Oceanographic Indicators for Northern Shortfin Squid, *Illex illecebrosus*, in the Northwest Atlantic

MAFMC May 2022 SSC Meeting

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SMAST | University of Massachusetts Dartmouth

Northeast Fisheries Science Center| NOAA Fisheries

Acknowledgements

Government: Anna Mercer, Brooke Lowman, Sarah Gaichas, Thomas Swiader, Andrew Jones, Sarah Turner, Lisa Hendrickson, Benjamin Galuardi, Daniel Hocking, Paula Fratantoni

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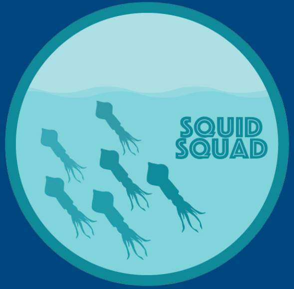
Industry: John Manderson, Katie Almeida, Bill Bright, Greg Didomenico, Jeff Kaelin, Meghan Lapp, Jimmy Ruhle

Management: Paul Rago



Oceanographic Indicators - Takeaways

Identified a suite of environmental variables which may serve as indicators of:

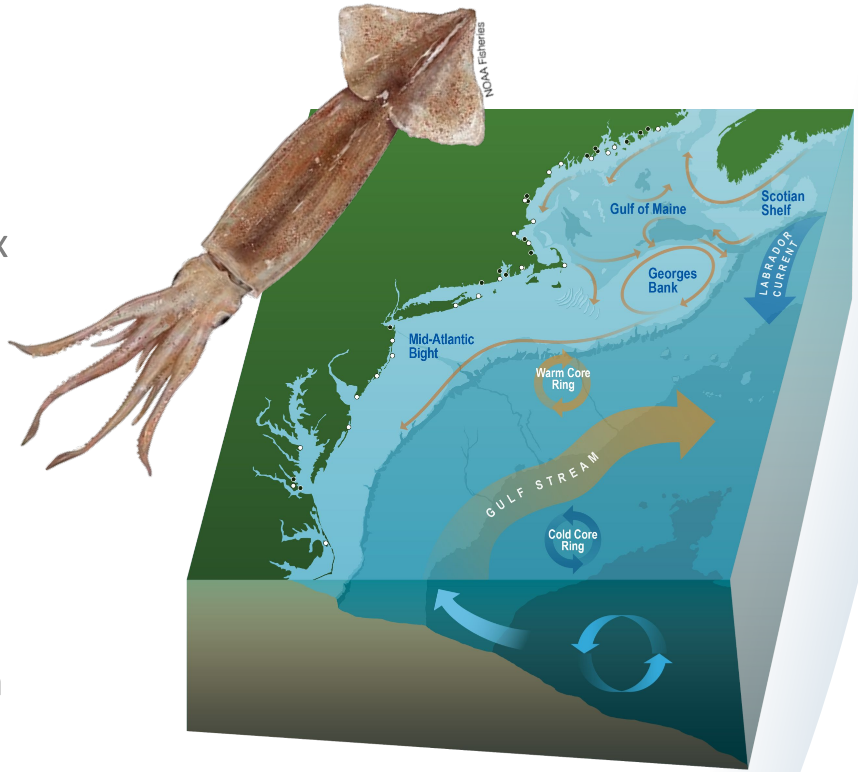
1. *Illex* habitat condition
2. Areas of increased productivity

Implications for:

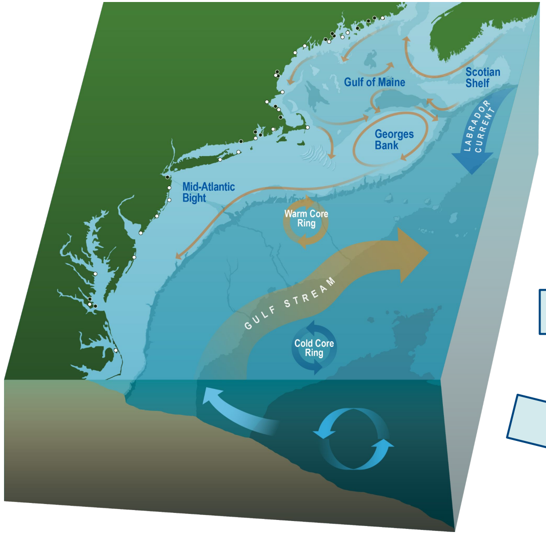
1. Identifying areas of *Illex* aggregation
2. Understanding distribution and availability

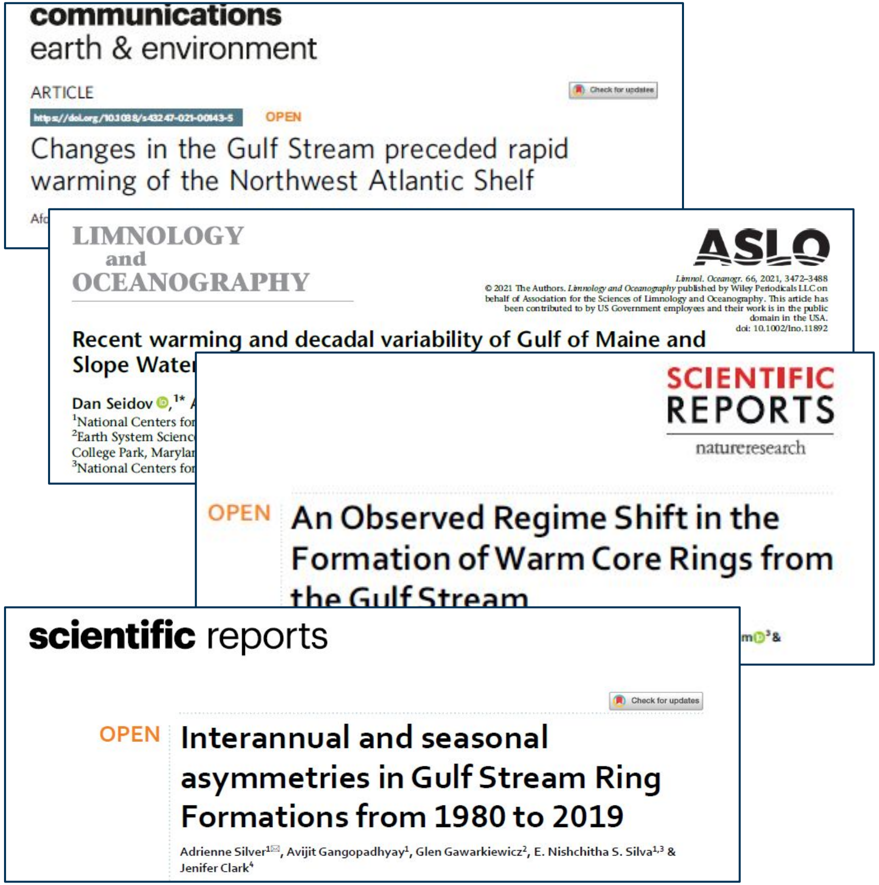
Background

- Northeast US shelf is a dynamically complex region
- Seasonal/interannual variations in oceanic and atmospheric conditions result in variability in
  - Timing, location, and magnitude of biological and physical features
- Changes in the latitudinal position, strength and seasonality of the shelf-break front can
  - Alter nutrient supplies, affect primary productivity



Northeast Continental Shelf





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ARTICLE

https://doi.org/10.1038/s43247-021-00143-5 OPEN

Changes in the Gulf Stream preceded rapid warming of the Northwest Atlantic Shelf

LIMNOLOGY and OCEANOGRAPHY

ASLO

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doi: 10.1002/lno.11892

Recent warming and decadal variability of Gulf of Maine and Slope Water

Dan Seidov[1]*

[1]National Centers for
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College Park, Marylan
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An Observed Regime Shift in the Formation of Warm Core Rings from the Gulf Stream

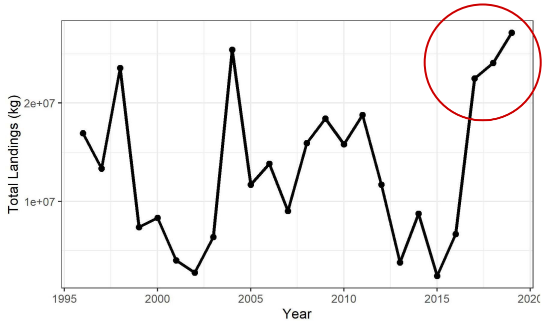
scientific reports

OPEN

Interannual and seasonal asymmetries in Gulf Stream Ring Formations from 1980 to 2019

Adrienne Silver[1], Avijit Gangopadhyay[1], Glen Gawarkiewicz[2], E. Nishchitha S. Silva[1,3] & Jenifer Clark[4]

Motivation



- → Goal: Identify spatiotemporal patterns of Illex catch in relation to oceanographic processes
- → Objectives :
  1. Analyze patterns in oceanographic conditions relative to catch rates
  2. Develop oceanographic indicators to support in season assessment

Image courtesy of: Lowman et. al 2021

TOR 4:

- Characterize annual and weekly, in-season spatio-temporal trends in body size based on length and weight samples collected from the landings by port samplers and provided by Illex processors. **Consider the environmental factors that may influence trends in body size and recruitment**. **If possible, integrate these results into the stock assessment**.
  - GAM results identify relationships between catch per unit effort and environmental factors
  - Resulting indicators may be useful for GDM hypothesis development and validation,

TOR 6:

- **Describe the data** that would be needed to conduct in-season stock assessments for adaptive management and **identify whether the data already exist or if new data would need to be collected and at what frequency**.
  - Results may help to identify the types and frequency of oceanographic data that exist and will continue to be collected going forward.

Methods

Combine data streams

Visualize patterns

Generate Hypotheses

Generalized additive models

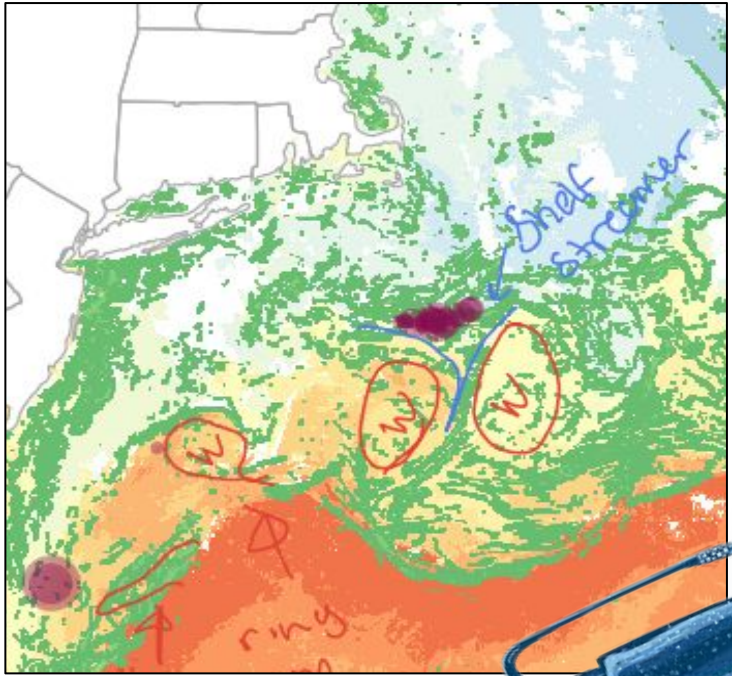
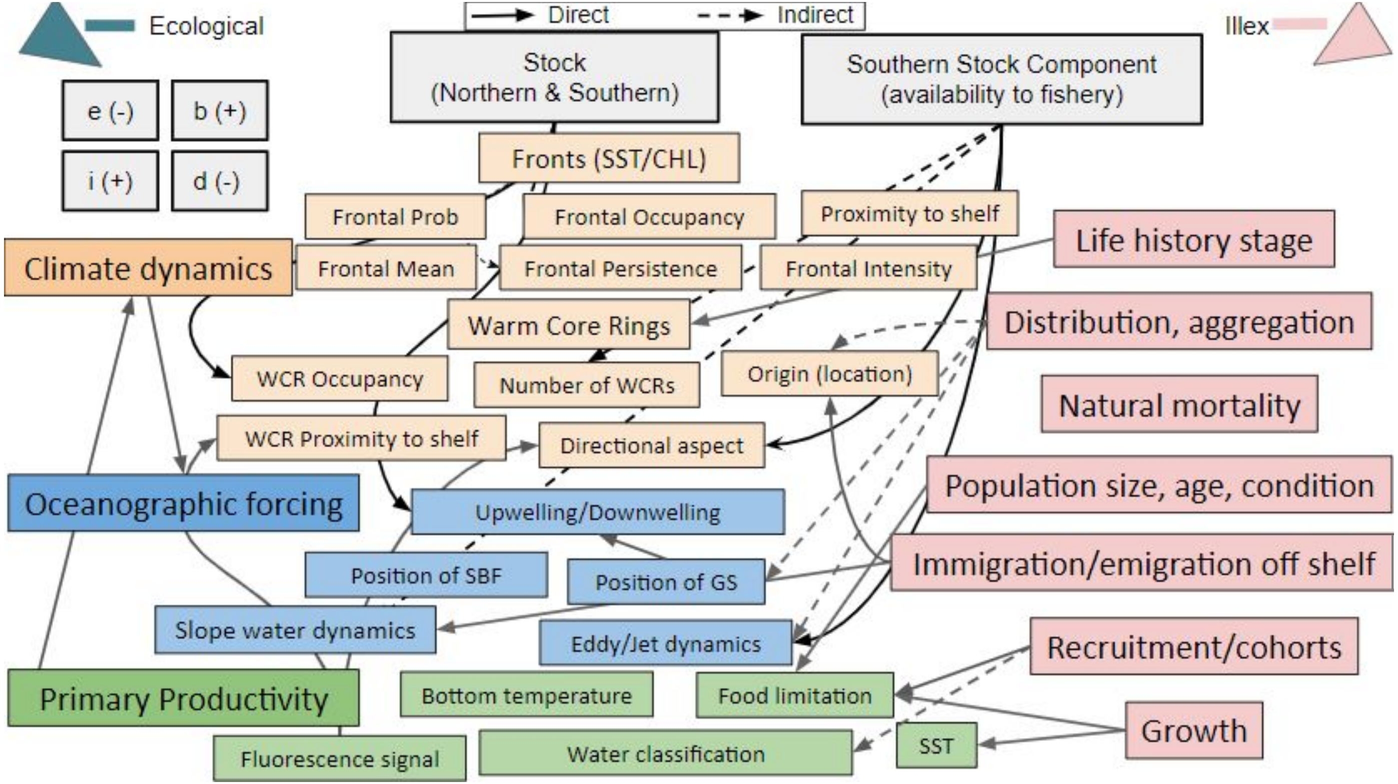


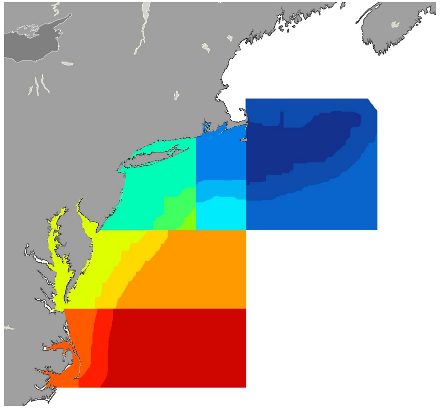
Image courtesy of the NOAA Office of Ocean Exploration and Research via Deep Connections 2019 expedition.

General Hypotheses



General Hypotheses

- → Frontal dynamics (abundance/distribution/growth/aggregation)
- → Warm core rings (immigration, mortality, emigration)
- → Fronts and WCRs (aggregation/abundance/growth/distribution)
- → Bottom temperature (emmigration, growth, aggregation)
- → Slope water composition (immigration/emigration)

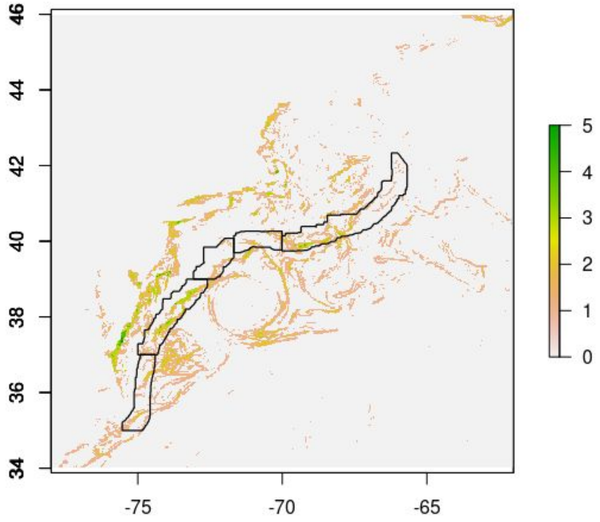


Response variable: Catch data

- Dataset:
  - Combined Study fleet and Observer data spanning 2008-2020
  - Nominal CPUE from wet boat fleet
  - Non-directed trips
- Rationale:
  - High resolution haul level VTR data
    - A. Jones et. al 2020 found that study fleet CPUE patterns were similar to other data sets, this work showed SF could be used to track trends
  - Wet boats may be more likely to capture environmental signal compared to freezer boats
    - B. Lowman's analyses found fleet differences
      - Likely due to differential processing capacity
  - Identify areas of low catch to get a more complete picture of spatial range/aggregation of Illex

Explanatory variables: Oceanographic data

- Fronts
  - Proportion of pixels identified as a front surrounding shelf break
- Warm Core Rings
  - Ring footprint (including lags)
  - Orientation to fishing point
- Slope/shelf conditions
  - SST mean, sd, anomalies
  - CHL mean, sd, anomalies
  - Bottom temperature
  - Salinity



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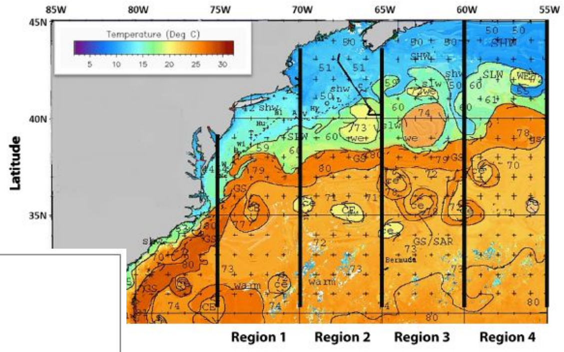

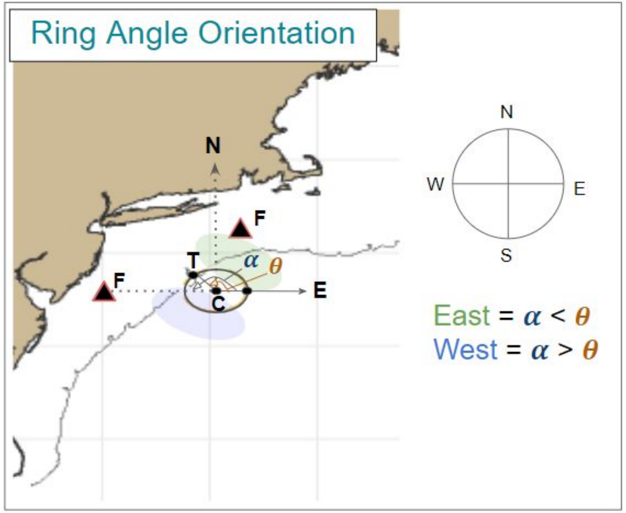

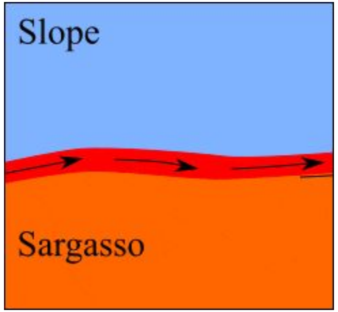

* Animation credit: SIRATES blog ,
* Annotated JC chart: Gangopadhyay et al. 2020

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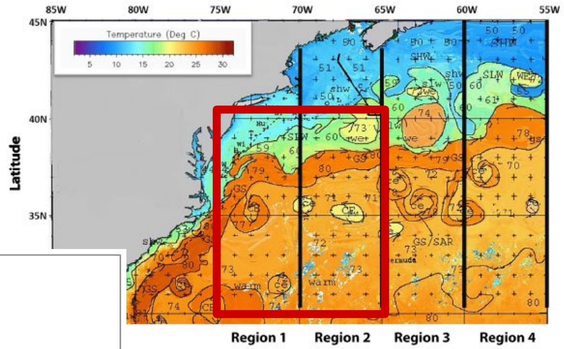

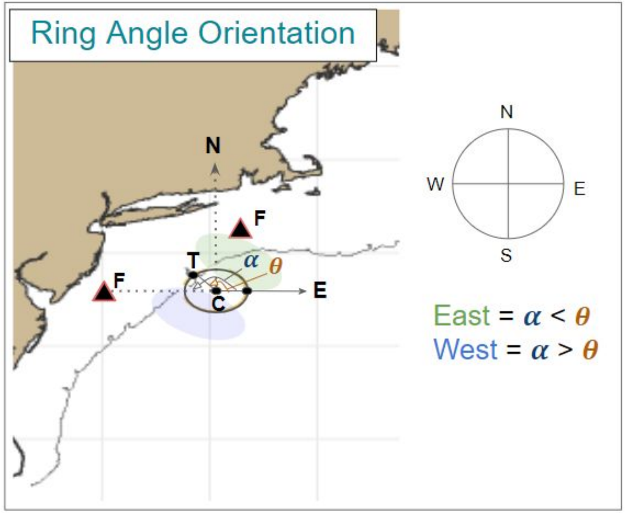

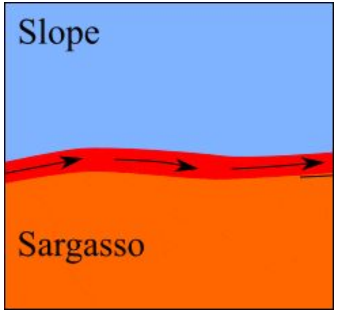

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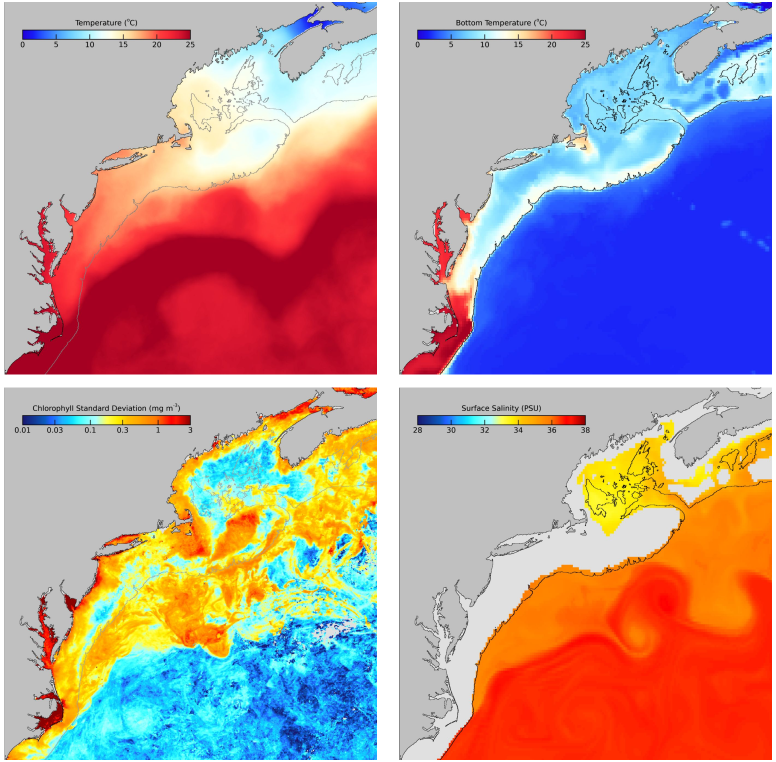

(Image credit: Kim Hyde)

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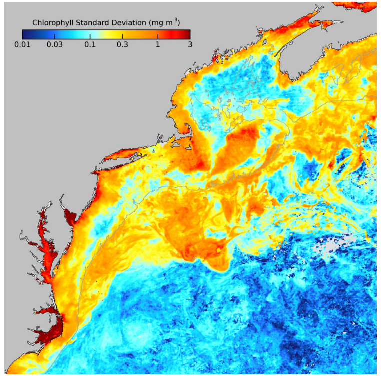
The Impact of Warm Core Rings on Middle Atlantic Bight Shelf Temperature and Shelf Break Velocity

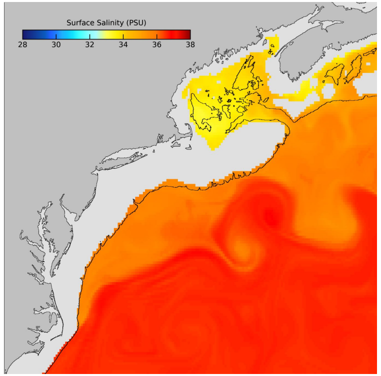
Jacob Forsyth[1,2], Glen Gawarkiewicz[1], and Magdalena Andres[1]

[1]Department of Physical Oceanography, Woods Hole Oceanographic Institution, Woods Hole, MA, USA, [2]Department Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA, USA

Diatom Hotspots Driven by Western Boundary Current Instability

Hilde Oliver[1], Weifeng G. Zhang[1], Walker O. Smith Jr.[2,3], Philip Alatalo[1], P. Dreux Chappell[4], Andrew J. Hirzel[1], Corday R. Selden[4], Heidi M. Sosik[1], Rachel H. R. Stanley[5], Yifan Zhu[4], and Dennis J. McGillicuddy Jr.[1]





(Image credit: Kim Hyde)

Variable	Range	Spatial Scale	Included
CPUE	2008 - 2020	74 – 66° W , 35 – 45° N	Yes (response)
Year	2011 - 2020	NES	Yes (f)
Week	18 – 44	NES	Yes (f)
Longitude	74.9 - 66.5	NES	Yes (s)
Latitude	35.9 - 45.5	NES	Yes (s)
CHL anomaly	0.53 - 2.08	NAFO	No (s)
CHL mean	0.35 – 2.11	NAFO	No (s)
CHL std. deviation	0.04 – 1.28	NAFO	No (s)
SST anomaly	-2.50 – 2.28	NAFO	No (s)
SST mean	10.24 – 28.41	NAFO	No (s)
SST std. deviation	0.17 – 1.58	NAFO	Yes (s)
CHL Fvalid	0.00 – 0.72	NESBR	Yes (s)
SST Fvalid	0.00 – 0.30	NESBR	No (s)
Bottom temp	3.75 – 14.04	FP	Yes (s)
Salinity 47m	34.55 – 35.92	NESBR	No (s)
Salinity 55m	33.56 – 36.04	NESBR	No (s)
Salinity 110m	34.86 – 36.05	NESBR	No (s)
Salinity 222m	35.21 – 35.83	NESBR	Yes (s)
Distance to ring (km)	3.45 – 886.68	KM	No (s)
Ring distance to shelf (km)	15.41 – 264.58	KM	No (s)
RFI, Zone 1	0.00 - 0.37	75 – 70° W	No (s)
RFI, Zone 2	0.00 – 0.64	70 – 65° W	No (s)
RFI, Zone 3	0.00 – 0.55	65 – 60° W	No (s)
RFI, Zone 4	0. 00 – 0.45	60 – 55°W	No (s)
RFI, Zone 1, lag 6mo	0.00 – 0.30	75 – 70° W	No (s)
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RFI, Zone 3, lag 6mo	0.00 – 0.43	65 – 60° W	No (s)
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RFI, Zone 4, lag 3mo	0. 00 – 0.42	60 – 55°W	No (s)
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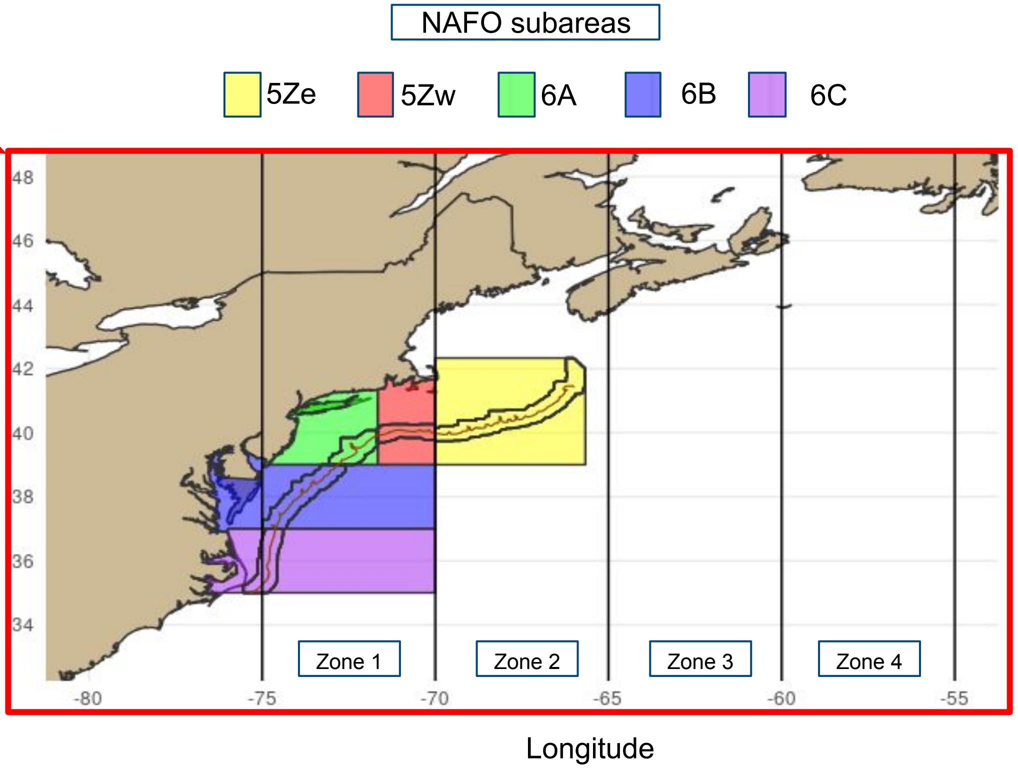
Shelf_occ_Lag6mo	0.00 – 14.00	NES	No (s)
Ring orientation	West, East	NES	Yes (f)
NAFO subarea	5Ze, 5Zw, 6A, 6B,6C	NAFO	Yes (f)



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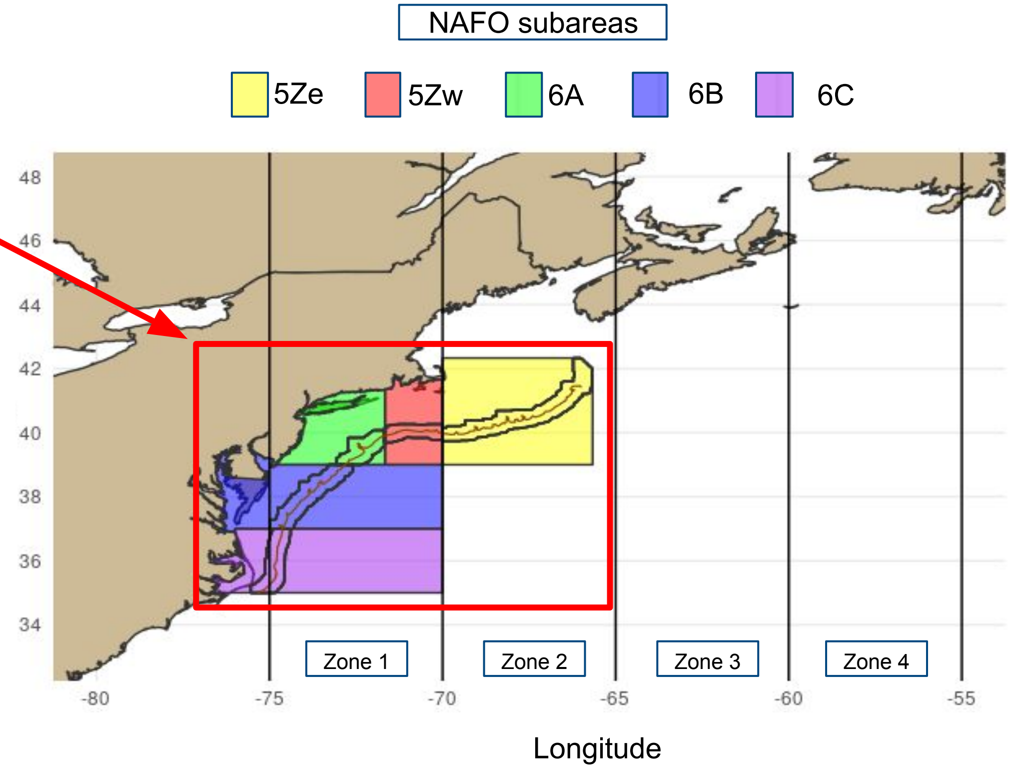

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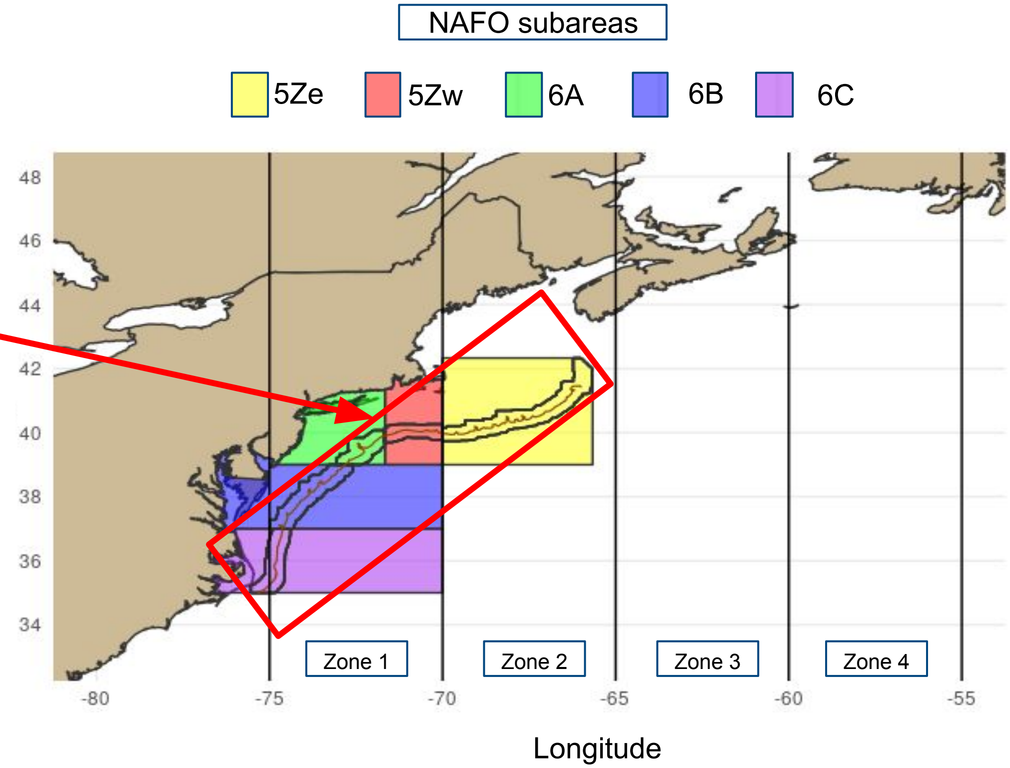

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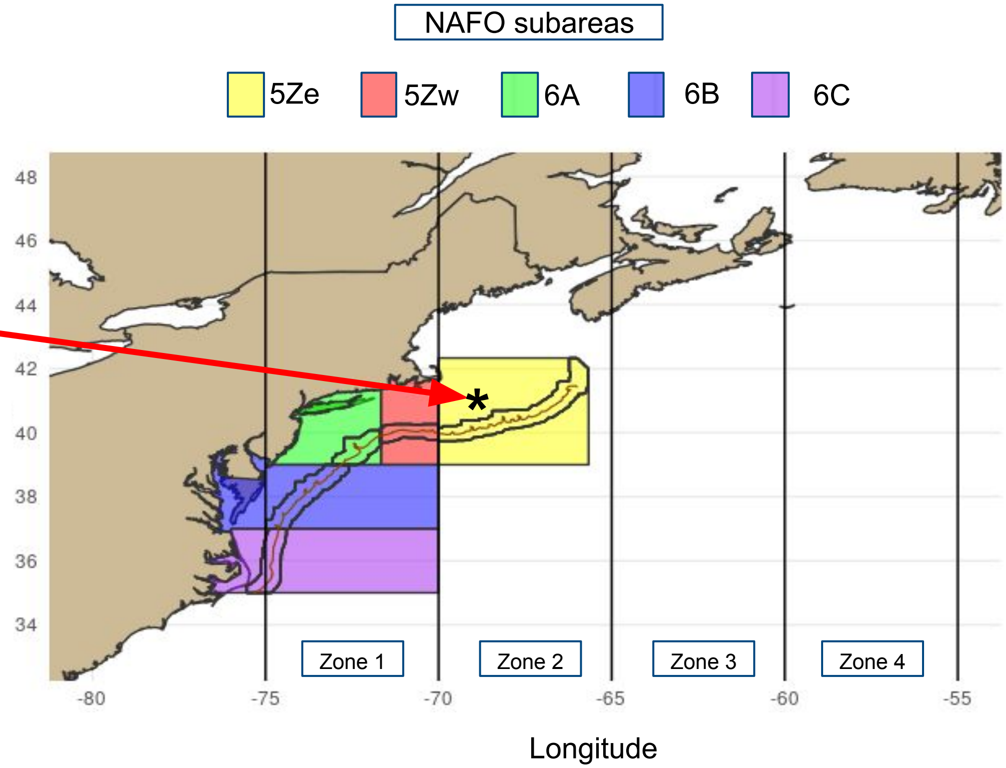
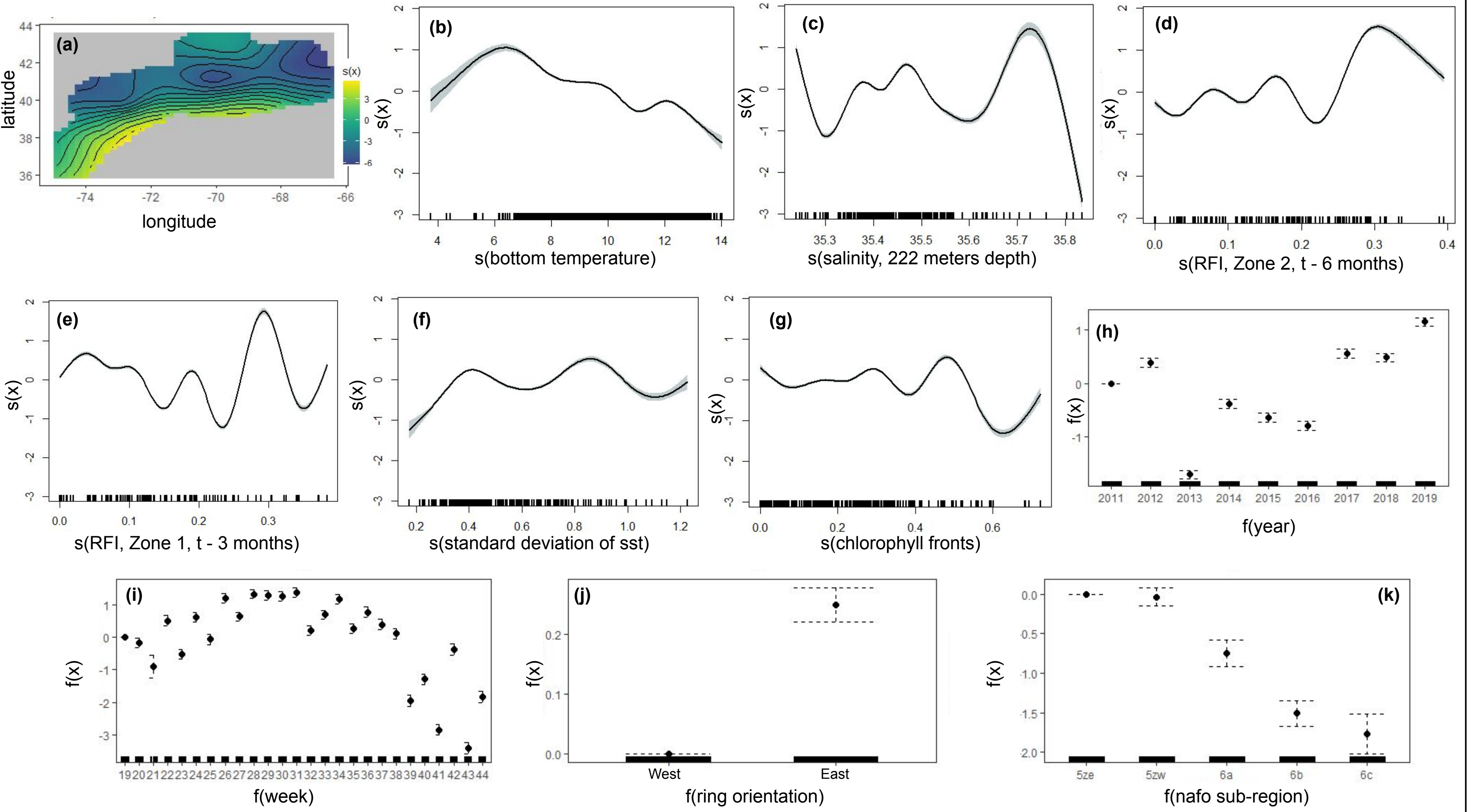
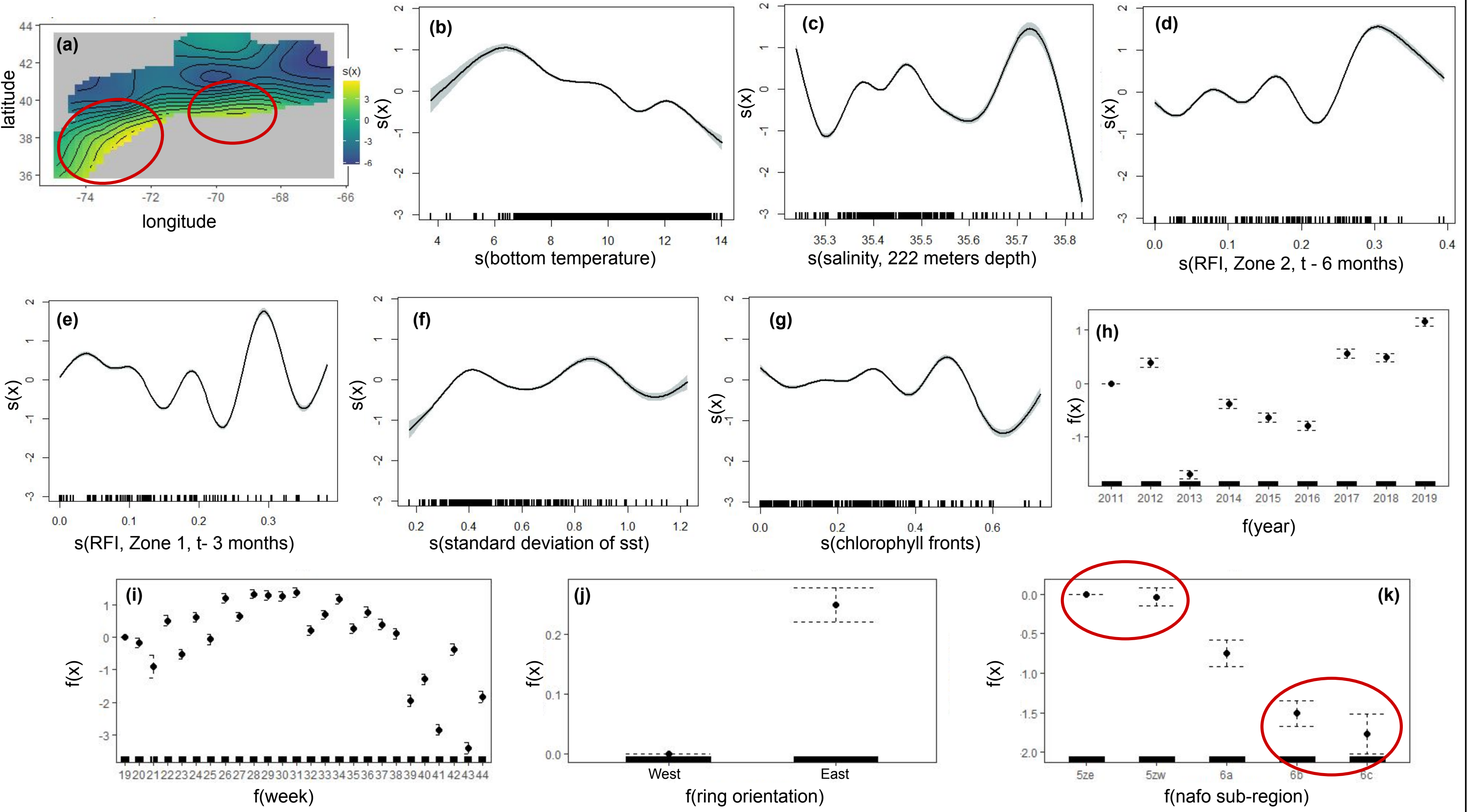
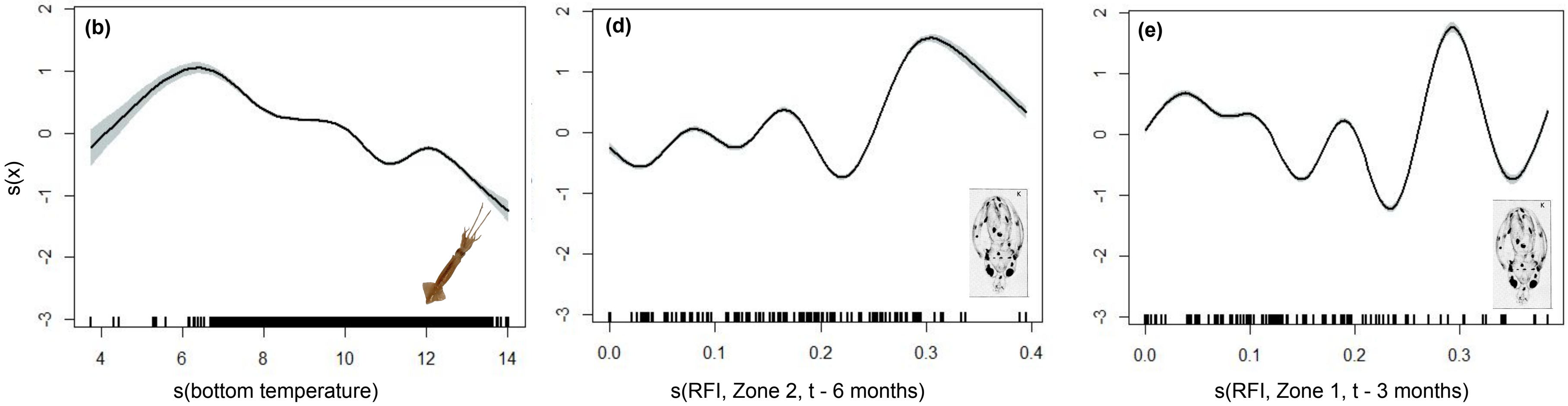



(a)
latitude
longitude
s(x)
(b)
s(bottom temperature)
(c)
s(salinity, 222 meters depth)
(d)
s(RFI, Zone 2, t - 6 months)
(e)
s(RFI, Zone 1, t - 3 months)
(f)
s(standard deviation of sst)
(g)
s(chlorophyll fronts)
(h)
f(year)
(i)
f(week)
(j)
West
East
f(ring orientation)
(k)
5ze
5zw
6a
6b
6c
f(nafo sub-region)
f(x)

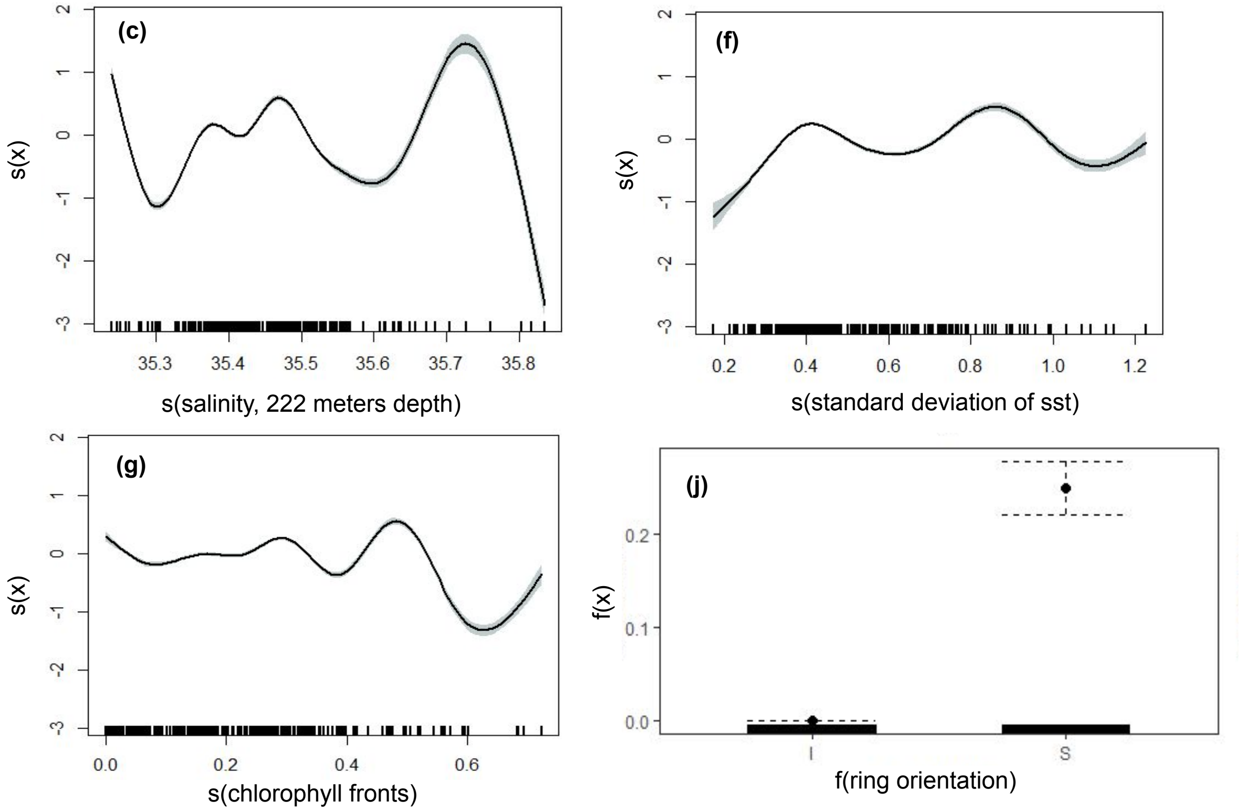


(a)
latitude
longitude
s(x)
(b)
s(bottom temperature)
(c)
s(salinity, 222 meters depth)
(d)
s(RFI, Zone 2, t - 6 months)
(e)
s(RFI, Zone 1, t- 3 months)
(f)
s(standard deviation of sst)
(g)
s(chlorophyll fronts)
(h)
f(year)
(i)
f(week)
(j)
West
East
f(ring orientation)
(k)
5ze
5zw
6a
6b
6c
f(nafo sub-region)

Indicators of habitat condition



Indicators of areas of productivity



TOR 4:

- Generalized Depletion Modeling (GDM)
  - Identify oceanographic signature for dates of catch perturbations
  - Contribute to biological realism component of hypothesis development
- Hidden Markov Models (HMM)
  - Inferences about system states
  - Covariates can affect mean states of the system
  - Covariates can inform transition probabilities

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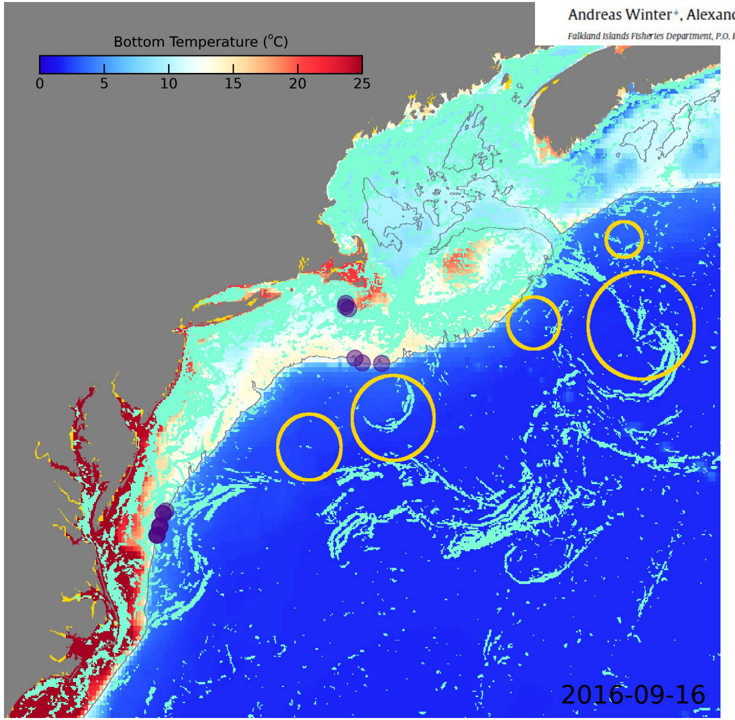
journal homepage: www.elsevier.com/locate/fishres

Environmental impacts on recruitment migrations of Patagonian longfin squid (*Doryteuthis gahi*) in the Falkland Islands with reference to stock assessment

Andreas Winter*, Alexander Arkhipkin

Falkland Islands Fisheries Department, P.O. Box 597, Stanley FIQQ 1ZZ, Falkland Islands



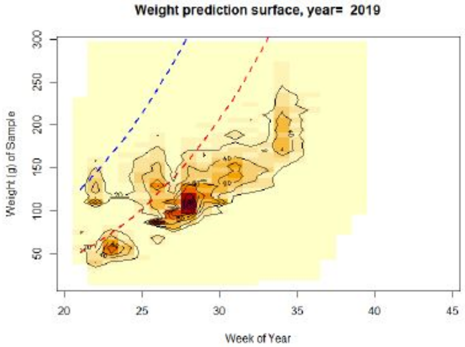
(Image credit: Kim Hyde)

Catch perturbation analysis

2016: Perturbation summary table

Week	Fleet Dyn	Wt. Freq	Freezer DF	Freezer H0_resid	Freezer Catch spikes N Par	Freezer Catch spikes Par	Wet DF	Wet H0_resid	Wet Catch spikes N Par	Wet Catch spikes Par	Hypothesis	Timings Wk
24	SW		0				0.73					
25	SW		5.02		-		0.52					
26	SW		0				2.26					E1.wet= -27
27	SW		0				4.65		-	-		E1.freeze= -29
28	SW		6.09				3.67	+	+	+	H3: P1E1P2E1	P1.wet=33
29	SW		4.22	-	-	-	3.7					P1.freeze=34
30	SW	+	11.02				4.16					P2.wet=38
31	SW		4.48	-	-	-	2.5					
32	SW & NE	+	11.63				5.69					
33	SW		0				4.61		+	+	H1: P1P1	P1.wet=33
34	SW	+	3.76	+		+	7.65	-				P1.freeze=34
35	SW & NE	+	6.04	+	+	+	3.46					
36	SW & NE		0				0.96					
37	SW & NE		5.49	+	+	+	1.61	+		-		
38	SW		0				3.04	+		+		
39	SW		5.61		+	+	2.38	+	+	+	H2: P2P2	P1.wet=33
40	SW		2			+	1.88	+		+		P1.freeze=34
41	SW		5.23				2.76					P2.freeze=37
42	SW		3.24				2.88					P2.wet=38
		Total	73.8				59.1					
		# Effort	56				44					

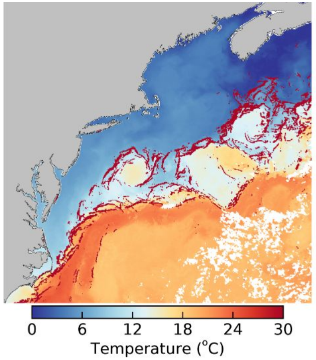
(Manderson et al. 2022)

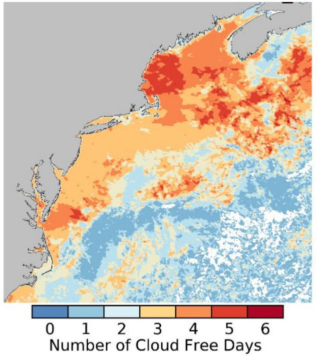


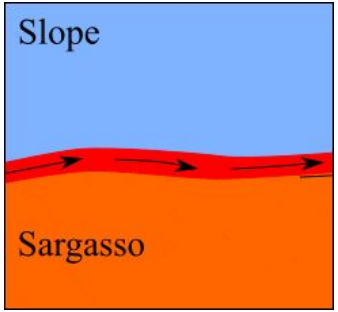
(Rago 2021)

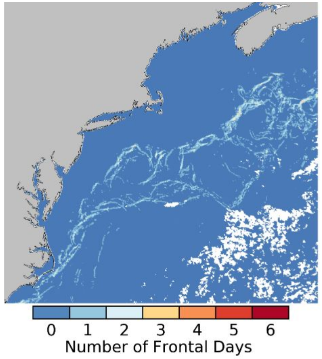
TOR 6:

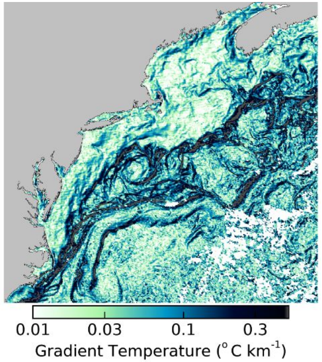
- Automation and validation of current data streams
- Oceanographic indicators and mechanistic drivers
- Continued and enhanced collaboration with science and industry











* *Animation credit: SIRATES blog*

(Image credit: Kim Hyde)

Conclusions & Takeaways

Identified a suite of environmental variables with significant associations to CPUE:

1. *Illex* habitat condition :
   a. **BT, Ring Footprint Index**
2. Areas of increased productivity
   a. **CHL fronts, salinity, orientation of ring, sd SST**

Potential for future assessments:

1. Identifying areas of *Illex* aggregation
   a. **Mechanistic drivers**
2. Understanding distribution and availability
   a. **Ingress/egress events**

NOAA FISHERIES

Thank you!

SQUID SQUAD

NORTHEAST FISHERIES SCIENCE CENTER
COOPERATIVE RESEARCH

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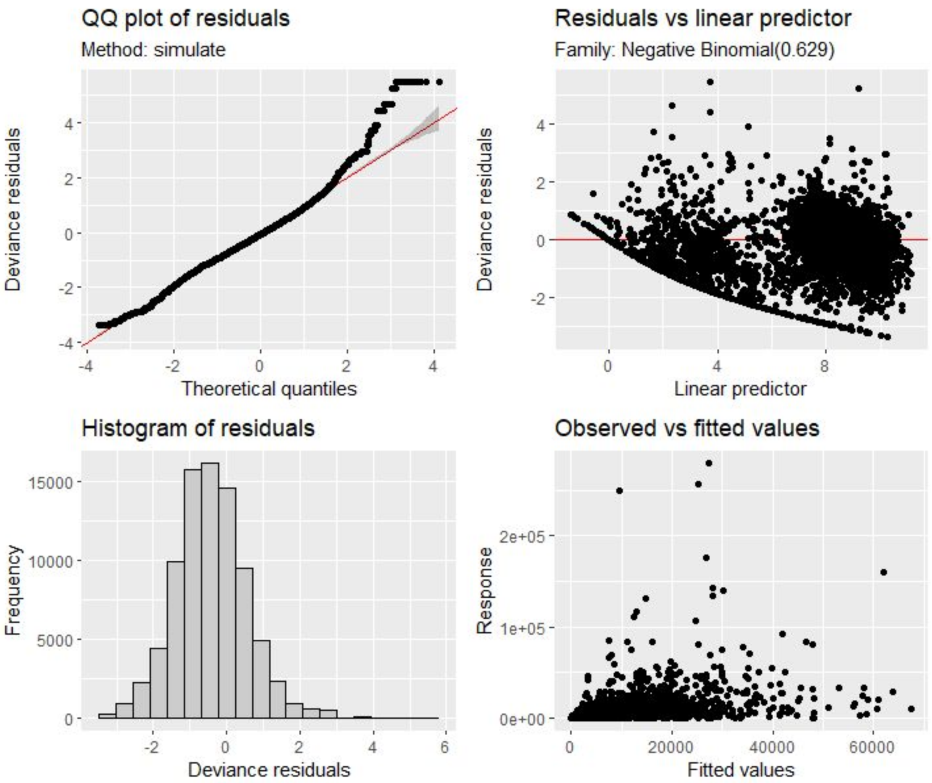
Diagnostics



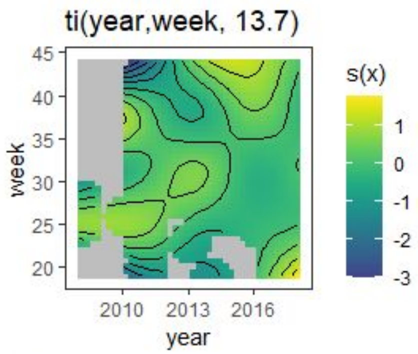
	para	s(lon,lat)	s(bt)	s(sal_222m)	s(z2lag6mo)	s(z1lag3mo)	s(sst_sd)	s(fvalid_chl)
worst	0.9978405	0.9850569	0.7611444	0.8579137	0.7944047	0.8697239	0.7526172	0.7232738
observed	0.9978405	0.8305200	0.6828201	0.6149561	0.6794605	0.7674654	0.5680970	0.4398301
estimate	0.9978405	0.8062464	0.6118442	0.7301453	0.7190283	0.8285253	0.6908998	0.6355781

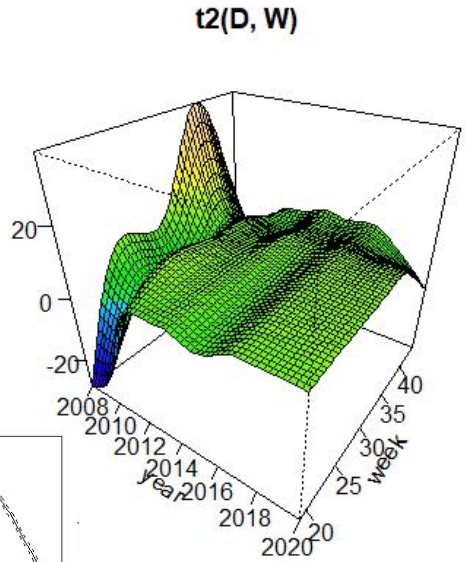
$worst

	para	s(lon,lat)	s(bt)	s(sal_222m)	s(z2lag6mo)	s(z1lag3mo)	s(sst_sd)	s(fvalid_chl)
para	1.000000e+00	3.359147e-26	2.423860e-27	1.448723e-24	7.945986e-26	3.189120e-24	1.332299e-24	1.710679e-23
s(lon,lat)	3.541122e-26	1.000000e+00	5.852027e-01	5.432314e-01	1.879673e-01	3.448533e-01	2.790431e-01	3.183178e-01
s(bt)	1.996658e-27	5.852027e-01	1.000000e+00	1.033201e-01	1.021077e-01	1.532674e-01	9.035643e-02	6.502473e-02
s(sal_222m)	1.451792e-24	5.432314e-01	1.033201e-01	1.000000e+00	2.004730e-01	2.707715e-01	2.274945e-01	1.872171e-01
s(z2lag6mo)	7.773789e-26	1.879673e-01	1.021077e-01	2.004730e-01	1.000000e+00	3.504526e-01	2.344424e-01	1.617594e-01
s(z1lag3mo)	3.196450e-24	3.448533e-01	1.532674e-01	2.707715e-01	3.504526e-01	1.000000e+00	2.999836e-01	2.164813e-01
s(sst_sd)	1.312706e-24	2.790431e-01	9.035643e-02	2.274945e-01	2.344424e-01	2.999836e-01	1.000000e+00	2.869425e-01
s(fvalid_chl)	1.707446e-23	3.183178e-01	6.502473e-02	1.872171e-01	1.617594e-01	2.164813e-01	2.869425e-01	1.000000e+00

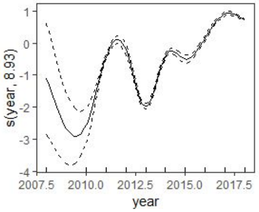
Year x Week

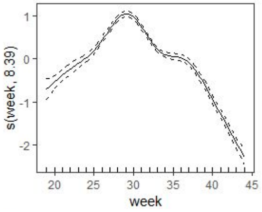
tensor(year, week) 2008:2020



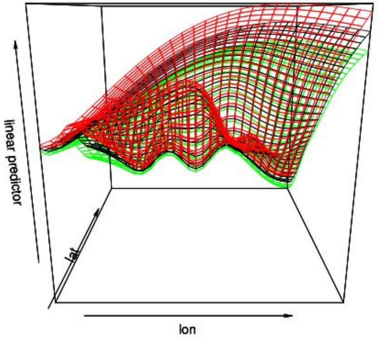


* excludes 2009

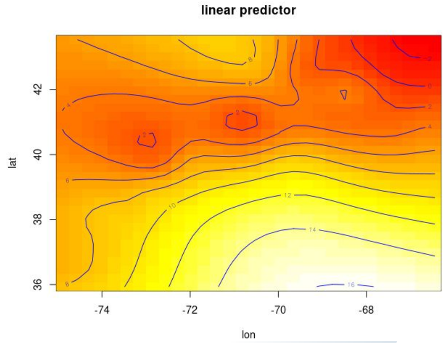


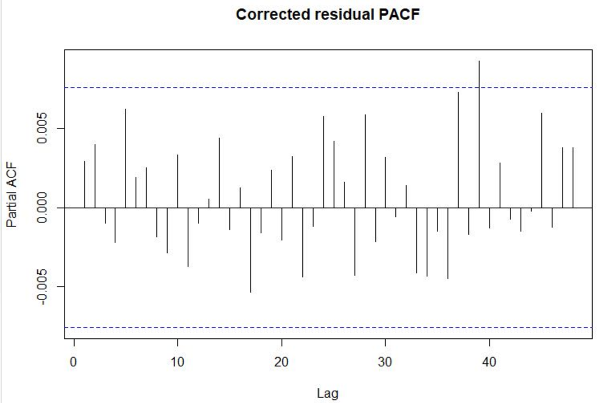


Year (as factor), week (as factor) 2011:2020



red/green are +/- 2 s.e.

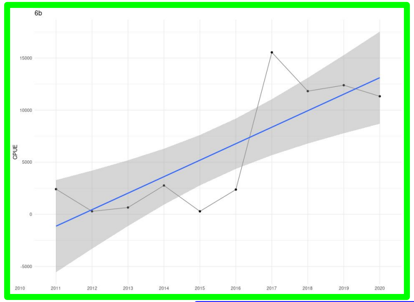


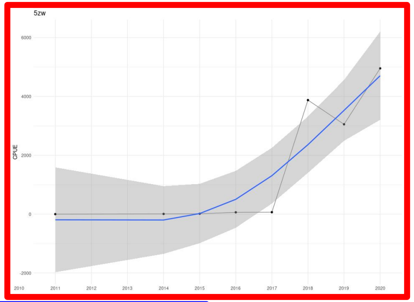


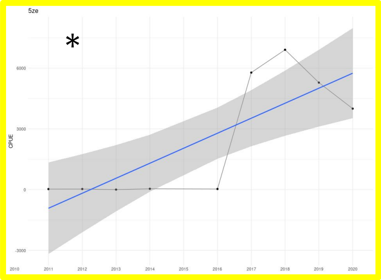
Formula	df	ResDeviance	Dev/df	PercDevExplained	AIC
year + week	72205	94834.41	1.31	36.43	1074027
s(year.int) + s(week.int) + ti(year.int, week.int)	72205	95255.98	1.32	34.55	1076780
te(year.int, week.int)	72215	96348.22	1.33	29.57	1083753

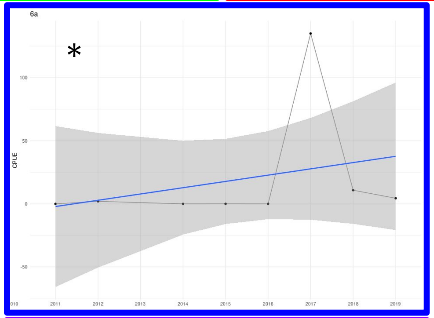
Details - Methods

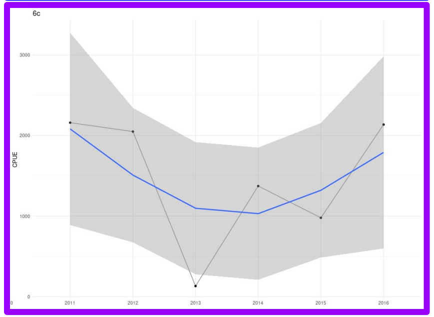
Exploring data



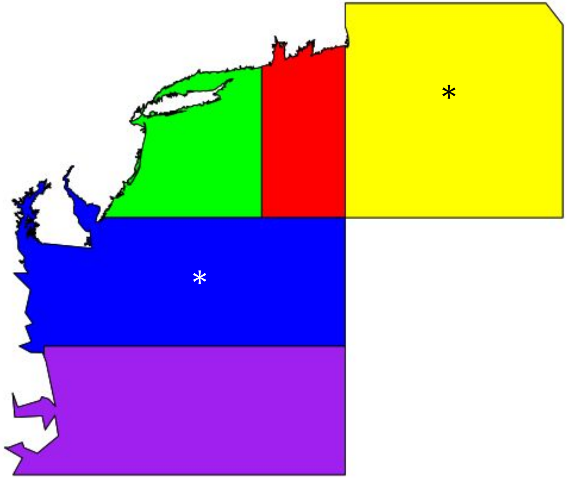




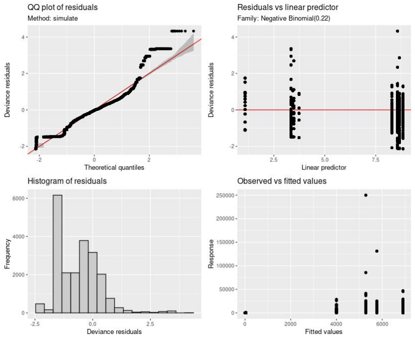


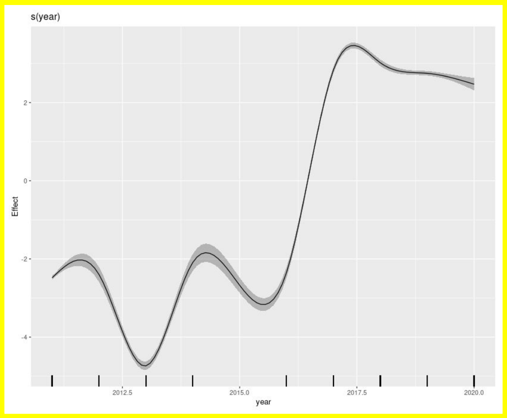



```
# A tibble: 5 × 2
# Groups:   nafo_zone [5]
  nafo_zone      n
  <fct>      <int>
1 5ze        21505  *
2 5zw         8390
3 6a          3220
4 6b         48020  *
5 6c          9165
```



Exploring data

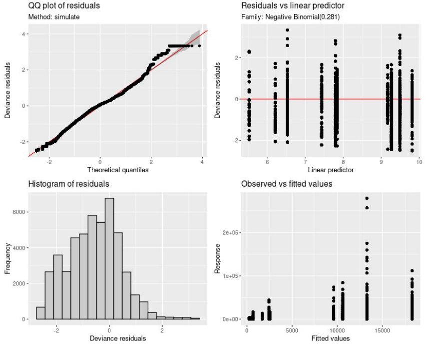


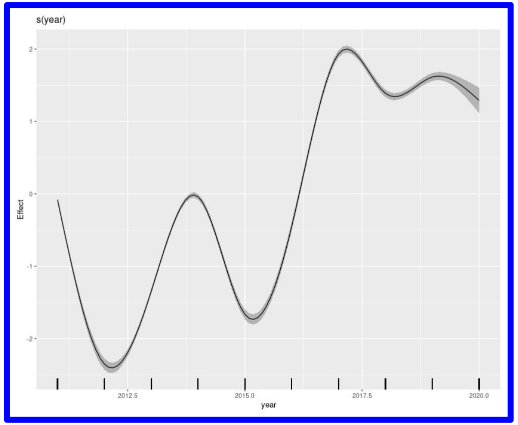


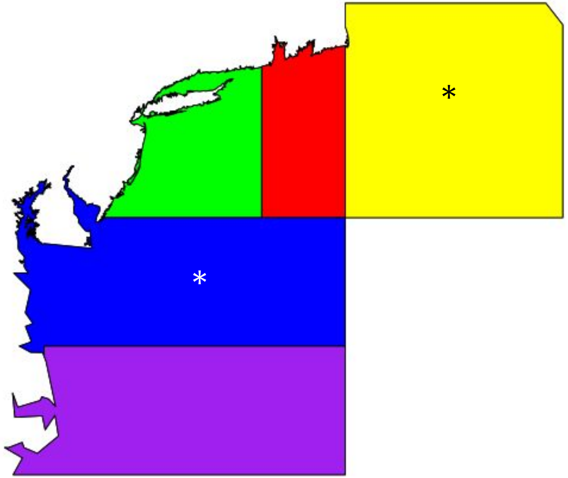
*

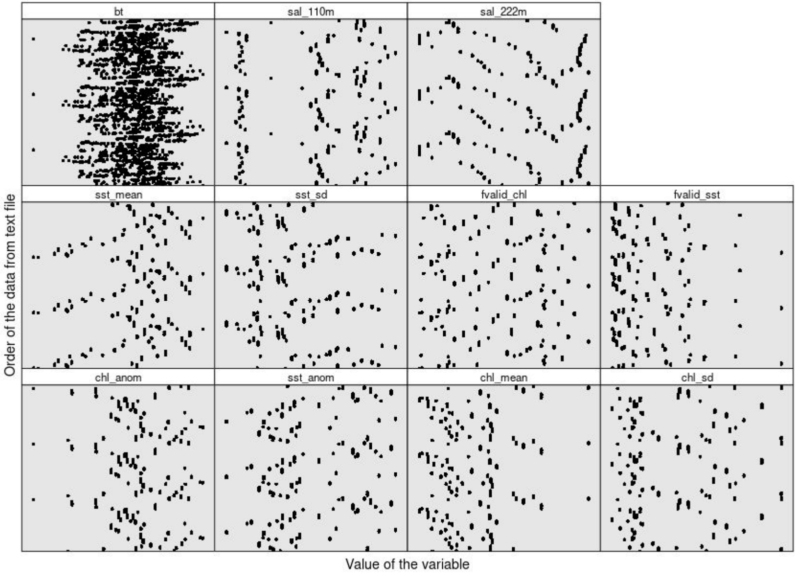
```
# A tibble: 5 × 2
# Groups:   nafo_zone [5]
  nafo_zone     n
  <fct>     <int>
1 5ze       21505 *
2 5zw        8390
3 6a         3220
4 6b        48020 *
5 6c         9165
```

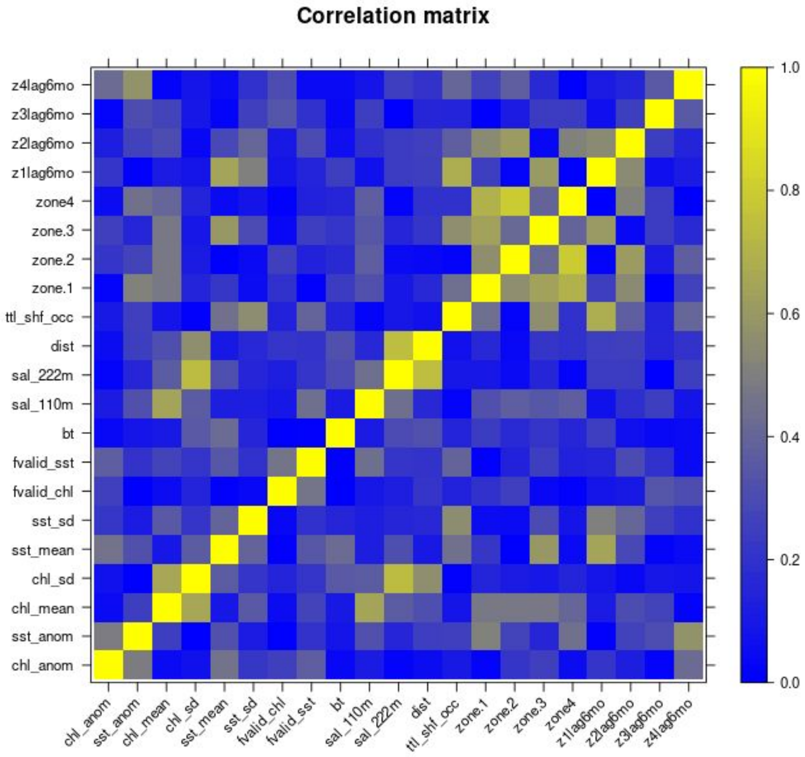
*








bt
sal_110m
sal_222m
sst_mean
sst_sd
fvalid_chl
fvalid_sst
chl_anom
sst_anom
chl_mean
chl_sd
Order of the data from text file
Value of the variable


Correlation matrix
z4lag6mo
z3lag6mo
z2lag6mo
z1lag6mo
zone4
zone.3
zone.2
zone.1
ttl_shf_occ
dist
sal_222m
sal_110m
bt
fvalid_sst
fvalid_chl
sst_sd
sst_mean
chl_sd
chl_mean
sst_anom
chl_anom
1.0
0.8
0.6
0.4
0.2
0.0

Oceanographic variables

- Frontal Metrics
  - BOA algorithm to compute gradients (Belkin & O'Reilly, 2009)
  - Applied a threshold to gradients to determine front
    - Δ_{GRAD_SST} >= 0.4 °C
    - Δ_{GRAD_CHL} >= 0.06 mgm^{-3}
- Frontal pixels (F_{valid}): number of days pixel was identified as a front (> threshold, 0.4°C)

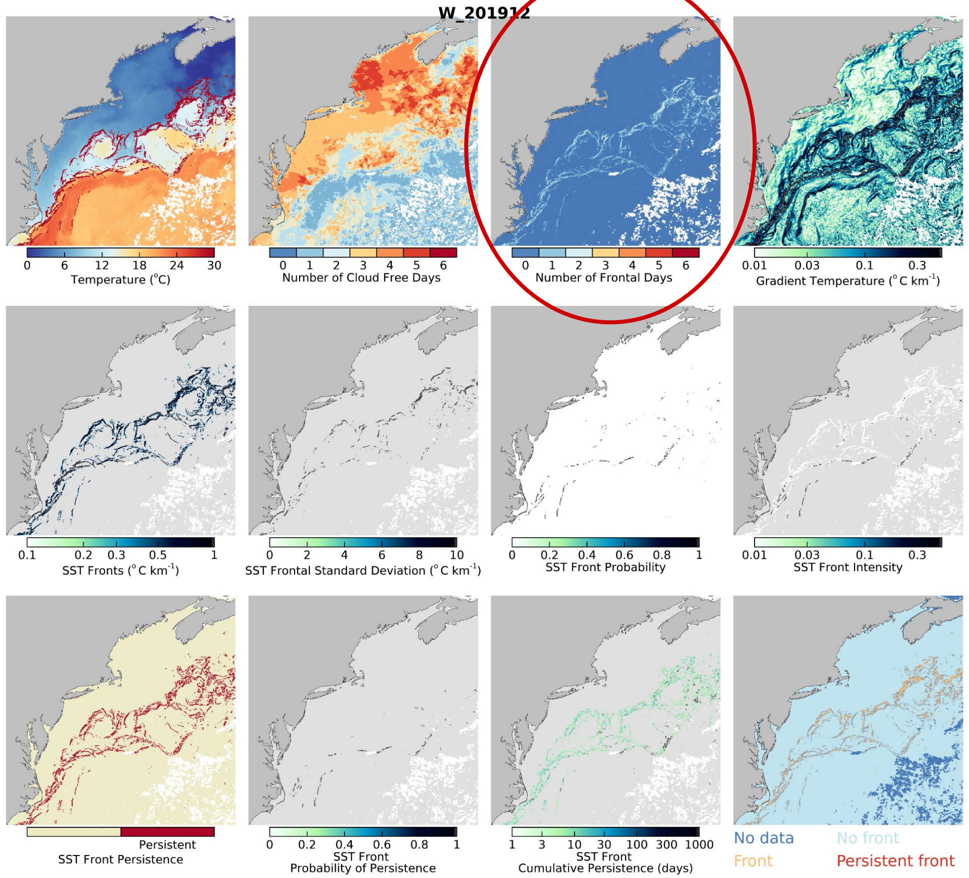
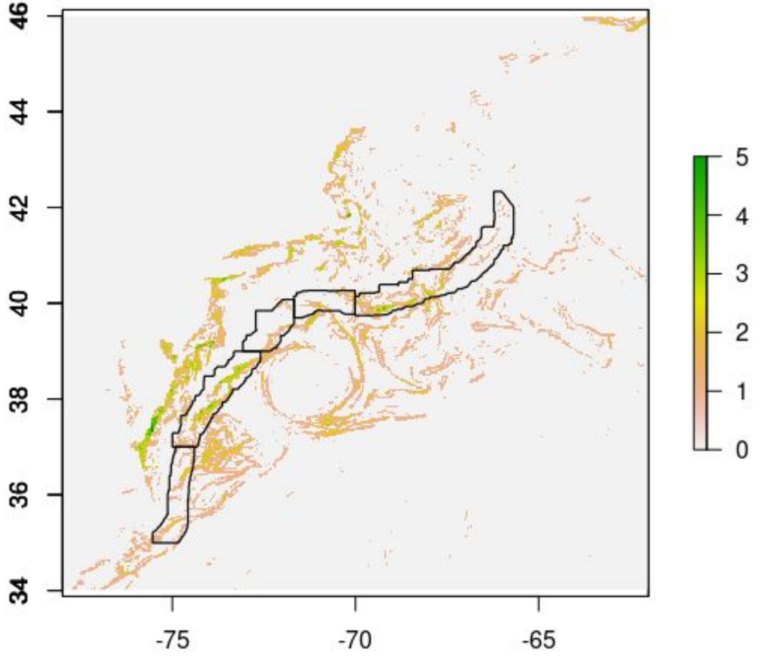


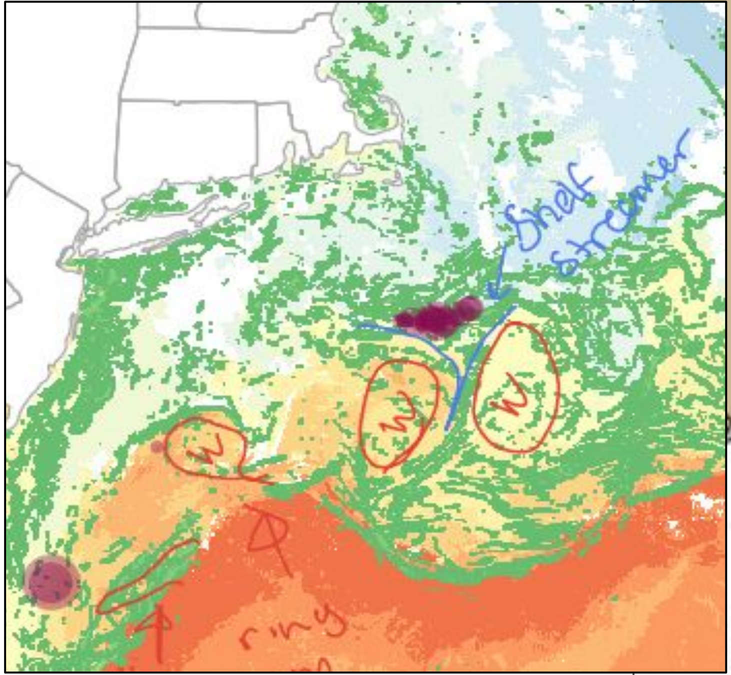
Image credit: Kim Hyde NEFSC

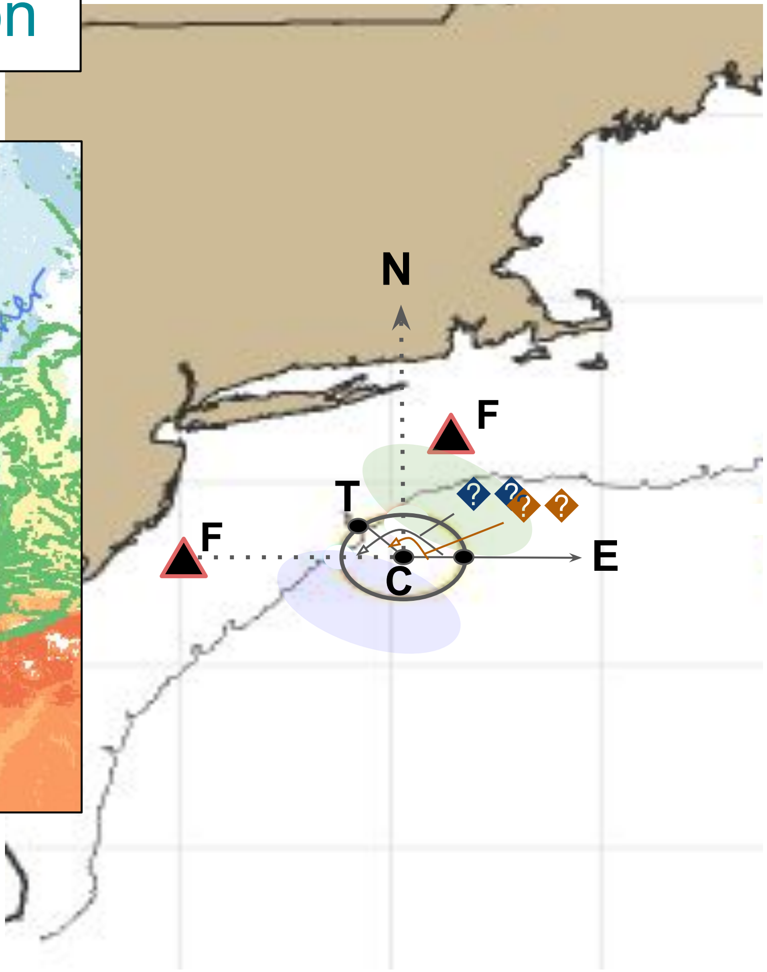
Proportion of pixels that were identified as a front in the shelf break region
(40 km on either side of shelf break)

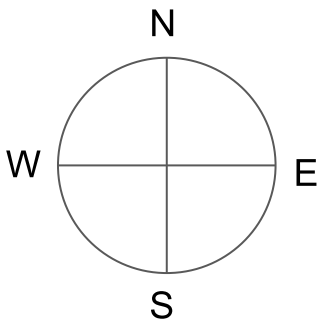



```
> 5Ze <- mean(fvalid[[1]] > 0)
[1] 0.28675
> 5Zw <- mean(fvalid[[2]] > 0)
[1] 0.2205246
> 6a <- mean(fvalid[[3]] > 0)
[1] 0.1801763
> 6b <- mean(fvalid[[4]] > 0)
[1] 0.3876345
> 6c <- mean(fvalid[[5]] > 0)
[1] 0.3141979
```

Ring Angle Orientation

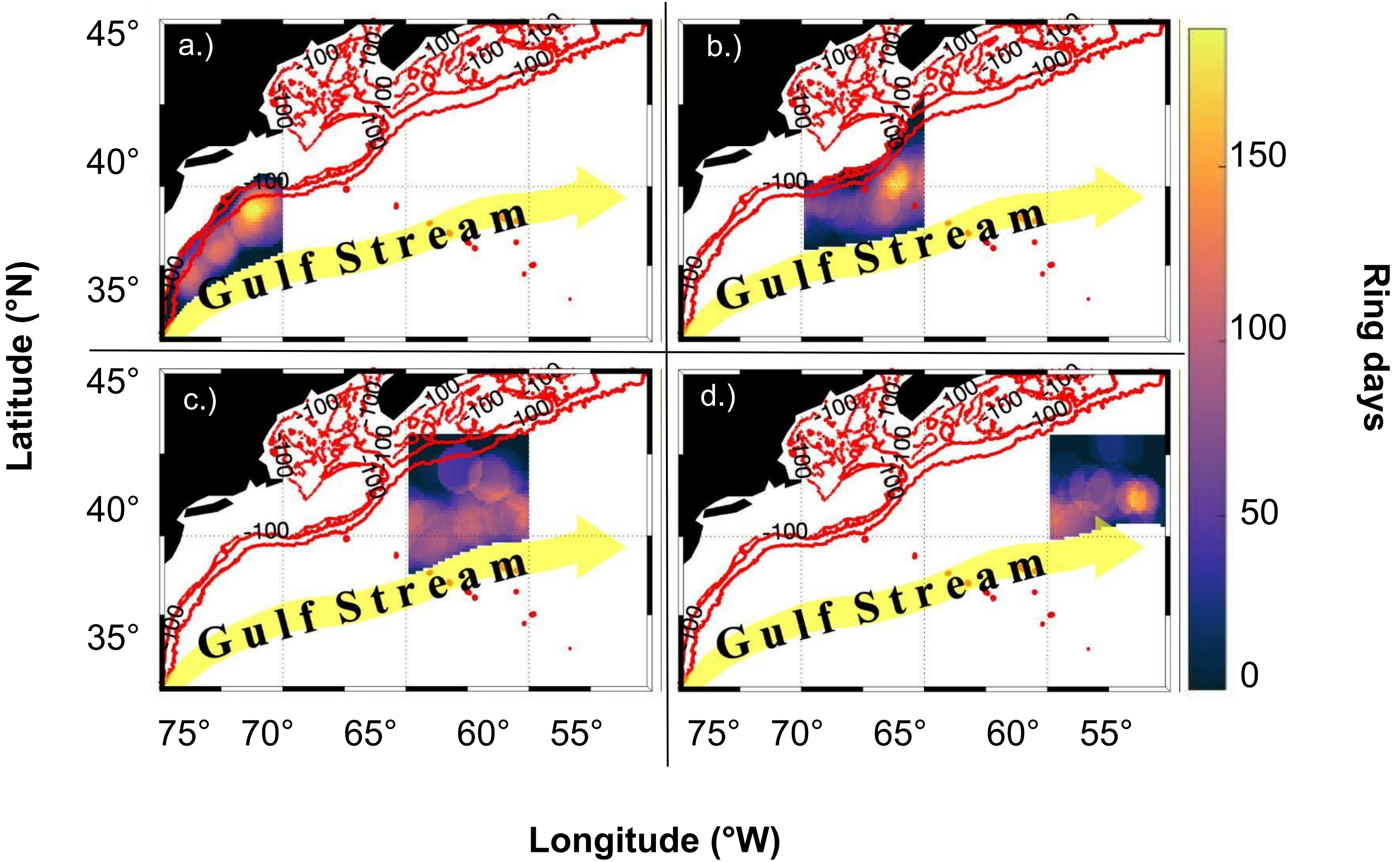






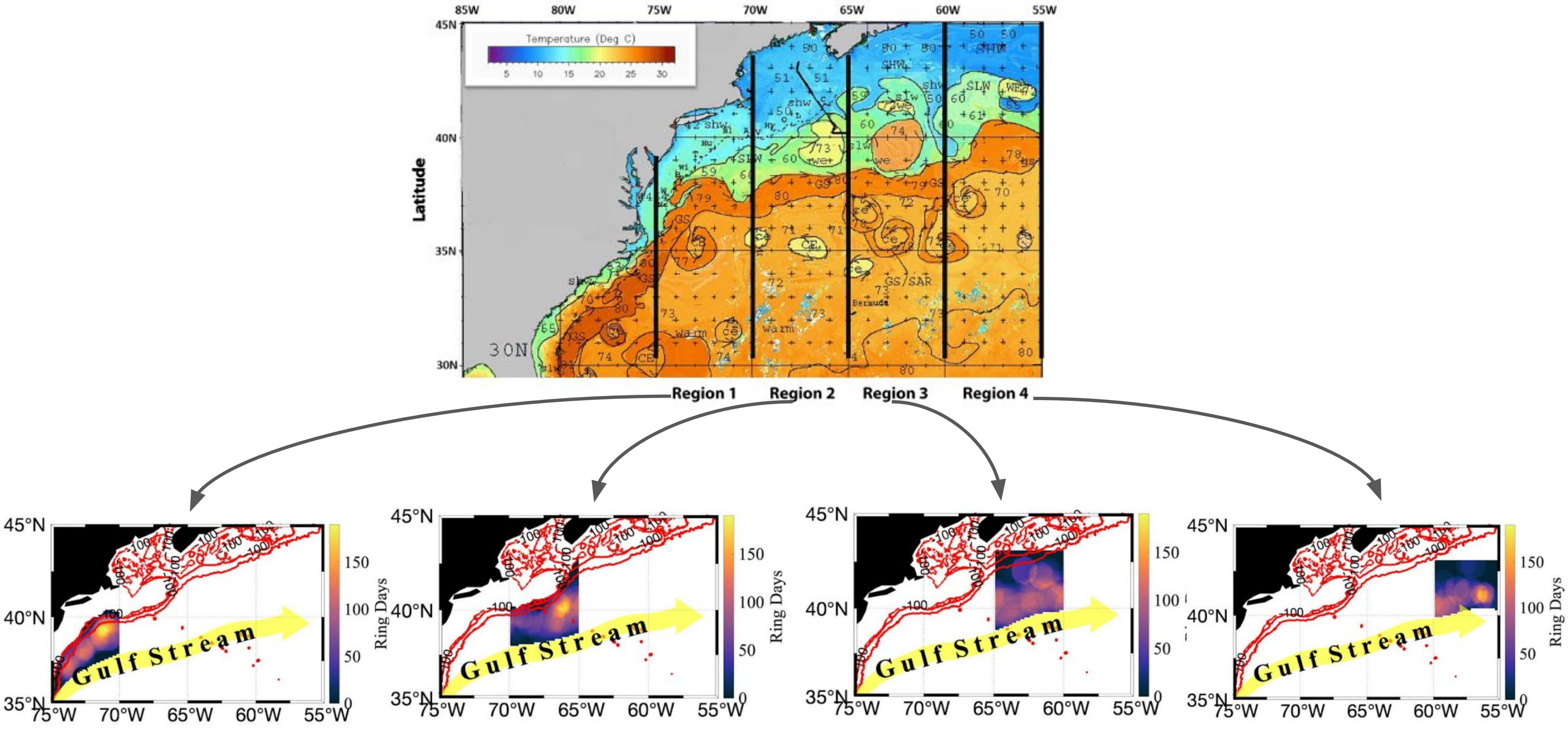
East = $\alpha < \theta$

West = $\alpha > \theta$

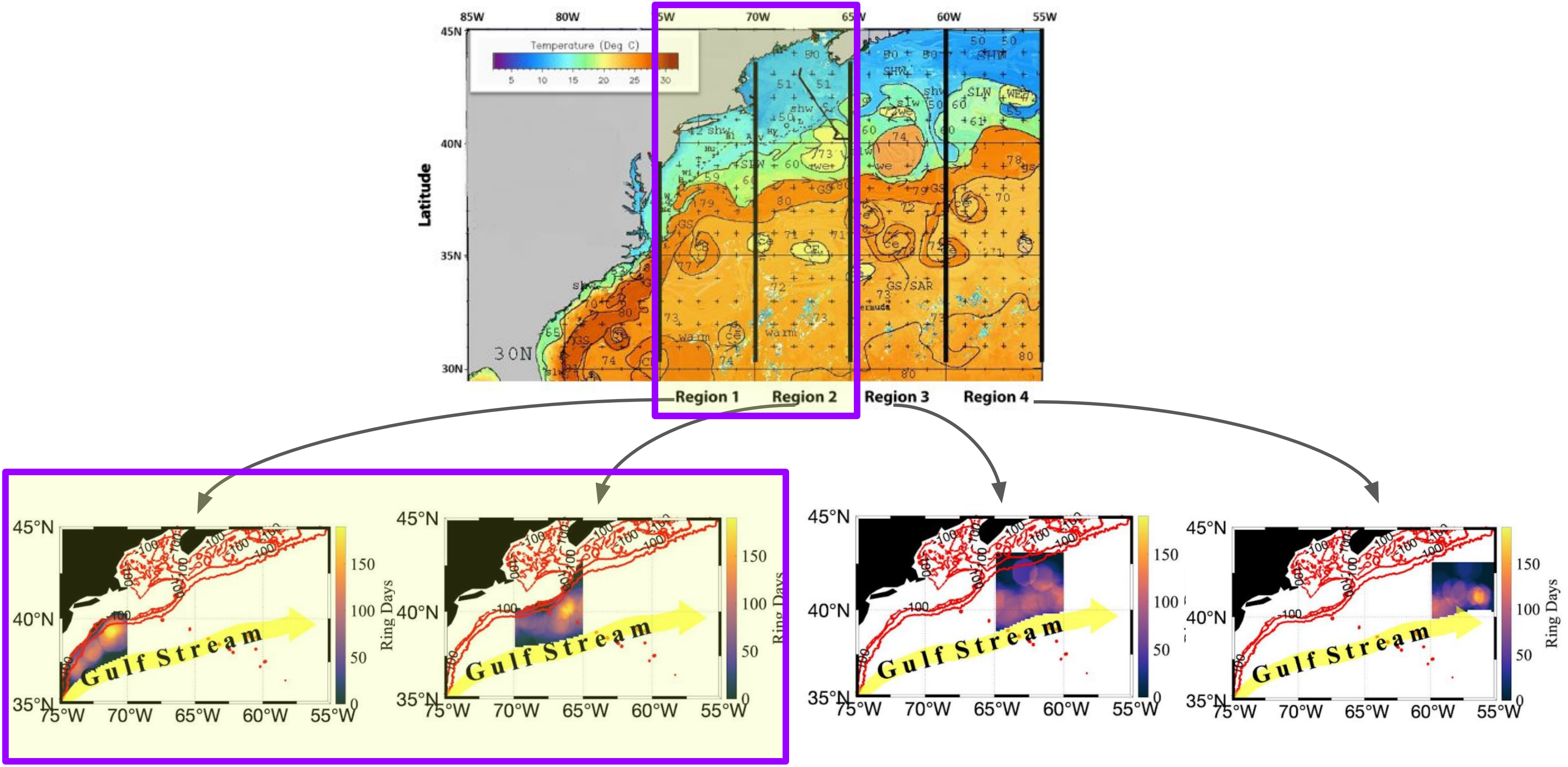


a.)
b.)
c.)
d.)
Gulf Stream
-100
45°
40°
35°
75°
70°
65°
60°
55°
Latitude (°N)
Longitude (°W)
Ring days
150
100
50
0

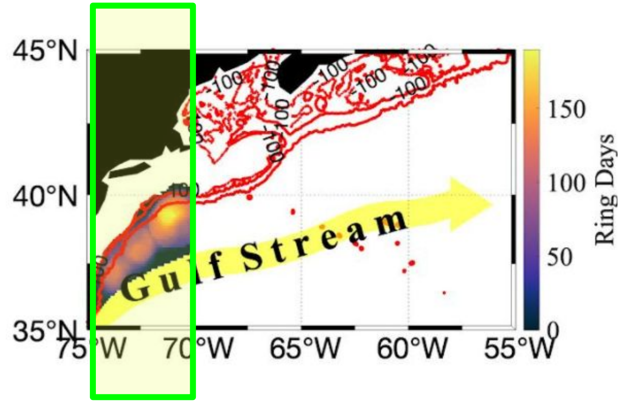
Slope Occupancy/Footprint by Region(Zone)

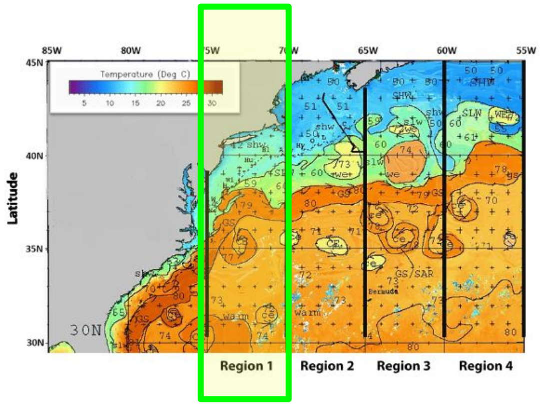


Slope Occupancy/Footprint by Region(Zone)

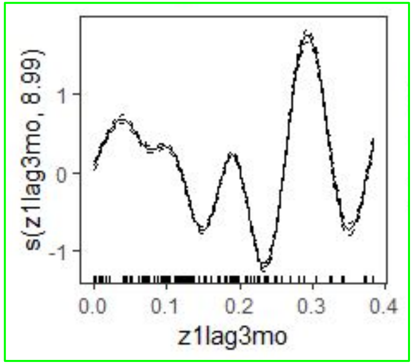


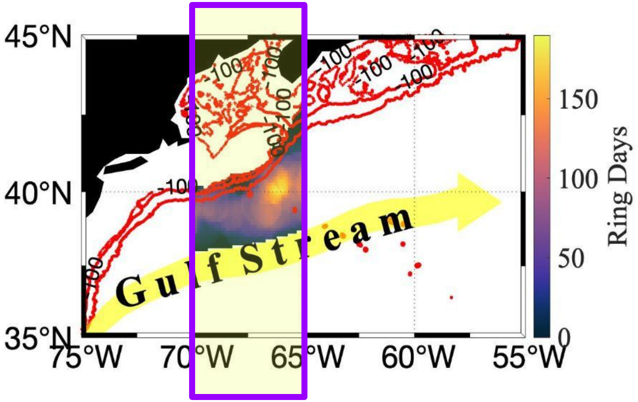
Slope occupancy/footprint by Region(Zone)

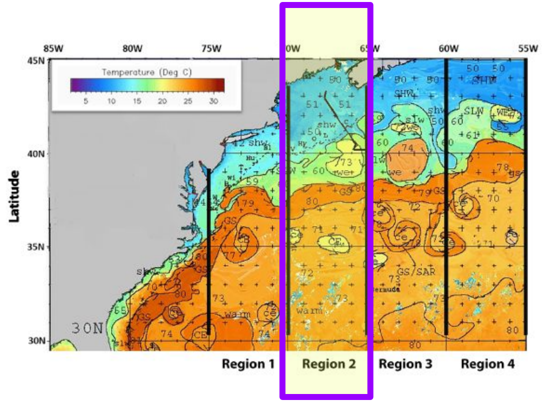




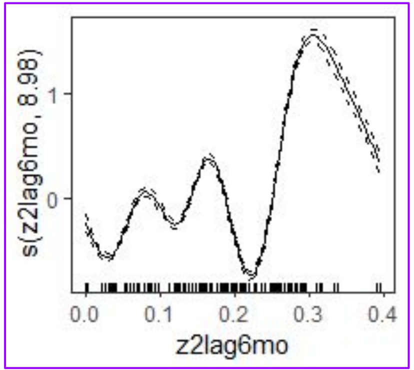
Slope Occupancy **Region 1**: **Lag 3 months**



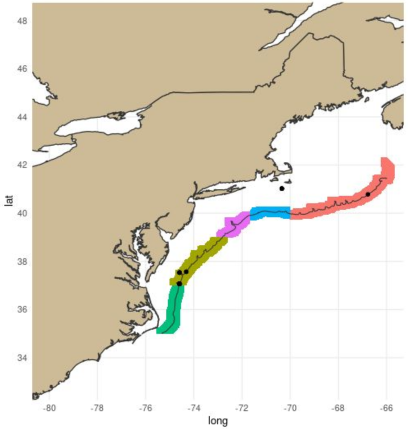




Slope Occupancy **Region 2**: **Lag 6 months**



Salinity smooths varying depths




```
range(na.omit(wet$depth))
[1]    1 425 fathoms
Min     1.8288M
Median 182.88M
Max     777.24M
Mode    201.168M
range(na.omit(frz$depth))
[1]    10 1119 fathoms
Min     18.288M
Median 149.9616M
Max     2046.427M
Mode    91.44M
```

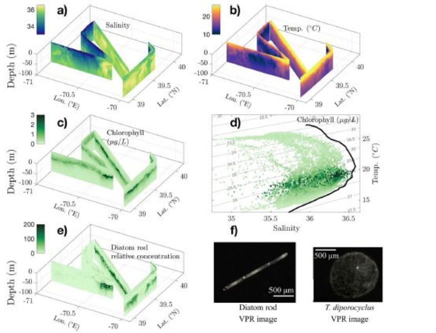
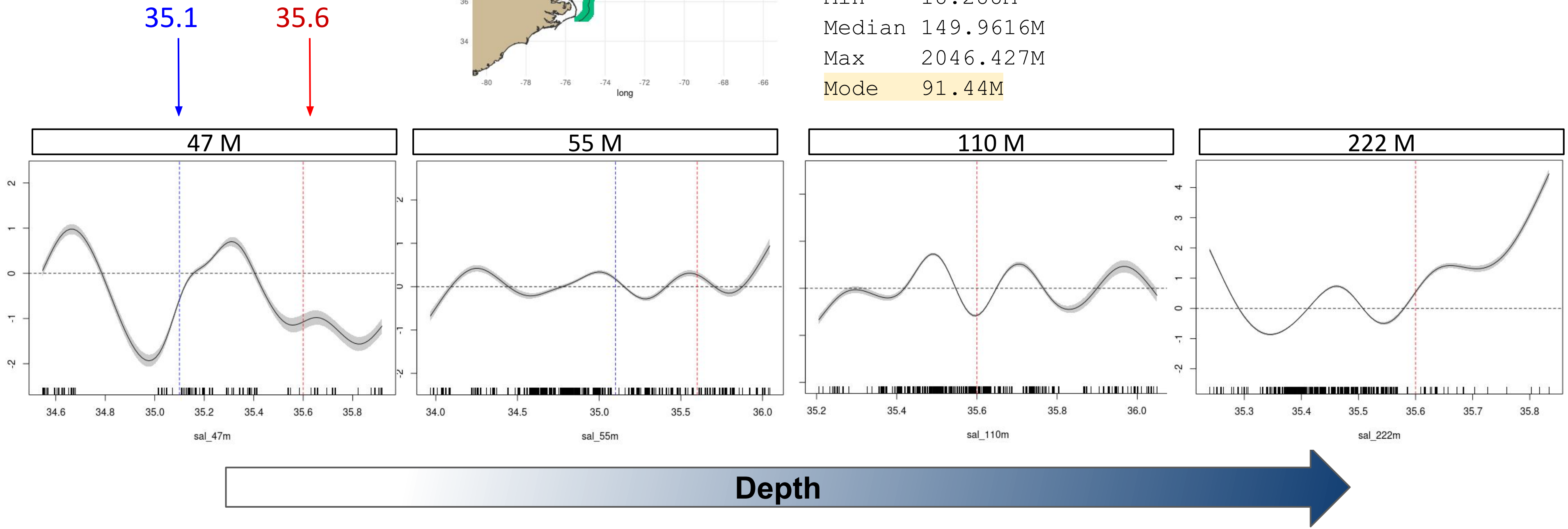
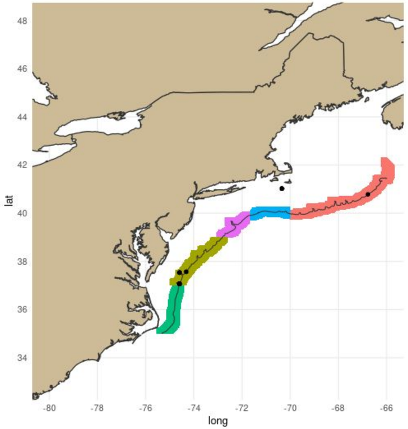


Figure 2. Video Plankton Recorder (VPR) tows 2, 7, and 8. (a) Salinity; (b) temperature; (c) chlorophyll (Chl) concentration; (d) corresponding T-S diagram from the tows, colored by Chl concentration, with the black line showing the Gulf Stream T-S profile from 69.5 E, 37 N from 1/10 summer objectively analyzed climatological means from the National Centers for Environmental Information Northwest Atlantic Regional Ocean Climatology, with the same Chl color bar used in (c); (e) relative diatom rod concentration; (f) two example VPR images: one classified as a "diatom rod," the other a *T. diporocyclus* diatom colony.



Salinity smooths varying depths




```
range(na.omit(wet$depth))
[1]    1 425 fathoms
Min     1.8288M
Median 182.88M
Max     777.24M
Mode    201.168M
range(na.omit(frz$depth))
[1]    10 1119 fathoms
Min     18.288M
Median 149.9616M
Max     2046.427M
Mode    91.44M
```

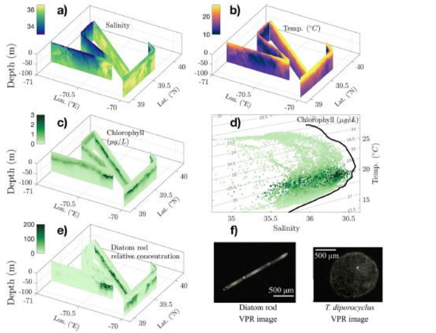
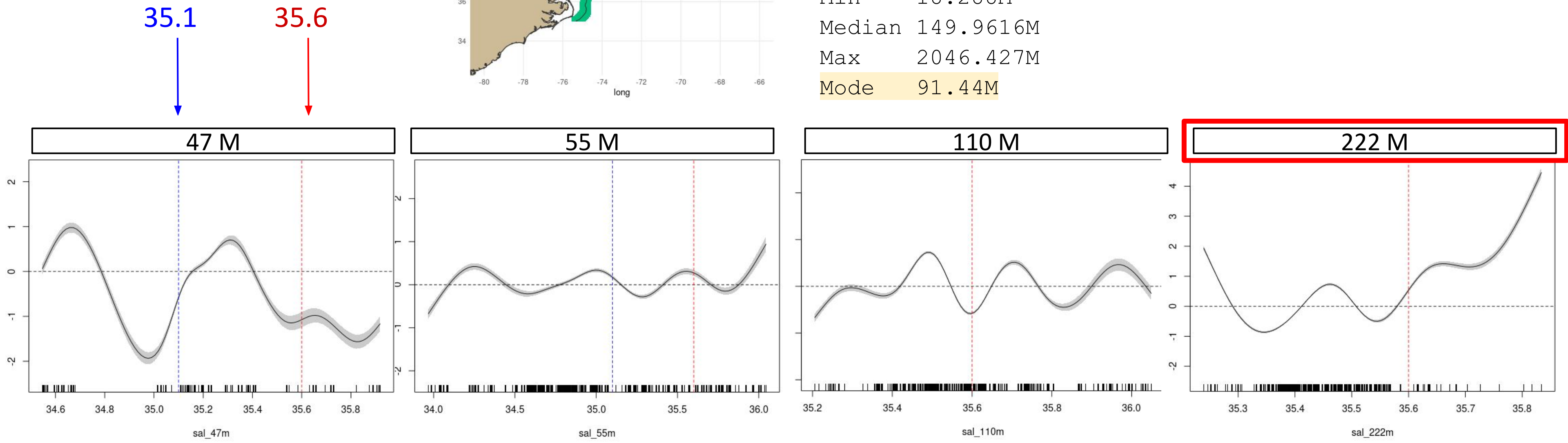
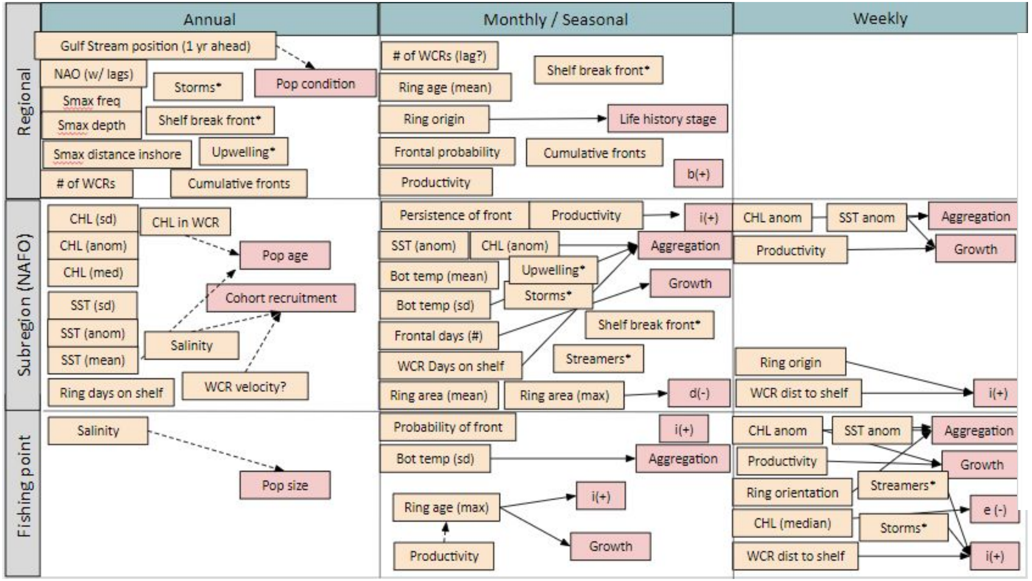


Figure 2. Video Plankton Recorder (VPR) tows 2, 7, and 8. (a) Salinity; (b) temperature; (c) chlorophyll (Chl) concentration; (d) corresponding T-S diagram from the tows, colored by Chl concentration, with the black line showing the Gulf Stream T-S profile from 69.5 E, 37 N from 1/10 summer objectively analyzed climatological means from the National Centers for Environmental Information Northwest Atlantic Regional Ocean Climatology, with the same Chl color bar used in (c); (e) relative diatom rod concentration; (f) two example VPR images: one classified as a "diatom rod," the other a *T. diporocyclus* diatom colony.



Depth

General Hypotheses



Oceanographic Data	Question / Model
Annual • Mean Path Short/Long lived WCR • Average age of demise WCRs • # Ring days on shelf • SST, CHL, BT anomalies • # of days of persistent front	Shifts between system states - good/bad fishing years (HMM) • Multinomial GAM
Monthly / Seasonal • # Ring days on shelf • Average/max area of WCR • SMAX frequency • SST,CHL, BT • Frontal metrics	Relationship between cpue & oceanographic indicators (GAMs)
Weekly • # Ring days on Shelf • Distance to WCR center vs edge • Average/max area of WCR • SST, CHL, BT • Frontal metrics	Perturbation Spikes; emigration/immigration/or fishing behavior (Depletion Model) • Relate X-factor to oceanographic feature Relationship between cpue & oceanographic indicators/fishing behavior (GAMs)