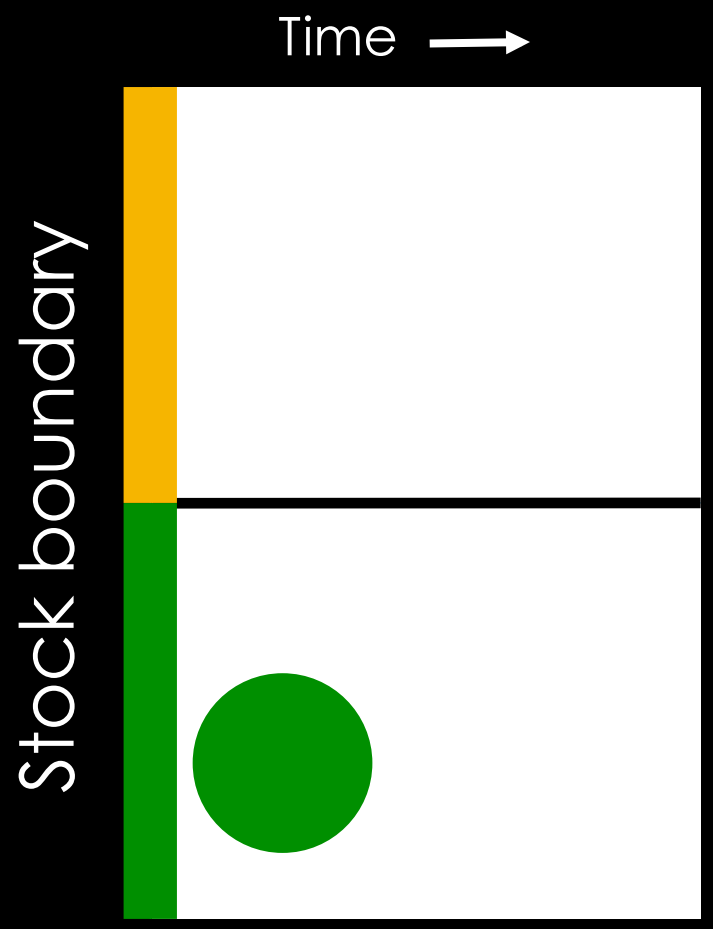
Implications for marine management

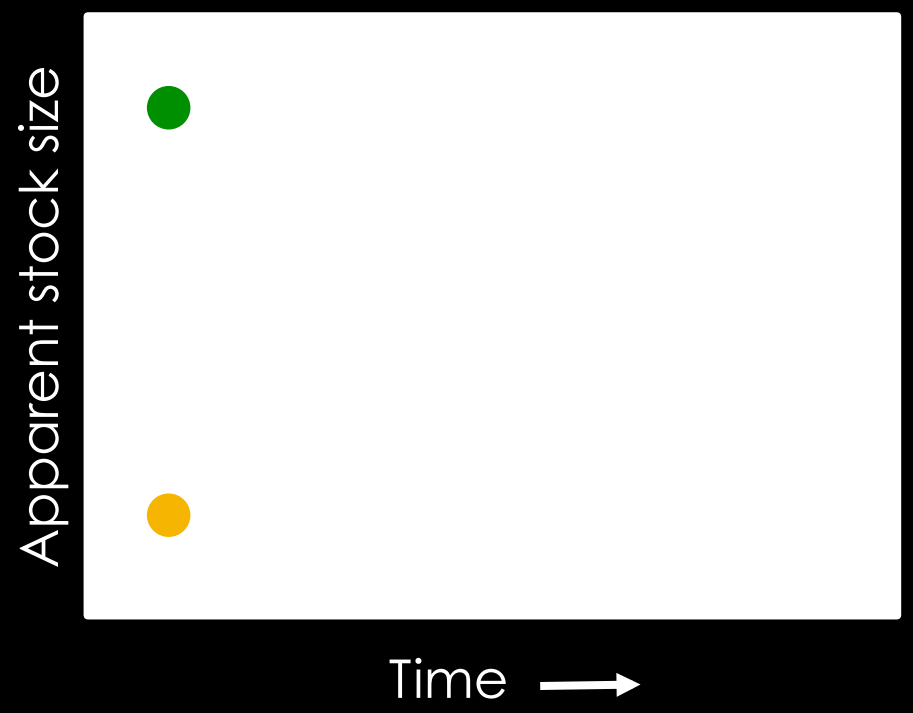
Marine spatial planning





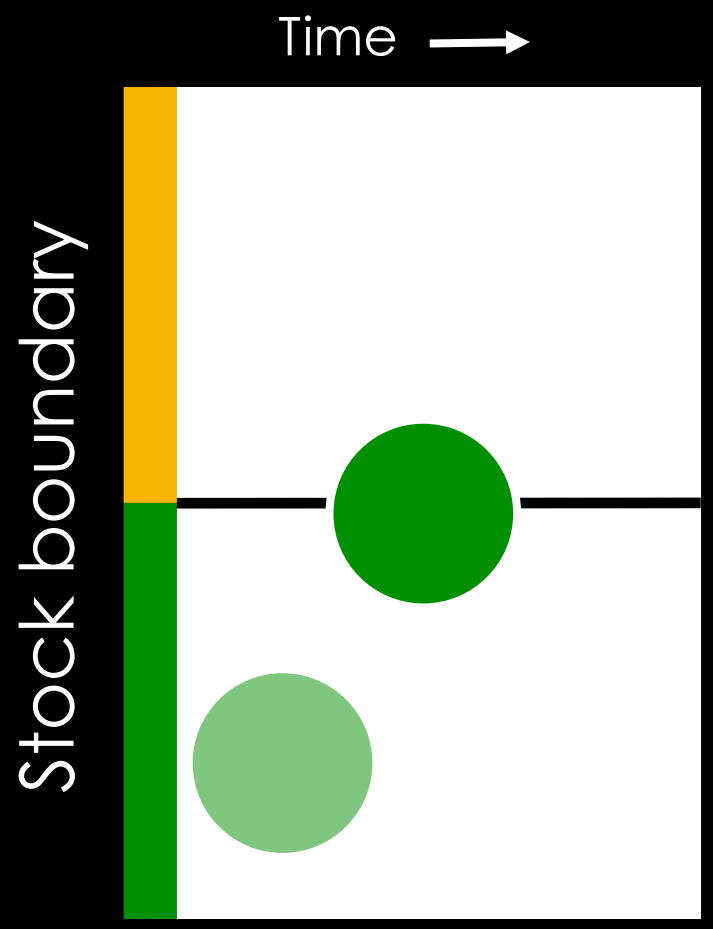
Fisheries management

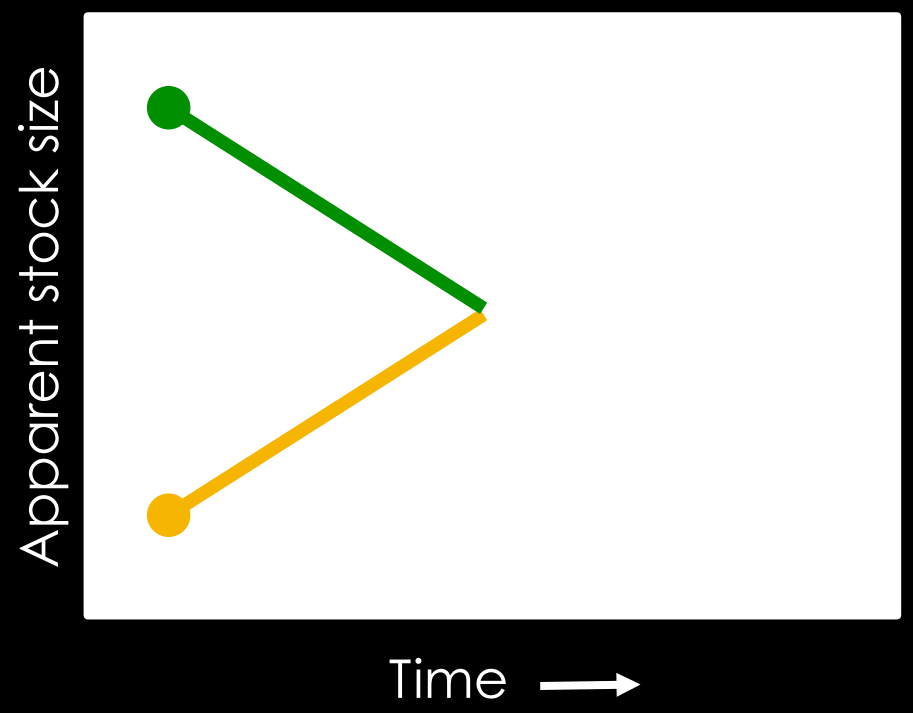




after Link et al. 2011 *Fish and Fisheries*

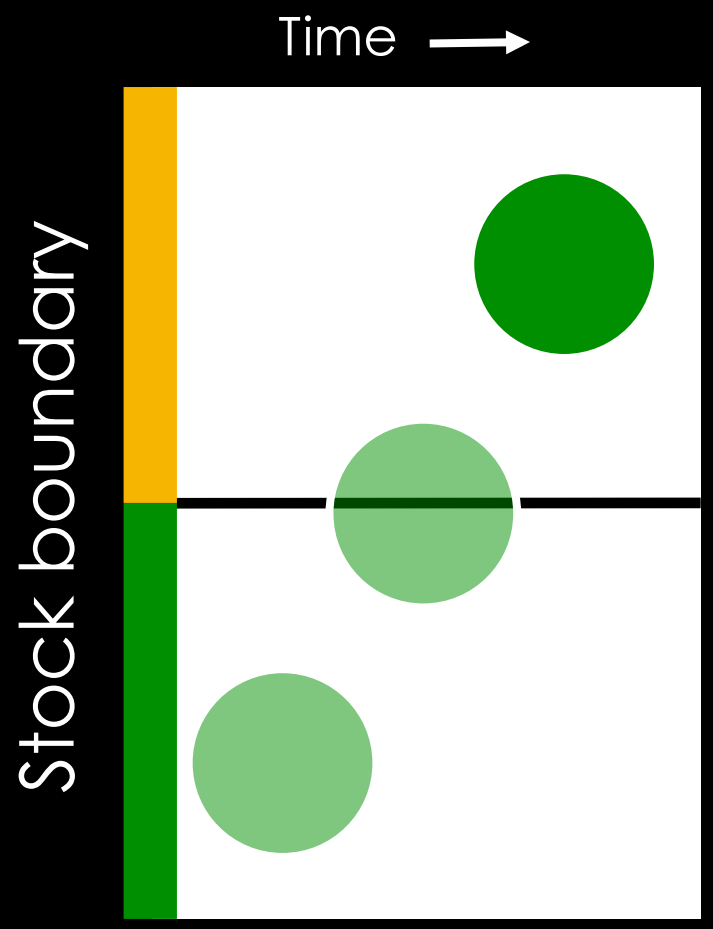
Fisheries management

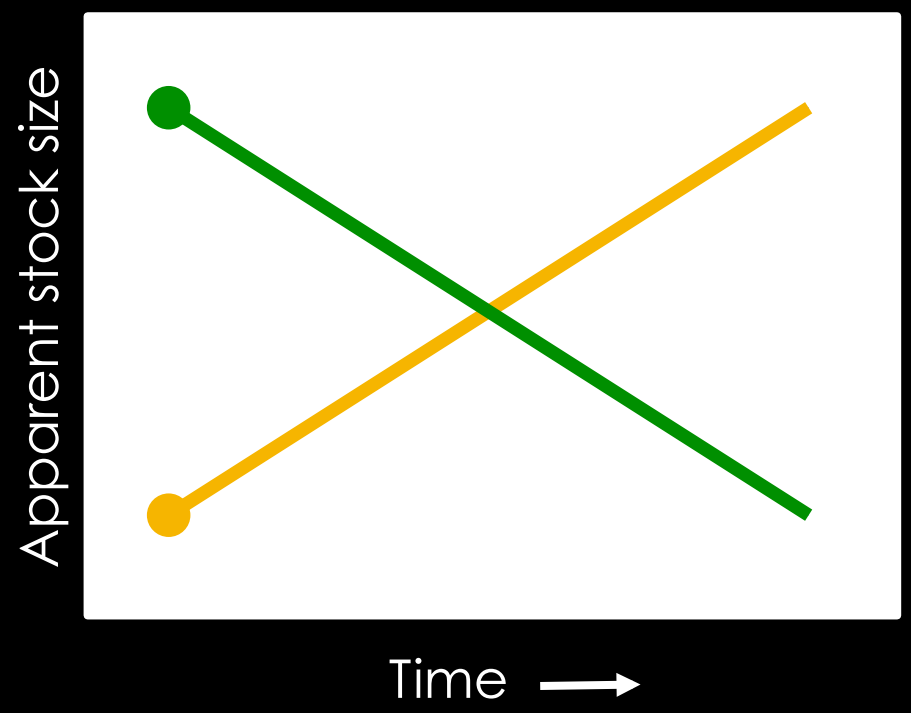




after Link et al. 2011 *Fish and Fisheries*

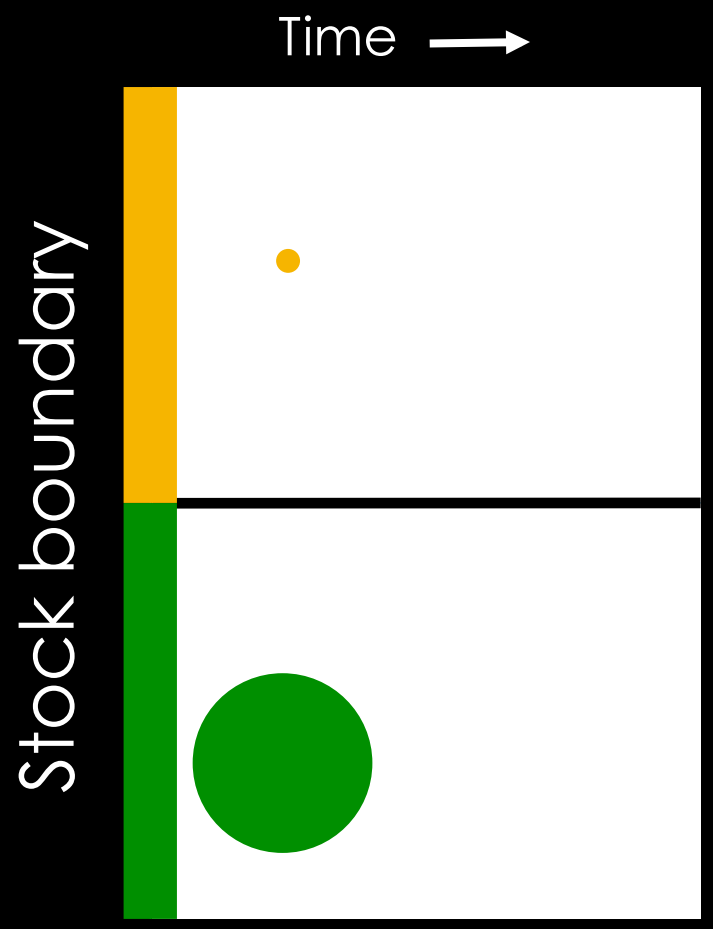
Fisheries management

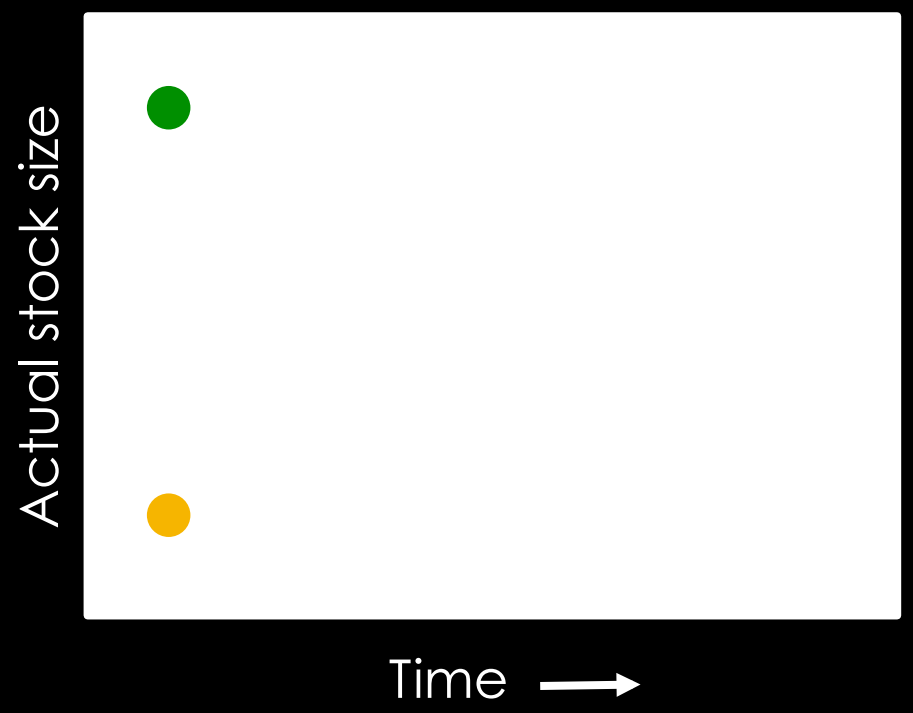




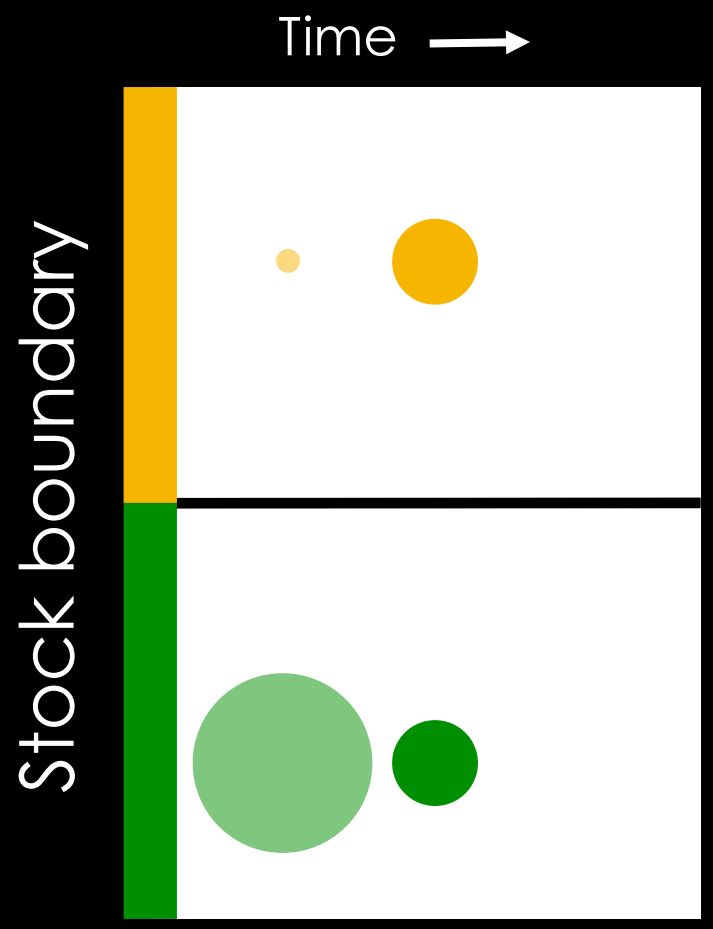
after Link et al. 2011 *Fish and Fisheries*

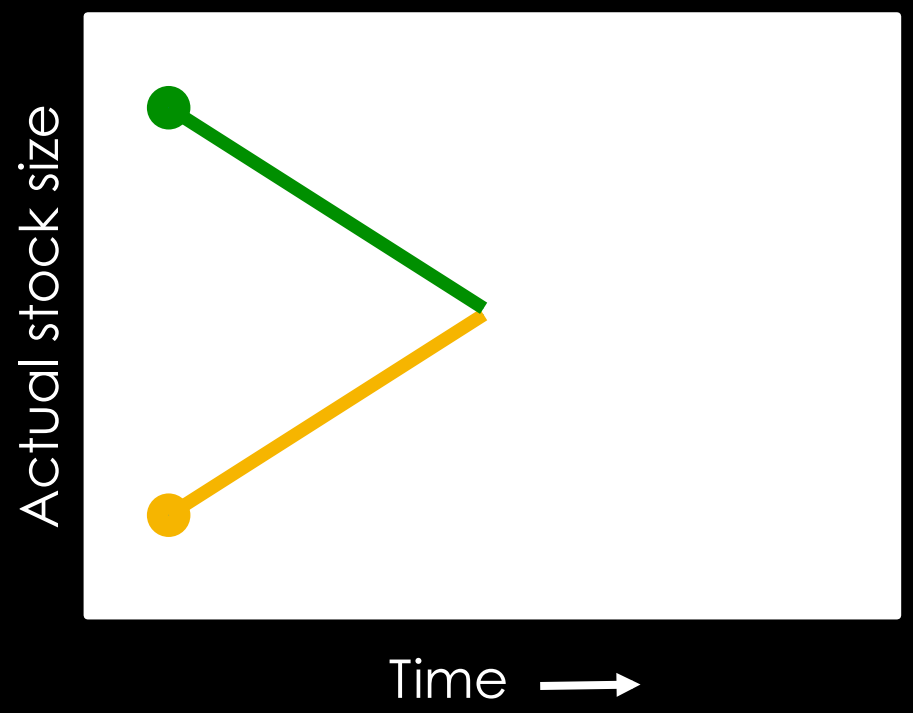
Fisheries management



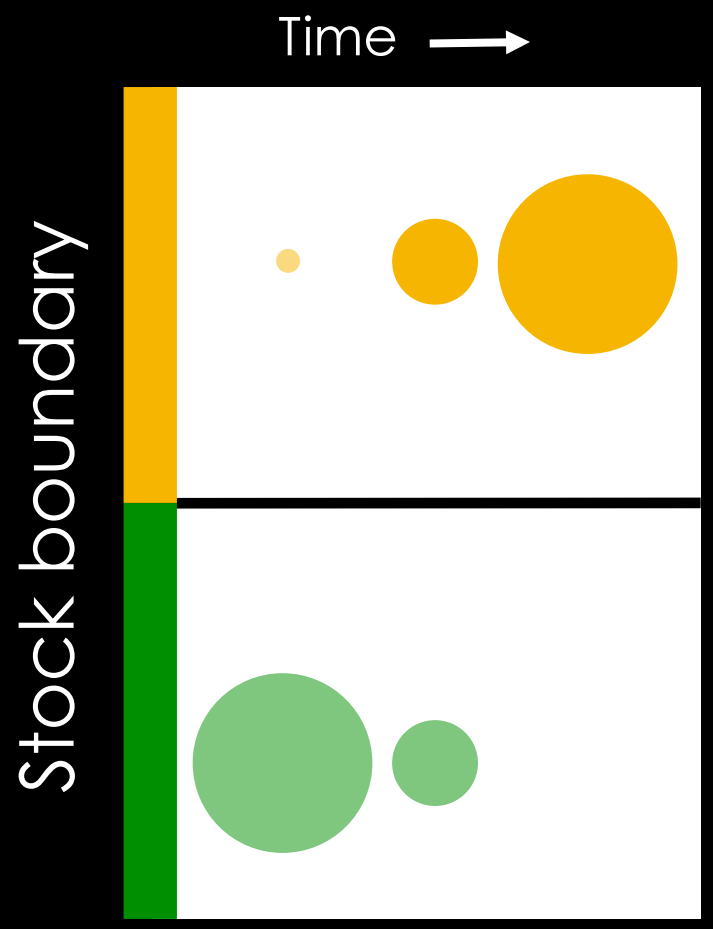


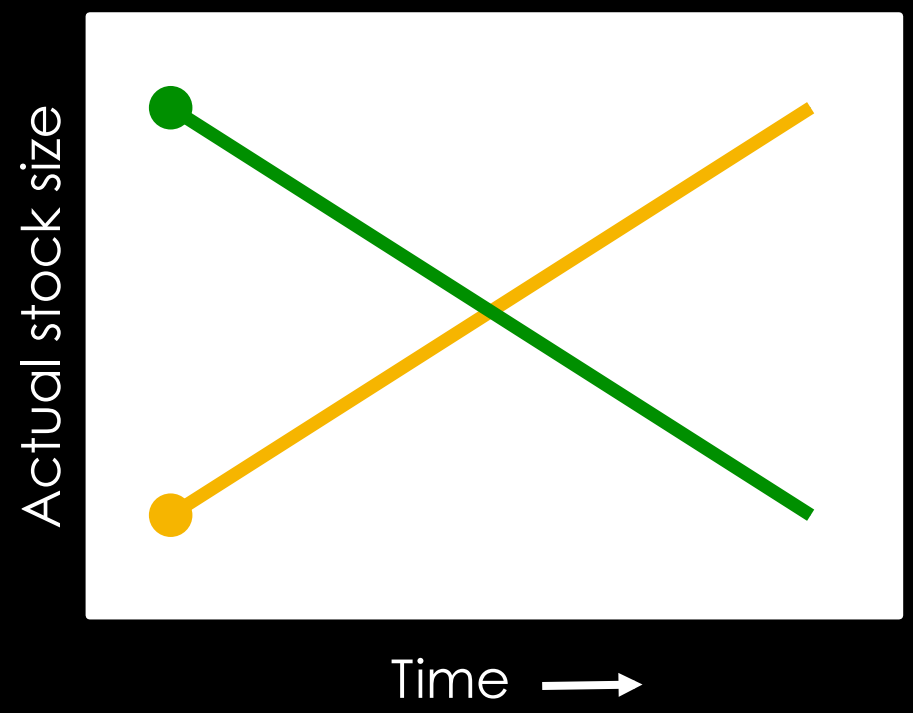
Fisheries management



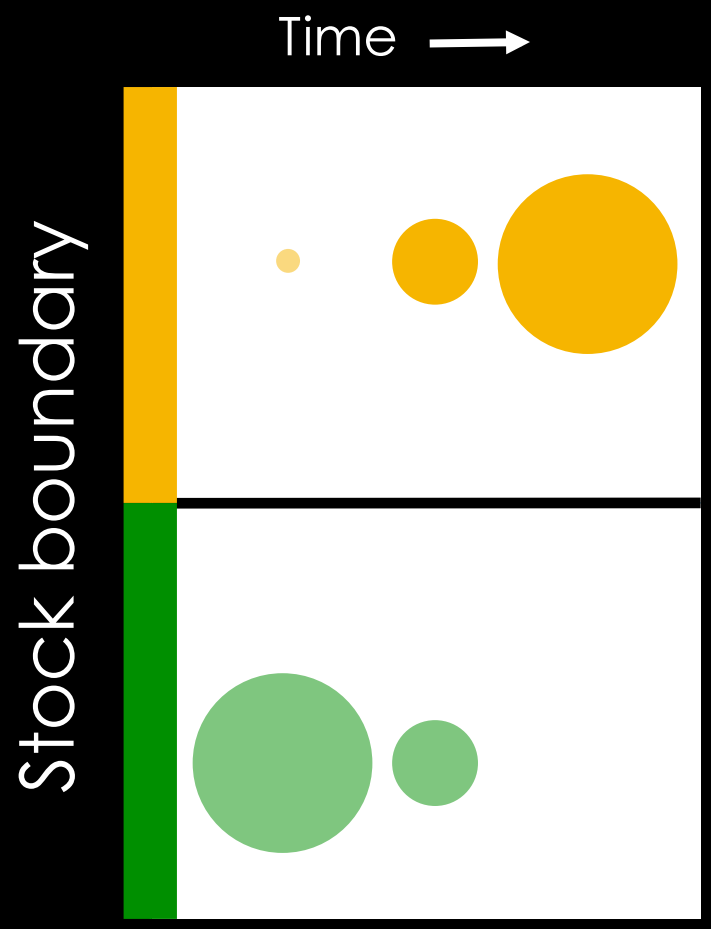


Fisheries management



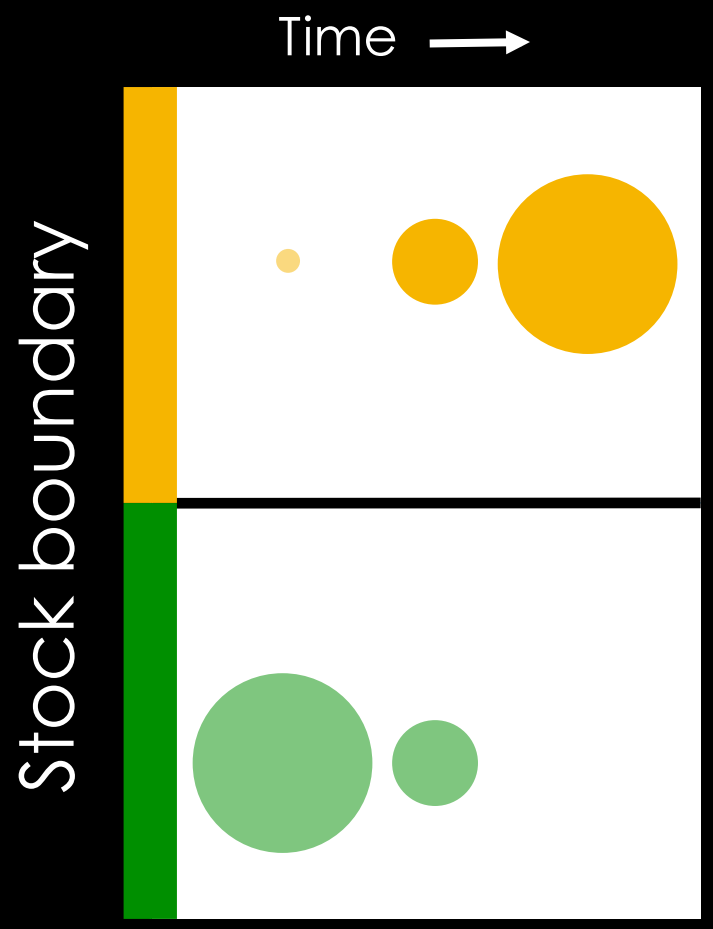


Fisheries management



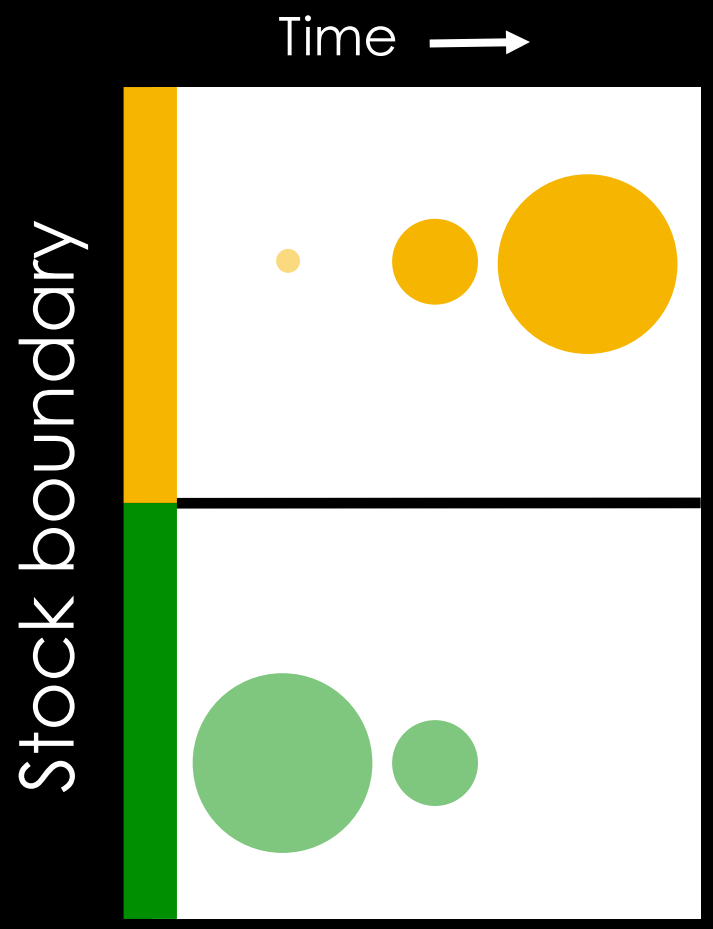
- New reference points

Fisheries management



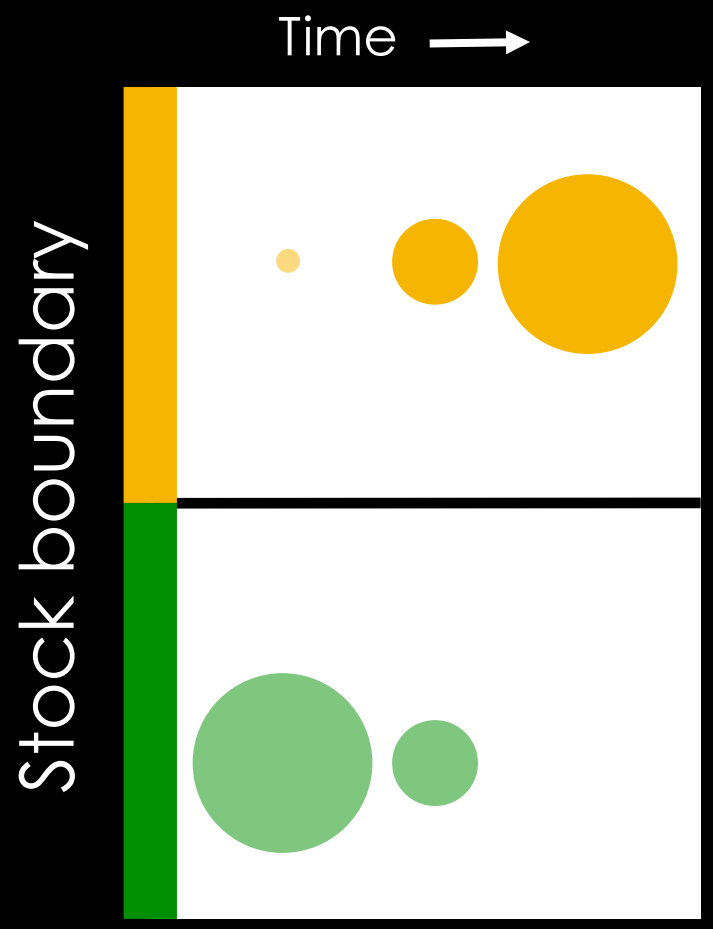
- New reference points
- New stock boundaries

Fisheries management



- New reference points
- New stock boundaries
- Spatially explicit assessments

Fisheries management



- New reference points
- New stock boundaries
- Spatially explicit assessments
- Whose fish are they?

Fisheries management

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- New stock boundaries
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- Whose fish are they?

Conclusions

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Conclusions

- Range shifts occur rapidly and can be explained by local climate velocity
- These shifts affect ocean management, including fisheries

Acknowledgments

Data

Michelle McClure & Beth Horness
Laura Col
Mark Wilkins & Bob Lauth
Jeff Rester
Don Clark
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Bror Jonsson
Enrique Curchitser
James Watson

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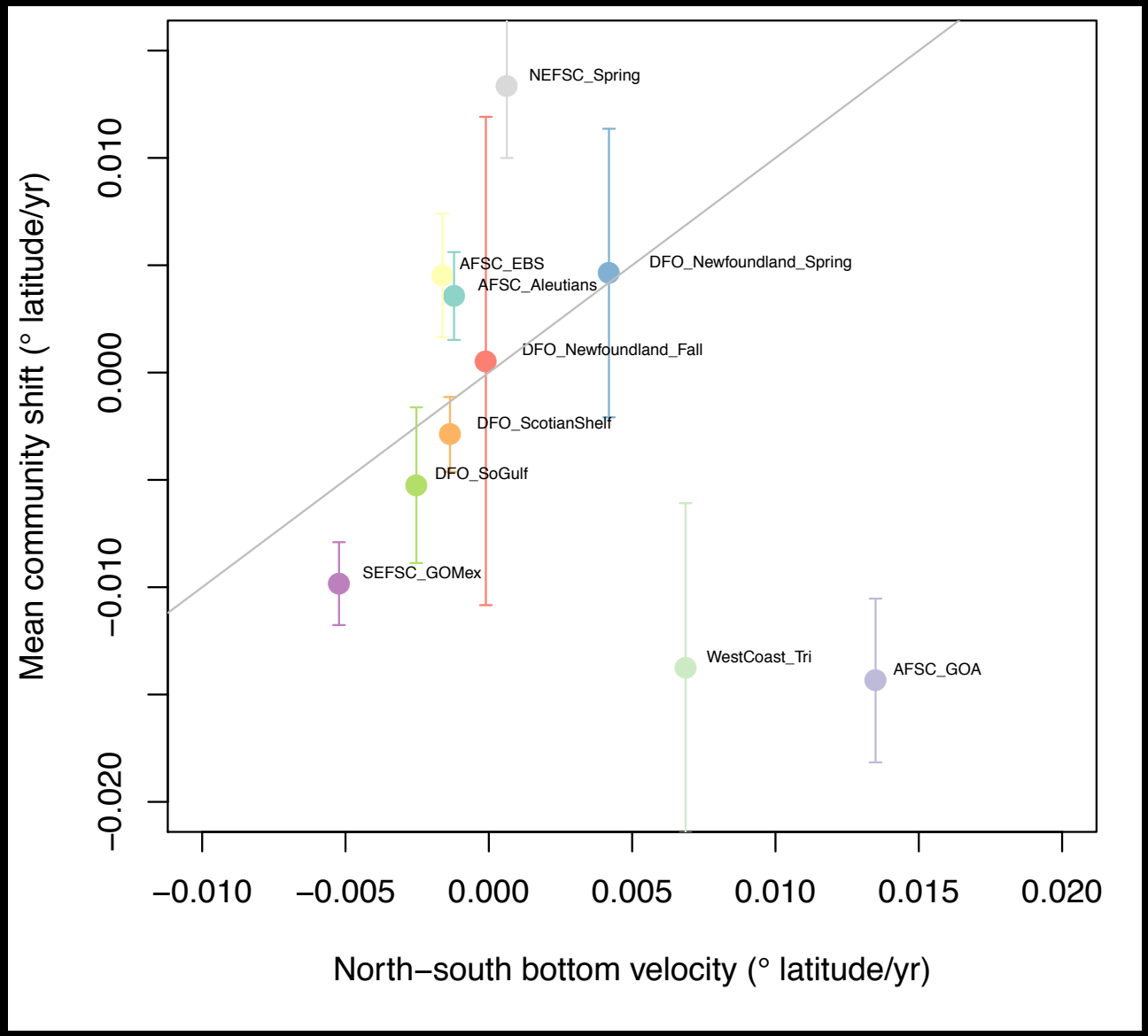
Fisheries and Oceans Canada

Smith Fellows

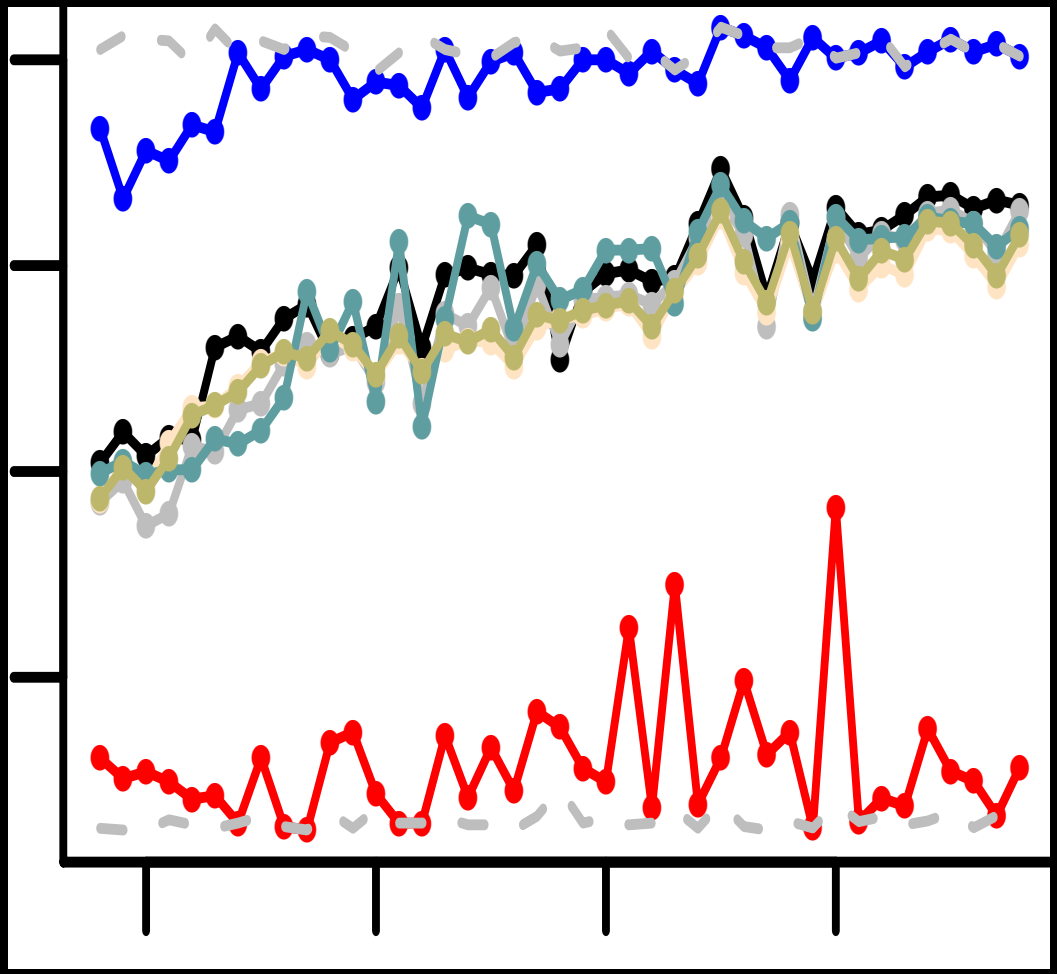
Society for Conservation Biology

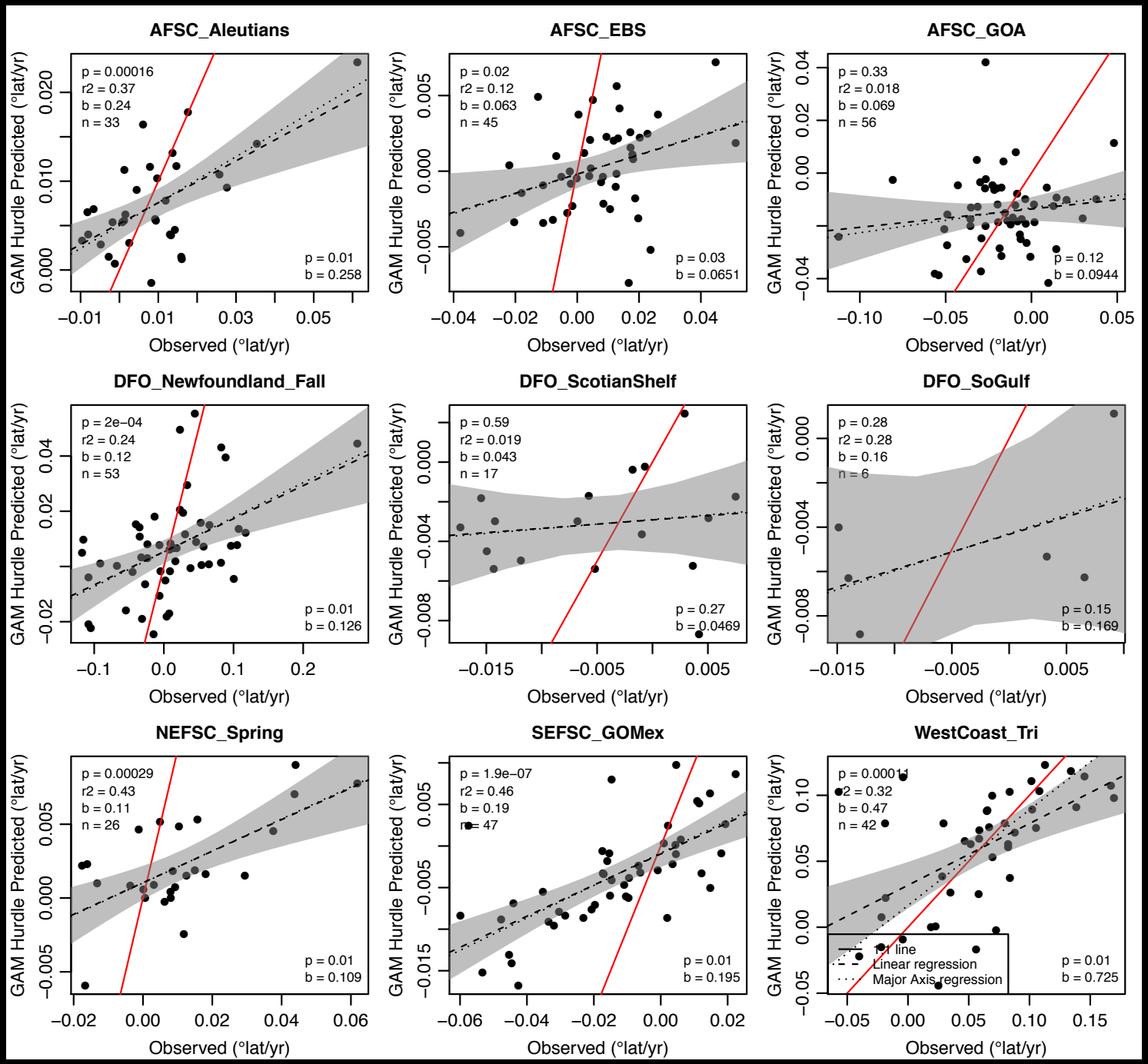
Climate velocity



Lobster

- black: weighted mean stratum
- grey: weighted mean
- turquoise: weighted median
- bisque: presence/ absence
- khaki: 4th-root transformed

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r2 = 0.37
b = 0.24
n = 33
p = 0.01
b = 0.258
AFSC_EBS
p = 0.02
r2 = 0.12
b = 0.063
n = 45
p = 0.03
b = 0.0651
AFSC_GOA
p = 0.33
r2 = 0.018
b = 0.069
n = 56
p = 0.12
b = 0.0944
DFO_Newfoundland_Fall
p = 2e−04
r2 = 0.24
b = 0.12
n = 53
p = 0.01
b = 0.126
DFO_ScotianShelf
p = 0.59
r2 = 0.019
b = 0.043
n = 17
p = 0.27
b = 0.0469
DFO_SoGulf
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r2 = 0.28
b = 0.16
n = 6
p = 0.15
b = 0.169
NEFSC_Spring
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r2 = 0.43
b = 0.11
n = 26
p = 0.01
b = 0.109
SEFSC_GOMex
p = 1.9e−07
r2 = 0.46
b = 0.19
n = 47
p = 0.01
b = 0.195
WestCoast_Tri
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r2 = 0.32
b = 0.47
n = 42
p = 0.01
b = 0.725
1:1 line
Linear regression
Major Axis regression
GAM Hurdle Predicted (°lat/yr)
Observed (°lat/yr)