Do marine species follow shifting ocean temperatures?

Insights from bottom trawl surveys in North America

Malin Pinsky
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Climate velocity

Temperature

km

°C

km
Climate velocity

\[ \frac{\text{km}}{\text{°C}} \]

Temperature vs. km
Climate velocity

Temperature

km

°C

km
Climate velocity

\[ \left( \frac{\text{km}}{\text{°C}} \right) \times \left( \frac{\text{°C}}{\text{decade}} \right) \]
Climate velocity

\[ \frac{\text{km}}{\text{°C}} \times \frac{\text{°C}}{\text{decade}} = \frac{\text{km}}{\text{decade}} \]
The median spatial gradient in temperature on land has been more than three times faster on land globally using April and October temperatures. We present seasonal shifts for spring and fall ratios of the long-term temperature trend (°C/year) to velocities and seasonal shifts corresponding to areas of warming and cooling. Peaks as seasonal shifts for ocean and Eastern Boundary Current regions values in the ocean than on land and many negative velocities are similar at most other latitudes (20° to 50°S and 15° to 45°N). At the scale of our analysis (Fig. 1C), but ocean and land are present (50°S to 80°N), velocities are similar at most other latitudes (20° to 50°S and 15° to 45°N).
Will species track climate velocity?

Burrows et al. 2011 Science
Range shifts around the world

Nye et al. 2009 Marine Ecology Progress Series

Perry et al. 2005 Science

Red hake
\textit{Urophycis chuss}

Examples of North Sea fish distributions, images show locations of different species.


This movement was likely influenced by changes in climate and temperature, as sea temperatures have increased over this period. The red hake is an important fish species in the North Sea, and its range shift has implications for commercial fisheries and marine ecosystems.
Idiosyncratic and unpredictable?

Nye et al. 2009 Marine Ecology Progress Series

Perry et al. 2005 Science
The complexity of a shifting range
The complexity of a shifting range
The complexity of a shifting range

Dispersal

Growth
The complexity of a shifting range

Dispersal

Growth

Habitat
The complexity of a shifting range

- Dispersal
- Growth
- Species interactions
- Habitat
The complexity of a shifting range

Dispersal

Growth

Species interactions

Habitat

Temperature, currents, $O_2$, pH, ... etc.
The complexity of a shifting range

- Dispersal
- Growth
- Habitat
- Harvest

Temperature, currents, O₂, pH, ... etc.
Outline

• Do species follow climate velocity?
Outline

• Do species follow climate velocity?
• Why do some species lag behind?
Outline

• Do species follow climate velocity?
• Why do some species lag behind?
• How does fishing affect range shifts?
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• Do fisheries follow range shifts?
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• Do species follow climate velocity?
• Why do some species lag behind?
• How does fishing affect range shifts?
• Do fisheries follow range shifts?
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
Standardizing the surveys

• Trimmed to taxa sampled every year
  – 721 populations across 422 taxa
Standardizing the surveys

- Trimmed to taxa sampled every year
  - 721 populations across 422 taxa
- Trimmed to a fixed set of strata
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*)
American lobster (Homarus americanus)

Biomass-weighted mean latitude
American lobster (Homarus americanus)
American lobster (*Homarus americanus*)
Centers of species’ ranges: 1968

Spring
Shifts in centers of species’ ranges: 1968-2008
Average shift to the northeast

20 km/decade

Spring
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

![Graph showing the relationship between change in bottom temperature and mean rate of range shift.](image)

- Change in bottom temperature (°C/year)
- Mean rate of range shift (° latitude/year)

**AFSC_Aleutians**
**AFSC_EBS**
**AFSC_GoA**
**DFO_Newfoundland_Fall**
**DFO_Newfoundland_Spring**
**DFO_ScotianShelf**
**DFO_SoGulf**
**NEFSC_Spring**
**SEFSC_GOMex**

**WestCoast_Tri**
**SEFSC_GO**

- **AFSC_Aleutians**: Negative change in bottom temperature with a slight positive range shift.
- **AFSC_EBS**: Positive change in bottom temperature with a slight negative range shift.
- **AFSC_GoA**: Negative change in bottom temperature with a slight positive range shift.
- **DFO_Newfoundland_Fall**: Positive change in bottom temperature with a slight negative range shift.
- **DFO_Newfoundland_Spring**: Negative change in bottom temperature with a slight positive range shift.
- **DFO_ScotianShelf**: Positive change in bottom temperature with a slight negative range shift.
- **DFO_SoGulf**: Negative change in bottom temperature with a slight positive range shift.
- **NEFSC_Spring**: Positive change in bottom temperature with a slight negative range shift.
- **SEFSC_GOMex**: Negative change in bottom temperature with a slight positive range shift.
- **WestCoast_Tri**: Positive change in bottom temperature with a slight negative range shift.
- **SEFSC_GO**: Negative change in bottom temperature with a slight positive range shift.
Bottom temperature and regional shifts

North

South

Mean rate of range shift (° latitude/year)

Change in bottom temperature (° C/year)
Bottom temperature and regional shifts

Change in bottom temperature (° C/year)

Mean rate of range shift (° latitude/year)

Colder

Warmer

AFSC_Aleutians
AFSC_EBS
AFSC_GOA
DFO_Newfoundland_Fall
DFO_Newfoundland_Spring
DFO_ScotianShelf
DFO_SoGulf
NEFSC_Spring
SEFSC_GOMex
WestCoast_Tri
SEFSC_GOA
Bottom temperature and regional shifts

Mean rate of range shift (° latitude/year)
Change in bottom temperature (° C/year)

Colder
Warmer

-0.05
0.00
0.05

-0.02
-0.01
0.00
0.01

AFSC_Aleutians
AFSC_EBS
AFSC_GOA
DFO_Newfoundland_Fall
DFO_Newfoundland_Spring
DFO_ScotianShelf
DFO_SoGulf
NEFSC_Spring
SEFSC_GOMex
WestCoast_Tri

warming, north
cooling, south
Gulf of Mexico

Mean rate of range shift (° latitude/year)

Change in bottom temperature (° C/year)
Gulf of Mexico: constrained by geography

warming, deeper

Mean rate of range shift (° latitude/year)

Mean community shift (° latitude/yr)

Change in bottom temperature (° C/year)

Change in bottom temperature (°C/yr)
Bottom temperature explains regional shifts

$p = 0.026$

$r^2 = 0.53$
Eastern Bering Sea

- Mean rate of range shift (° latitude/year)
- Change in bottom temperature (° C/year)

AFSC_Aleutians
AFSC_EBS
AFSC_GOA
DFO_Newfoundland_Fall
DFO_Newfoundland_Spring
DFO_ScotianShelf
DFO_SoGulf
NEFSC_Spring
SEFSC_GOMex
WestCoast_Trip

$p = 0.026$
$r^2 = 0.53$
Eastern Bering Sea

Change in latitude (° N)

Year

Bottom temperature (° C)

-0.4
-0.2
0.0
0.2

Eastern Bering Sea

Change in latitude (° N) vs. Year

Temperature (° C) vs. Bottom temperature (° C)
Eastern Bering Sea: lagged response

- Change in latitude (° N)
- Bottom temperature (° C)

Year:
- 1985
- 1990
- 1995
- 2000
- 2005
- 2010

Change in latitude:
- 0
- 0.2
- 0.4

Temperature (° C):
- 0
- 1
- 2
- 3
- 4
Eastern Bering Sea: lagged response

Change in latitude (° N)

Bottom temperature (° C)

Year

Sea surface temperature: no relation

Mean rate of range shift (° latitude/year)

Change in surface temperature (° C/year)

$p = 0.72$

$r^2 = 0.02$
Assemblages track multi-decadal bottom temperature trends
Distribution of Silver hake (*Merluccius bilinearis*)

1968 to 2008

- Observed
- Absent
Biomass relative to temperature

1968 to 2008

Bottom temperature

- Observed
- Absent
Thermal envelope from Generalized Additive Models

1968 to 2008

Effect
-2.0 -1.0 0.0 1.0

Bottom temperature

-76 -72 -68

36 38 40 42 44 46

Observed

Absent
Thermal envelope from Generalized Additive Models

\[ p(\text{Present}) \sim s(\text{Bottom temperature}) \]
Thermal envelope from Generalized Additive Models

\[ p(\text{Present}) \sim \]
\[ s(\text{Bottom temperature}) + \]
\[ s(\text{Surface temperature}) \]

Bottom temperature

Effect

-2.0  0.0  1.0

5  10  15
Thermal envelope from Generalized Additive Models

\[ p(\text{Present}) \sim s(\text{Bottom temperature}) + s(\text{Surface temperature}) + \text{stratum} \]
p(\text{Present}) \sim 
\begin{align*}
& s(\text{Bottom temperature}) + \\
& s(\text{Surface temperature}) + \\
& \text{stratum} + \\
& \text{mean biomass}
\end{align*}
Thermal envelope from Generalized Additive Models

\[ p(\text{Present}) \sim s(\text{Bottom temperature}) + s(\text{Surface temperature}) + \text{stratum} + \text{mean biomass} + e \]

\[ e \sim \text{Binomial}(n, p) \]
Thermal envelope from Generalized Additive Models

\[ \text{E}(\log(\text{Biomass}) \mid \text{Present}) \sim \]
\[ s(\text{Bottom temperature}) + \]
\[ s(\text{Surface temperature}) + \]
\[ \text{stratum} + \]
\[ \text{mean biomass} + \]
\[ \epsilon \]
\[ \epsilon \sim \text{Gaussian}() \]
Thermal envelope from Generalized Additive Models

\[
E(\log(\text{Biomass}) \mid \text{Present}) \sim \\
   s(\text{Bottom temperature}) + \\
   s(\text{Surface temperature}) + \\
   \text{stratum} + \\
   \text{mean biomass} + \\
   e \\
   \\
   P(\text{presence}) \times E(\text{biomass} \mid \text{present})
\]
Thermal envelope from Generalized Additive Models

E(log(Biomass) | Present) ~

s(Bottom temperature) +

s(Surface temperature) +

\textbf{stratum} +

\textbf{mean biomass} +

e

\textit{static through time}
Thermal envelope from Generalized Additive Models

\[
E(\log(\text{Biomass}) \mid \text{Present}) \sim
\]
\[
s(\text{Bottom temperature}) + s(\text{Surface temperature}) + \text{stratum} + \text{mean biomass} + e
\]

\text{static through time}

\text{static through space}
Thermal envelope from Generalized Additive Models

\[ E(\log(\text{Biomass}) \mid \text{Present}) \sim \]

\[ s(\text{Bottom temperature}) + \]
\[ s(\text{Surface temperature}) + \]

\[ \text{stratum} + \]
\[ \text{mean biomass} + \]
\[ e \]

range shifts?

static through time

static through space
Distribution of Silver hake (*Merluccius bilinearis*)

1968 to 1979

- **●**: Observed
- **X**: Absent
Predicted distribution of Silver hake
Temperature explains range contractions

- **1968 to 1979**: The observed species distribution shows a different pattern compared to the predicted distribution. The observed data points are more clustered in the southern part of the map.
- **2001 to 2009**: The observed data points are spread out more evenly across the region, with a noticeable absence in the northern part of the map.

Observed: Green dots
Predicted: Black dots
Absent: X
Across 325 populations

- Predicted rate of shift (° lat/yr)
- Observed rate of shift (° lat/yr)

Linear regression
- $p = 1.9 \times 10^{-35}$
- $r^2 = 0.38$
- $b = 0.4$

Type II Major Axis Regression with 1:1 line
- $p = 0.001$
- $b = 0.503$
Climate velocity explains shifts

\[ p = 2 \times 10^{-35} \]
\[ r^2 = 0.38 \]
Do populations lag climate velocity?

![Graph showing correlation between predicted and observed rate of shift with regression line and statistical metrics.](image)

- **Predicted rate of shift (° lat/yr)**
- **Observed rate of shift (° lat/yr)**

- Linear regression:
  - $p = 1.9 \times 10^{-35}$
  - $r^2 = 0.38$

- Type II Major Axis Regression with 1:1 line:
  - $p = 2 \times 10^{-35}$
  - $r^2 = 0.38$
Do populations lag climate velocity?

![Graph showing the relationship between predicted and observed rates of shift (° lat/yr)]

**Linear regression**
- $p = 1.9 \times 10^{-35}$
- $r^2 = 0.38$
- $b = 0.4325$

**Type II Major Axis Regression with 1:1 line**
- $p = 0.001$
- $b = 0.503$
- 325 pops

**Legend**
- North
- South
Do populations lag climate velocity?

**Linear regression**
- Part GAM Predicted (° lat/yr)
- Observed (° lat/yr)
  - \( p = 1.9 \times 10^{-35} \)
  - \( r^2 = 0.38 \)
  - \( b = 0.4325 \) pops

**Type II Major Axis Regression with 1:1 line**
- Part GAM Predicted (° lat/yr)
- Observed (° lat/yr)
  - \( p = 0.001 \)
  - \( b = 0.503 \)
  - 325 pops

North
South

Lagging behind
Do populations lag climate velocity?

![Graph showing relationship between predicted and observed rates of shift. The graph has a red line indicating a 1:1 relationship, with data points scattered around it. The graph is labeled with axes: Predicted rate of shift (° lat/yr) on the x-axis, and Observed rate of shift (° lat/yr) on the y-axis. The graph indicates speeding ahead in the northern direction.]
Do populations lag climate velocity?

Histogram of direction $\text{direction} \cdot \text{g} \cdot \text{h} \cdot \text{lat} \cdot \text{lag}$

Frequency

0 20 40 60 80 120

Difference in rate of shift (°lat/yr)

-0.1 0.0 0.1 0.2
Do populations lag climate velocity?

Histogram of direction (°lat/yr)

Frequency

Difference in rate of shift (°lat/yr)

Lagging behind

Speeding ahead
No evidence for an overall lag

$p = 0.12$
mean = 0.003 ° yr$^{-1}$
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?
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?
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
- Commercially fished/not
- Biomass trend
Can we explain different rates?

Observed rate of shift (° lat/yr) ~

- Climate velocity
- Demersal/pelagic
- Commercially fished/not
- Biomass trend
- Fish/invertebrate
Can we explain different rates?

Observed rate of shift (° lat/yr) ~
- Climate velocity
- Demersal/pelagic
- Commercially fished/not
- Biomass trend
- 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

$r^2 = 0.32$
$p < 1 \times 10^{-10}$
Lags in fished, demersal species

Observed shift =
  + Climate velocity
  + 0.005 x Unfished
  + 0.012 x Pelagic

\[ r^2 = 0.32 \]
\[ p < 1 \times 10^{-10} \]
Lags in fished, demersal species

Observed shift =
+ Climate velocity
+ 0.005 x Unfished
+ 0.012 x Pelagic

$r^2 = 0.32$
$p < 1\times10^{-10}$
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

$r^2 = 0.50$
$p < 1 \times 10^{-10}$

$r^2 = 0.44$
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
• Fished, demersal species shift slightly slower
• How does fishing affect range shifts?
• Do fisheries follow range shifts?
Model for a species’ range

Disperse → Reproduce → Fished → Disperse

with Emma Fuller & Eleanor Brush
Model for a species’ range

Disperse → Reproduce → Fished

Space

time t

with Emma Fuller & Eleanor Brush
Model for a species’ range

Disperse → Reproduce → Fished

Space

time $t+1$

with Emma Fuller & Eleanor Brush
Model for a species’ range

Disperse → Reproduce → Fished →

\[ \text{time } t+2 \] →

Space

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

\[ n_{t+1}(x) = f(a_t(y)) \]

- offspring
- adults
- reproduction

with Emma Fuller & Eleanor Brush
Model for a species’ range

\[ n_{t+1}(x) = k(x-y)f(a_t(y)) \]

- \textit{offspring}
- \textit{dispersal}
- \textit{reproduction}

with Emma Fuller & Eleanor Brush
Model for a species’ range

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

offspring  \rightarrow  habitat  \rightarrow  dispersal  \rightarrow  reproduction  \rightarrow  adults

with Emma Fuller & Eleanor Brush
Model for a species’ range

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

with Emma Fuller & Eleanor Brush
Model for a species’ range

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

\[ a_t(y) = n_t(y) \]

with Emma Fuller & Eleanor Brush
Model for a species’ range

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

adults

\[ a_t(y) = n_t(y) - h(n_t(y)) \]

with Emma Fuller & Eleanor Brush
Idealized species range

with Emma Fuller & Eleanor Brush
Idealized species range

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

with Emma Fuller & Eleanor Brush
Fishing: constant harvest rate

Constant Escapement

Abundance

Without fishing

With fishing

Constant Harvest

Abundance

Without fishing

With fishing

with Emma Fuller & Eleanor Brush
With climate: constant escapement

Population shifts and survives

with Emma Fuller & Eleanor Brush
With climate: constant harvest

Population goes extinct

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
• Do fisheries follow range shifts?
Outline

• Assemblages and species follow local climate velocities
• Fished, demersal species shift slightly slower
• Fishing at leading edge slows range shift
• Do fisheries follow range shifts?
Fisheries lag behind fish

Red hake (Urophycis chuss)

Pinsky & Fogarty in review
Fisheries lag behind fish

Red hake (Urophycis chuss)

Biomass

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
<table>
<thead>
<tr>
<th>Fish</th>
<th>Percentage Slower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red hake</td>
<td>75%</td>
</tr>
<tr>
<td>American lobster</td>
<td>87%</td>
</tr>
<tr>
<td>Yellowtail flounder</td>
<td>85%</td>
</tr>
<tr>
<td>Summer flounder</td>
<td>68%</td>
</tr>
</tbody>
</table>
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

Stock boundary

Time

Apparent stock size

Time

after Link et al. 2011 Fish and Fisheries
Fisheries management

after Link et al. 2011 Fish and Fisheries
Fisheries management

Stock boundary

Actual stock size
Fisheries management
Fisheries management

Stock boundary

Actual stock size

Time
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

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

• Assemblages and species follow local climate velocities
Conclusions

• Assemblages and species follow local climate velocities

• Fished, demersal species shift slightly slower
Conclusions

• Assemblages and species follow local climate velocities
• Fished, demersal species shift slightly slower
• Fishing at leading edge slows range shift
Conclusions

• 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
Conclusions

• Range shifts occur rapidly and can be explained by local climate velocity
Conclusions

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

Mean community shift (° latitude/yr)

North–south bottom velocity (° latitude/yr)

nspp = 711

AFSC_Aleutians
AFSC_EBS
AFSC_GOA
DFO_Newfoundland_Spring
DFO_Newfoundland_Fall
DFO_ScotianShelf
DFO_SoGulf
NEFSC_Spring
SEFSC_GOMex
WestCoast_Tri
AFSC_GOA
Lobster

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