

The Northwest Atlantic Continental Shelf Model of Intermediate Complexity for Ecosystem Assessment (NWACS-MICE)

David Chagaris

SEDAR 102

ASMFC Atlantic Menhaden and Ecological Reference Points Review Workshop

August 12-15, 2025

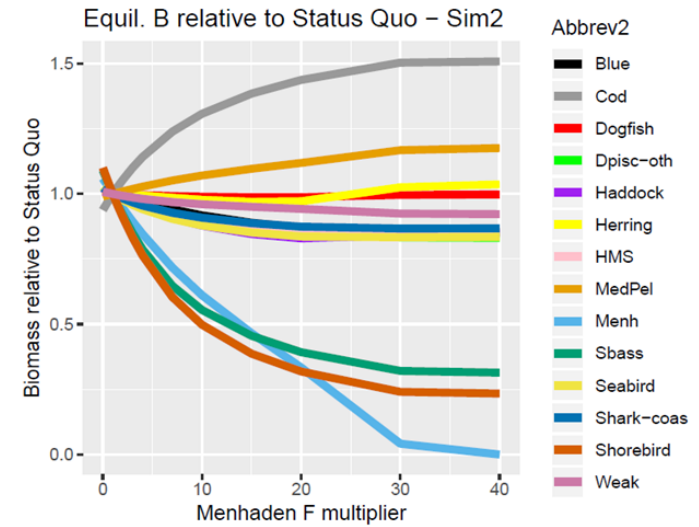
Charleston, SC

Ecological Reference Points for Atlantic Menhaden Established Using an Ecosystem Model of Intermediate Complexity

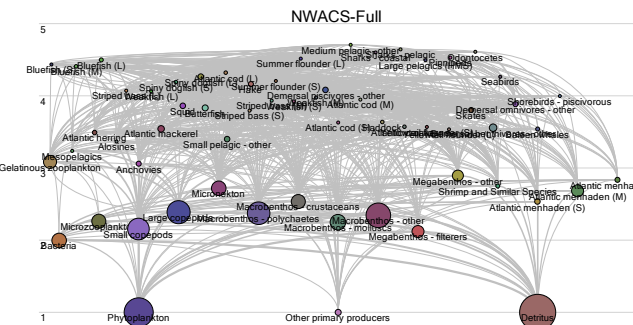
David Chagaris^{1*}, Katie Drew², Amy Schueller³, Matt Cieri⁴, Joana Brito^{1,5} and Andre Buchheister⁶

<https://doi.org/10.3389/fmars.2020.606417>

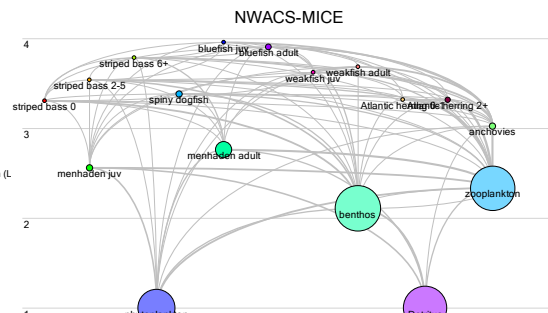
Ecological sensitivity analysis using these models identified striped bass as the most sensitive fish predator.



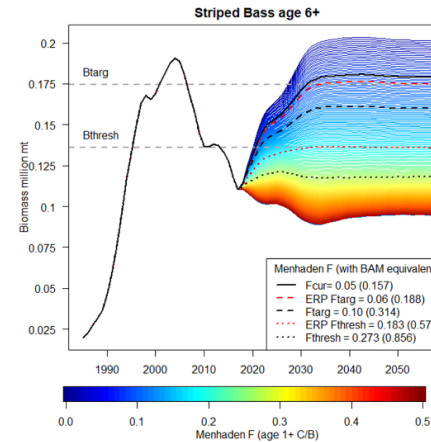
The ERPs were developed using a simplified Ecopath with Ecosim model of the Northwest Atlantic Continental Shelf (NWACS)



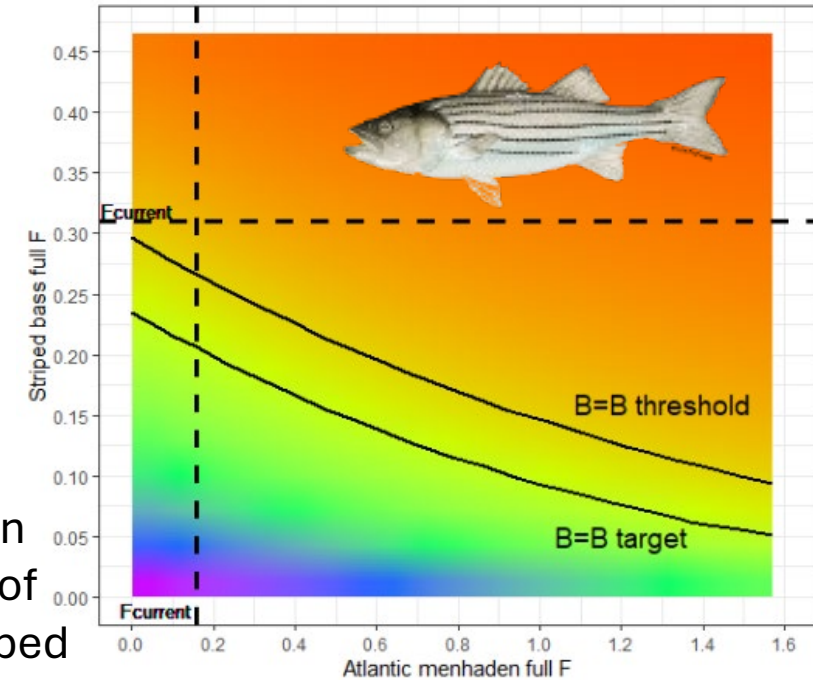
Buchheister et al. (2017): 61 biomass pools, FULL model



Chagaris et al. (2020): 17 biomass pools; MICE model



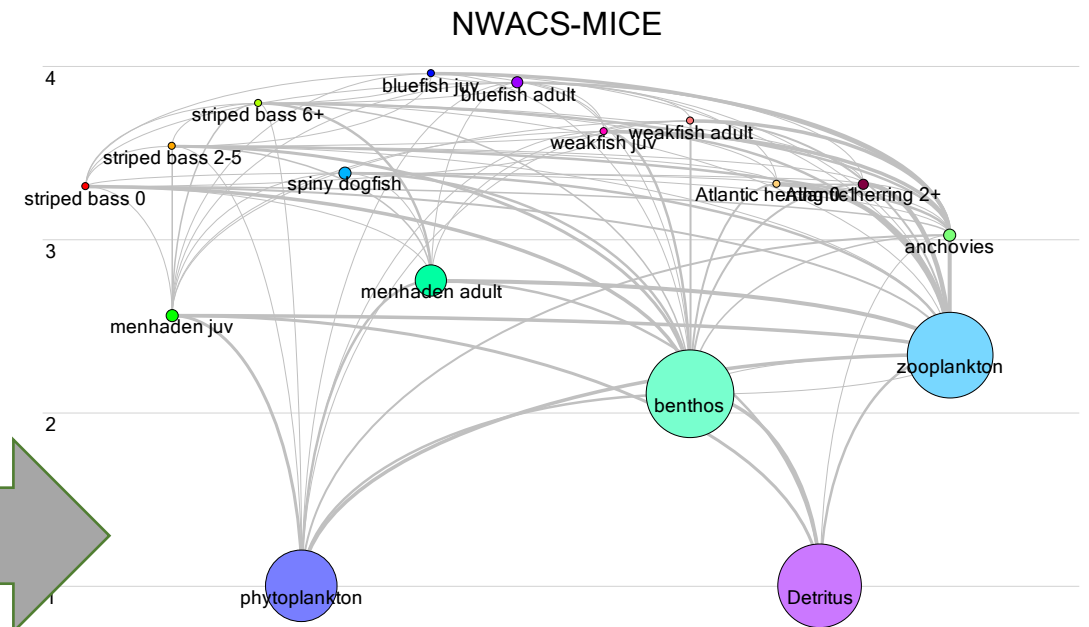
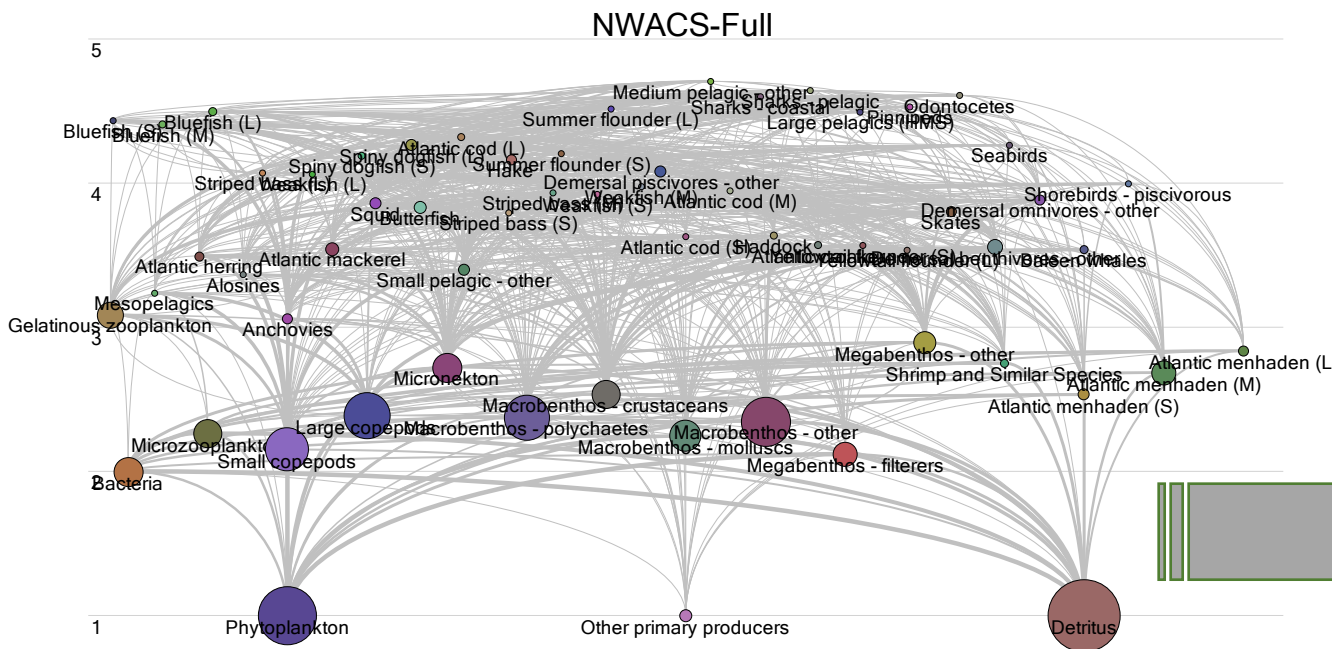
Equilibrium (30yr) projections were run over combinations of menhaden and striped bass F.



Why use a MICE model?

- Remove groups with high uncertainty and few data
- Focus on the key predators managed by ASMFC
- Easier to update within assess. & mgmt. timeframe
- Computational efficiency

Northwest Atlantic Continental Shelf (NWACS) EwE Models



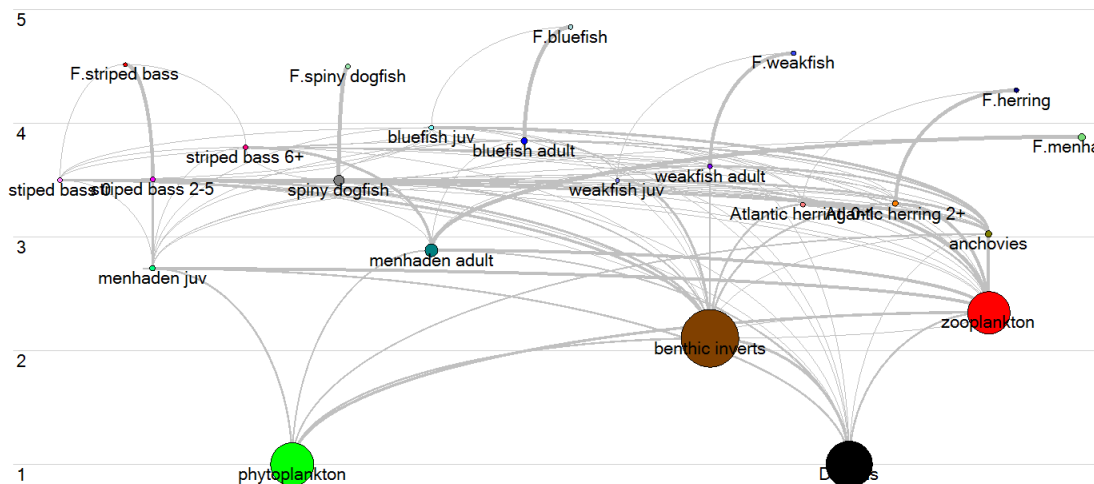
Buchheister, A., Miller, T.J. and Houde, E.D., 2017. Evaluating ecosystem-based reference points for Atlantic menhaden. *Marine and Coastal Fisheries*, 9(1), pp.457-478.



Chagaris, D., Drew, K., Schueller, A., Cieri, M., Brito, J. and Buchheister, A., 2020. Ecological reference points for Atlantic Menhaden established using an ecosystem model of intermediate complexity. *Frontiers in Marine Science*, p.1043.

NWACS-MICE Model Structure

- 17 biomass pools
- Emphasis on 6 ERP species – with age structure
- 6 fishing “fleets”, one for each ERP species
- Ecopath base year 1985, model area 441,000 km²



num	name	Biomass (mt/km2)	BA rate (/year)	Z or PB (/year)	Q/B (/year)	vbK	Wmat/ Winf	Landings (mt/km2)	EE	Trophic Level
1	stiped bass 0	0.008		1.040	7.573			0.000	0.080	3.500
2	striped bass 2-5	0.041	0.168	0.420	3.122	0.183	0.261	0.002	0.636	3.505
3	striped bass 6+	0.040		0.153	1.869			0.000	0.750	3.789
4	menhaden juv	0.313		1.398	9.521			0.011	0.238	2.722
5	menhaden adult	2.525	0.129	1.295	3.804	0.331	0.379	0.788	0.405	2.883
6	spiny dogfish	1.668	0.000	0.201	1.810			0.054	0.163	3.500
7	bluefish juv	0.007		0.934	10.684			0.002	0.730	3.962
8	bluefish adult	0.465	-0.176	0.749	3.139	0.310	0.112	0.116	0.459	3.845
9	weakfish juv	0.002	-0.535	0.726	11.371			0.001	0.990	3.501
10	weakfish adult	0.039	-0.321	1.146	3.770	0.190	0.041	0.024	0.990	3.622
11	Atlantic herring 0-1	0.023		1.021	10.027			0.009	0.925	3.285
12	Atlantic herring 2+	0.318	0.331	0.759	3.700	0.340	0.277	0.130	0.906	3.292
13	anchovies	0.635		2.200	7.333				0.320	3.027
14	benthic inverts	51.910		2.432	12.469				0.497	2.108
15	zooplankton	24.470		45.850	154.600				0.905	2.337
16	phytoplankton	25.450		186.436					0.423	1.000
17	Detritus	29.420							0.234	1.000

not required	Ecopath Calculated	NWACS EwE	Survey Data	Stock Assessment	Balancing/ Other input
--------------	--------------------	-----------	-------------	------------------	------------------------

NWACS-MICE Ecopath Inputs – ERP species

Biomass, mortality rates, and catch were extracted from stock assessment output files.

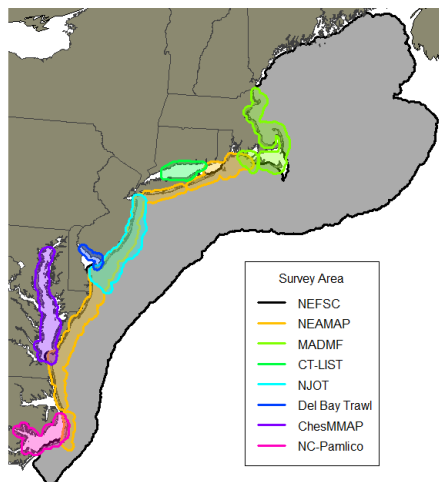
- **Biomass:** Mid-year 1985 abundance or biomass (\bar{B}_a), or approximated as $B_a * (1 - \exp(-Z_a)) / Z_a$. Summed \bar{B}_a over ages within a stanza, converted to mt/km².
- **Catch:** Converted to total killed in units weight, aggregated across fleets and ages, converted to mt/km².
- **Natural Mortality:** Age-dependent M averaged across ages for each stanza, weighted by N_a .
- **Biomass accumulation rate:**
- **Maturity:** W_{mat} / W_{inf} from growth and maturity vectors

Species	Assess. Year	Term. Year	Status
Atlantic herring - ASAP	2024	2023	✓
Atlantic menhaden – BAM (M=0.925 base run)	2024	2023	✓
Bluefish - WHAM	2023	2022	✓
Striped bass - SCA	2024	2023	✓
Spiny dogfish – SS3	2023	2022	✓
Weakfish - ASAP	2024	2023	✓

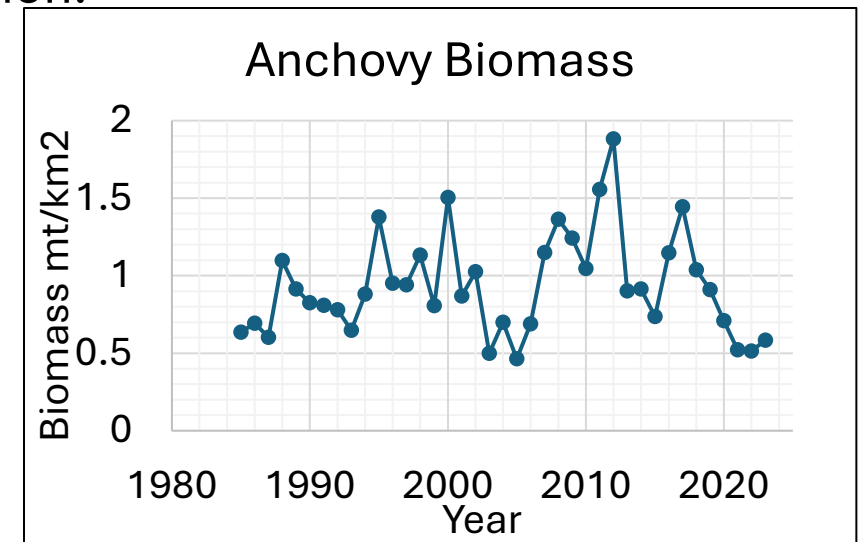
NWACS-MICE Ecopath Inputs – anchovies

SEDAR 102-WP-05: A species distribution model (SDM) approach to representing anchovies in the NWACS ecosystem model

- Biomass estimated using species distribution models with Gaussian Markov random fields (R sdmTMB). Monthly predictions from 1985-2023 made using depth and bottom temperature grids (SEDAR 102-WP-05).
- 59,119 anchovy cpue observations from 8 trawl surveys
- 1985 biomass estimated to be 0.635 mt/km² from SDM
- P/B = 2.2, Q/B = 7.3, and diet unchanged from last model version.



Acronym	n Tows	% Positive
NEFSC	22,833	10%
NEAMAP	4,724	51%
MADMF	7,358	5%
CT-LISTS	4,122	28%
NJOT	5,813	39%
DBTrawl	1,863	95%
ChesMMAP	7,440	22%
NC-Pamlico	4,966	63%
total	59,119	25%

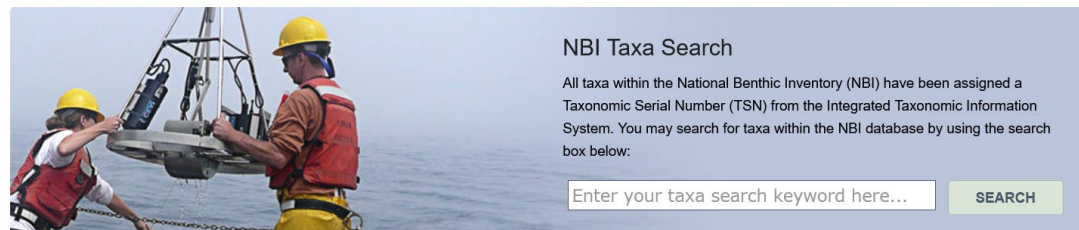


NWACS-MICE Ecopath Inputs – benthic invertebrates

- NOAA national benthic inventory database (NBI) num/m² converted to biomass using individual weights generated by GPT-4 turbo (by genus). No data north of MA.
- New biomass is 51.91 mt/km²
- P/B = 2.432, Q/B = 12.47, and diet unchanged from previous model


 NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE
 
 NOAA National Benthic Inventory

[Home](#)
[About NBI](#)
[Datasets](#)
[Taxa Search](#)
[Contact Us](#)

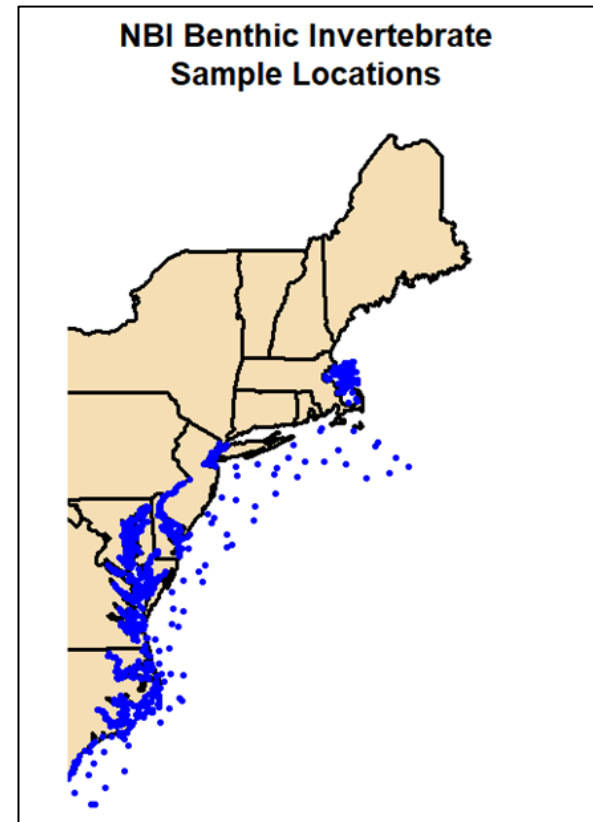


NBI Taxa Search

All taxa within the National Benthic Inventory (NBI) have been assigned a Taxonomic Serial Number (TSN) from the Integrated Taxonomic Information System. You may search for taxa within the NBI database by using the search box below:

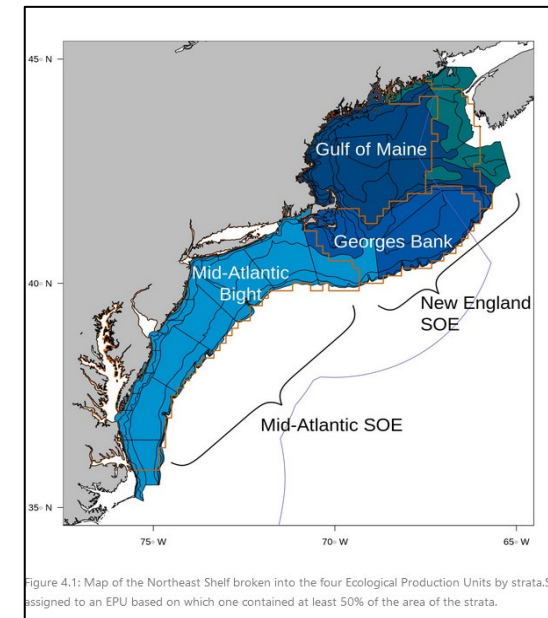
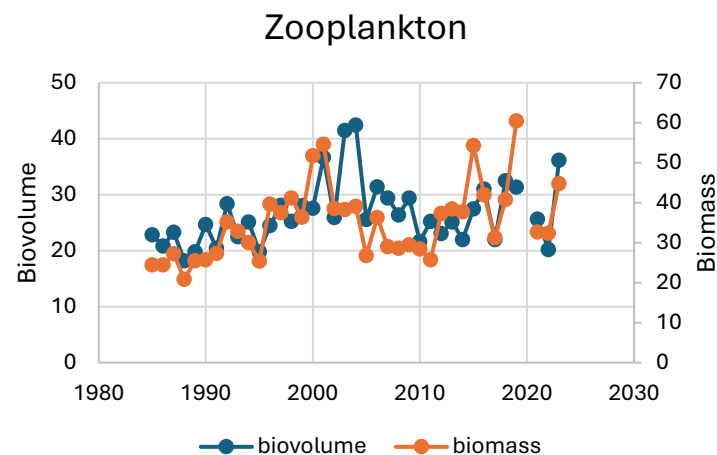
Enter your taxa search keyword here...

Genus	Min Body Mass (g)	Max Body Mass (g)
Apocorophium	0.0001	0.0006
Ampelisca	0.0001	0.001
Streblospio	0.0001	0.001
Marenzelleria	0.0001	0.04
Prionospio	0.0001	0.012
Leptocheirus	0.0001	0.001
Polydora	0.0001	0.01
Tellina	0.01	0.1
Mulinia	0.01	0.1
Acteocina	0.0001	0.001
Paraprionospio	0.0001	0.01
Exogone	0.0001	0.001
Gemma	0.01	0.1
Gammarus	0.001	0.1



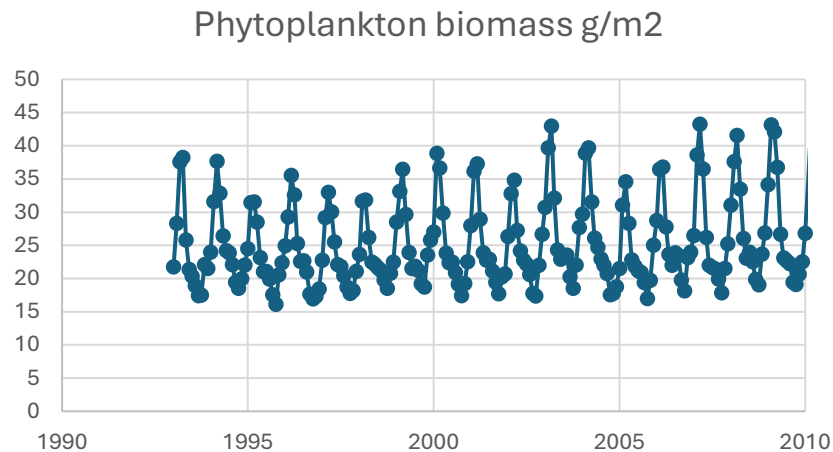
NWACS-MICE Ecopath Inputs – zooplankton

- Biomass estimates were derived from seasonal zooplankton data from the NEFSC plankton cruises, 1985-2023 (SEDAR 102-WP-06)
- Aggregated into 5 groups: microzooplankton, small copepods, large copepods, gelatinous, and micronekton
- Numerical density converted to weights based on sizes of representative species, extrapolated within four geo-regions, and summed for total biomass
- 1985 biomass 24.47 mt/km² (10.8 million mt)
- P/B = 45.85, Q/B = 154.6, and diet unchanged from previous model
- Ecosim timeseries is biovolume (ml/m³)



NWACS-MICE Ecopath Inputs – phytoplankton

- Biomass was derived from phytoplankton carbon (phC) estimates from the GLORYS Global Ocean Biogeochemistry Hindcast (1993-2023)
- phC summed over depth layers and averaged over the spatial grid for all months
- phC mmol C m^{-2} converted to g C using atomic mass (12.011), then dry mass (x5.4), and wet weight (x7.7).
- Biomass input 25.45 mt km^{-2}
- PB = $186.4 \text{ mt km}^{-2} \text{ yr}^{-1}$, unchanged from last model



The screenshot shows the Copernicus Marine Service website for the Global Ocean Biogeochemistry Hindcast. The page includes a navigation menu with links for Services, Opportunities, Access Data, Use Cases, User Corner, and About. The main content area is titled 'Global Ocean Biogeochemistry Hindcast' and features a description, an overview, and a map of the global ocean. The overview section provides details about the model and data, including the NEMO version (v3.6_STABLE), forcings (FREEGLORYS2V4 ocean physics and ERA-Interim atmosphere), and outputs (daily and monthly fields for various parameters). The map shows the global ocean with a color scale for biomass, ranging from 0 to 4,000 g/m².

cmems_mod_glo_bgc_my_0.25deg_P1M-m

NWACS-MICE Ecopath Inputs – diet compositions

1. Combine datasets – ChesMAP, NEAMAP, NEFSC, NJOT, RI, MSVPA
2. Get prey taxonomy – R ‘taxize’ package
3. Predator and prey assignments to model groups
4. MLE diet estimates
5. Assign UI prey
6. Assign to prey stanzas

Predator	ChesMMAP	MSVPA	NEAMAP	NEFSC	NJOT	RIDEM	total
anchovy				15			15
Atlantic herring 0-1	1		147				148
Atlantic herring 2	15		333	23491			23839
bluefish adult	29	1283	378	5492	57	210	7449
bluefish juv	553	5661	3434		111	22	9781
menhaden adult	2			205			207
spiny dogfish	145		2710	71431	304	15	74605
striped bass 0	2747	2460	57		4	12	5280
striped bass 2-5	1436	7166	169	984	44	235	10034
striped bass 6	91	2578	161	614	12	53	3509
weakfish adult	1164	1459	1267	5477	80	161	9608
weakfish juv	5874	535	6925		266	35	13635

NWACS-MICE Ecopath Inputs – diet compositions

4. MLE diet estimates

- 10,000 bootstraps of 30% of the data
- Weighted resampling based on N stomachs
- Fits Dirichlet distribution to bootstrapped data (R ‘compositions’ package)
- MLE based on beta posterior distribution function
- Outputs variance and confidence intervals
- Averages (weighted) also computed
- Successfully applied to striped bass, dogfish, bluefish, weakfish, and Atlantic herring



A probabilistic representation of fish diet compositions from multiple data sources: A Gulf of Mexico case study



M.D. Masi^{a,*}, C.H. Ainsworth^a, D. Chagaris^b

^a College of Marine Science, University of South Florida, 140 7th Avenue S, St Petersburg, FL 33701, USA

^b Florida Fish and Wildlife Conservation Commission, 100 8th Avenue SE, St Petersburg, FL 33701, USA

NWACS-MICE Ecopath Inputs – diet compositions

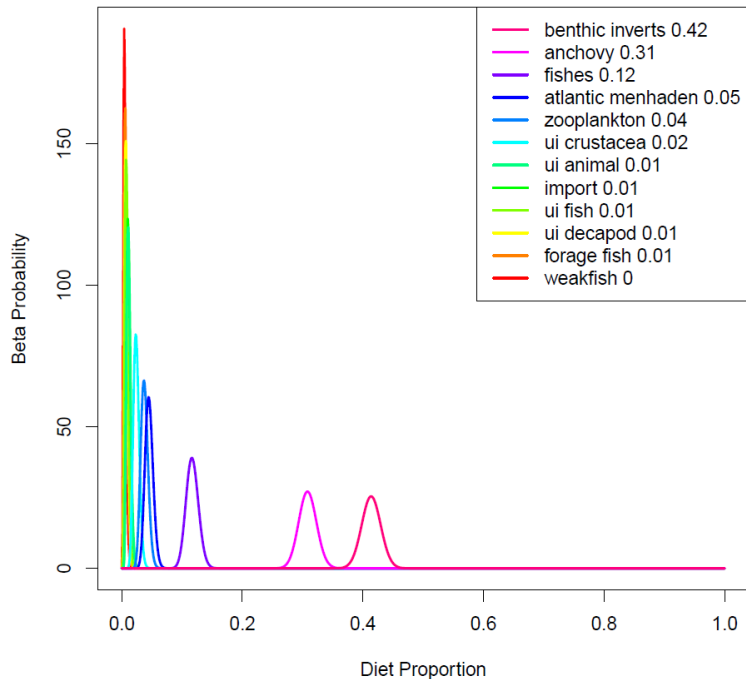


4. MLE diet estimates – Striped bass

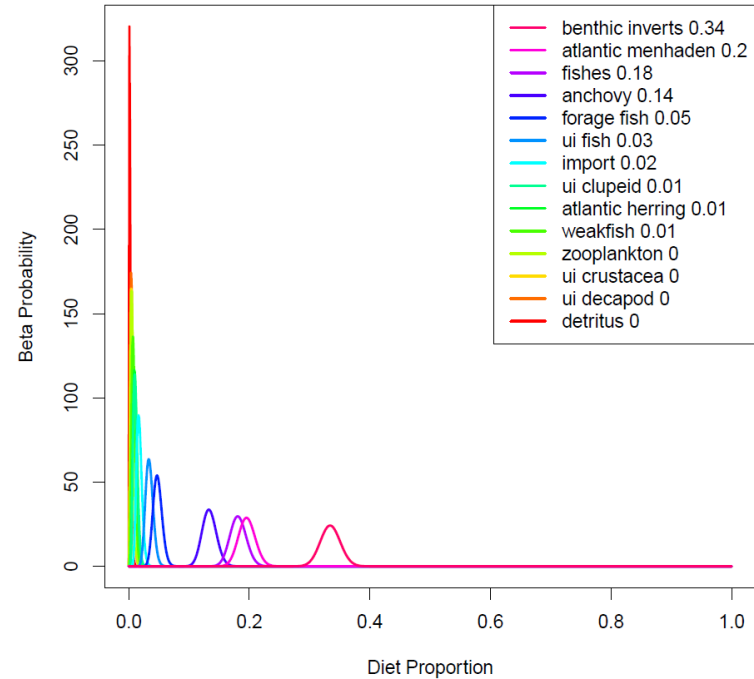
- A generalist predator; consumes more fish with age
- Re-analysis of the diet data resulted in more (~2x) menhaden in striped bass diet than previous model.

Prey	striped bass 0	striped bass 2-5	striped bass 6+
menhaden juv	0.02	0.08	0.08
menhaden adult	0.02	0.08	0.23
Atlantic herring 0-1	0.00	0.00	0.01
Atlantic herring 2+	0.00	0.02	0.05

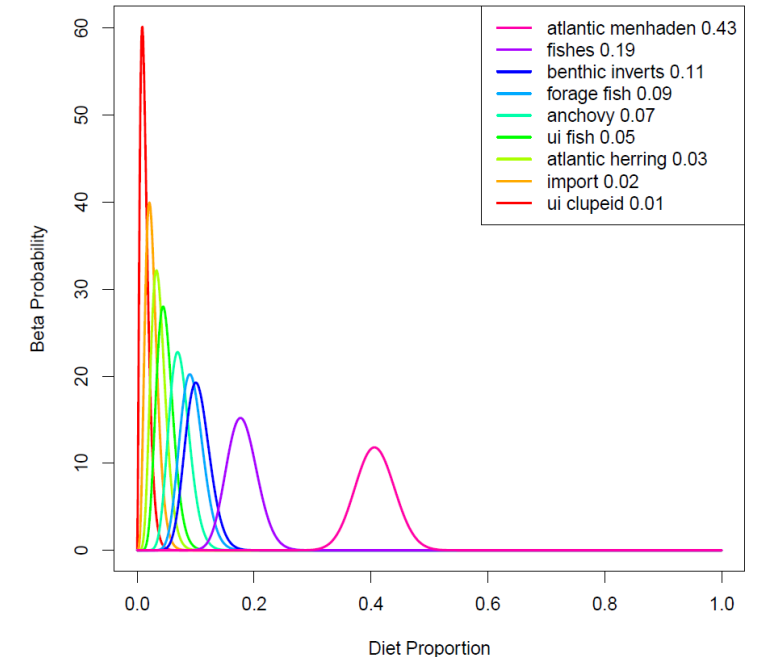
striped bass 0



striped bass 2-5



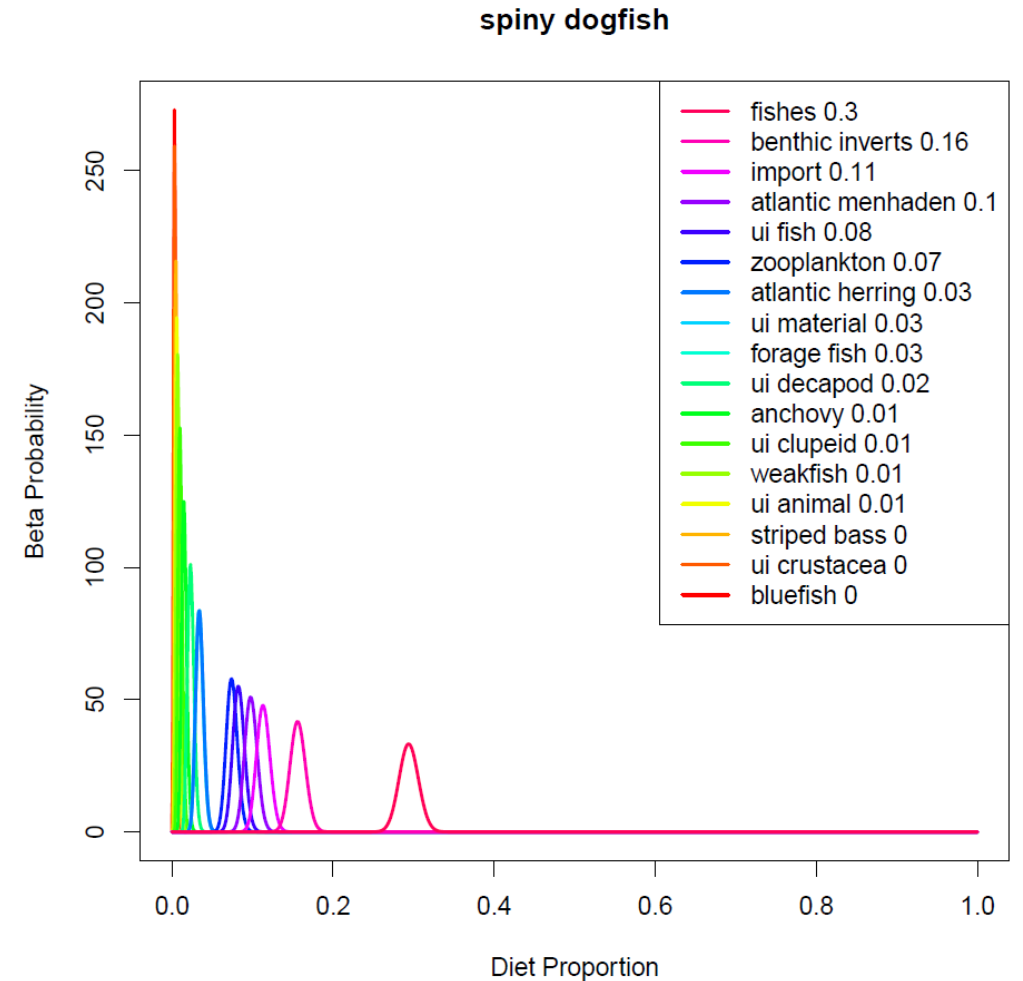
striped bass 6



NWACS-MICE Ecopath Inputs – diet compositions

4. MLE diet estimates – Spiny dogfish

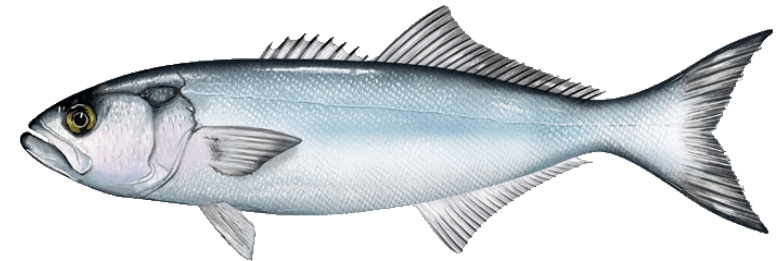
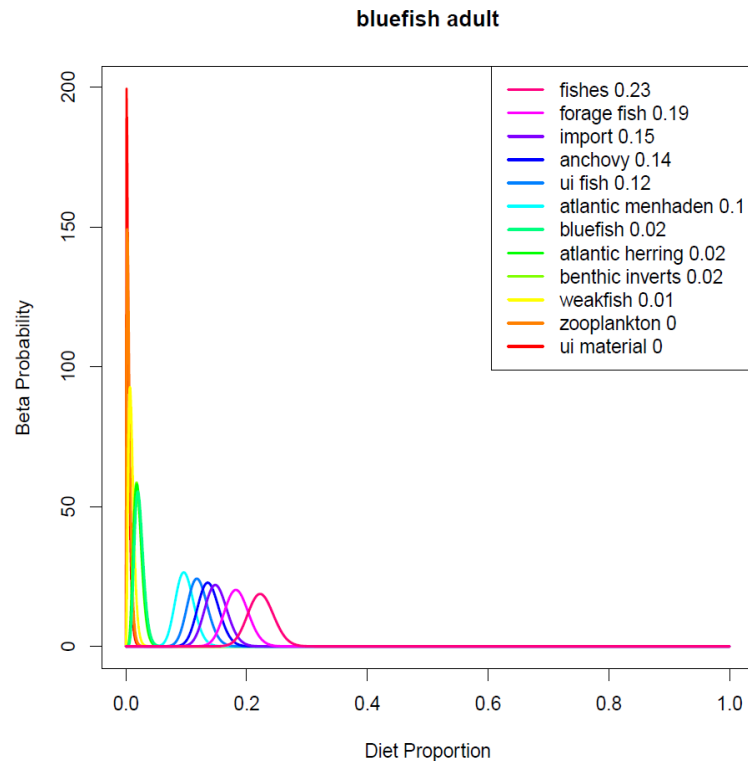
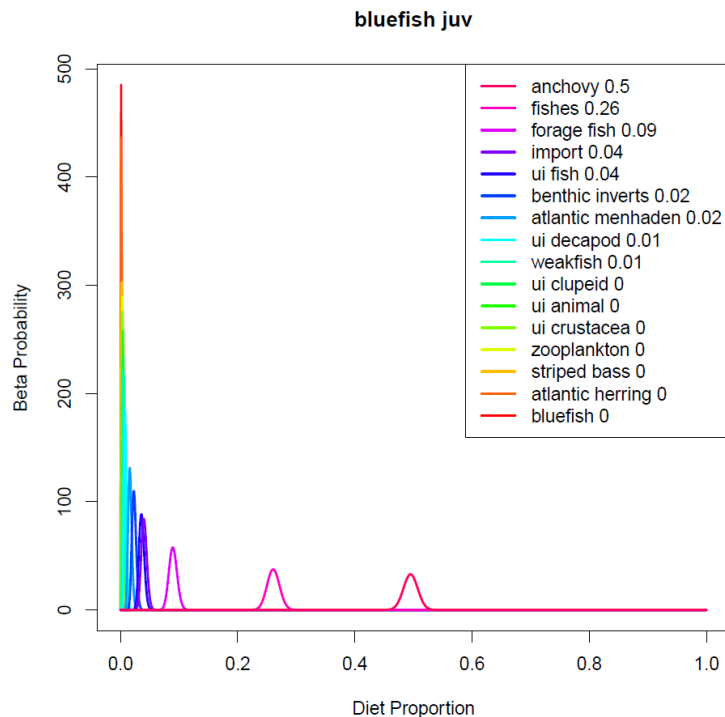
- Generalist predator
- Large portion of diet from prey items not included in the model (>40%). Treated as diet ‘import’



NWACS-MICE Ecopath Inputs – diet compositions

4. MLE diet estimates – bluefish

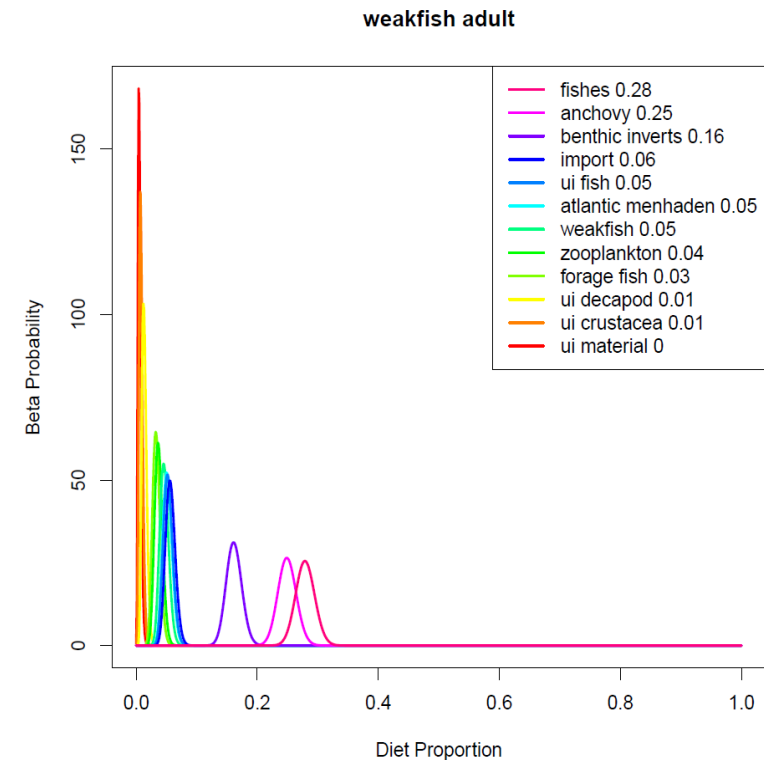
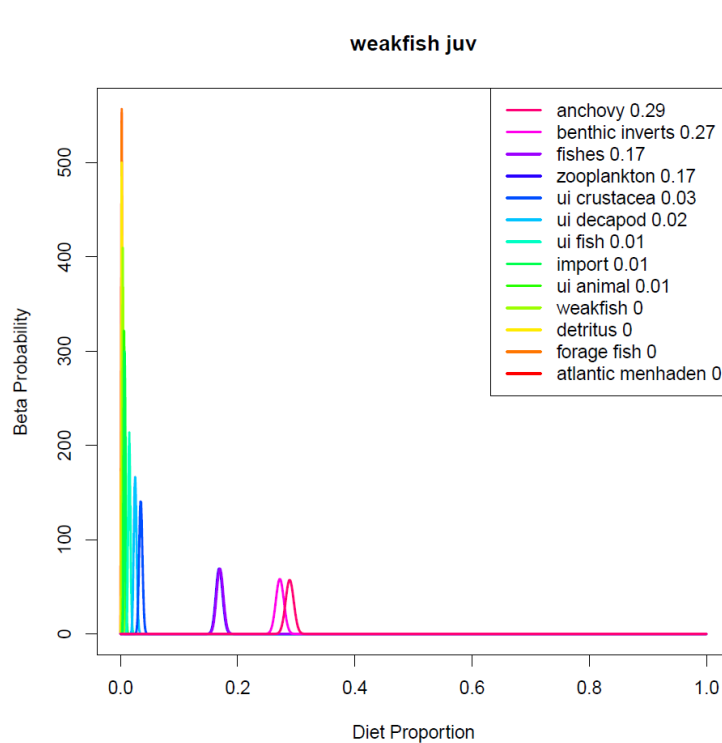
- A generalist predator, more piscivorous than striped bass but consume less menhaden
- Cannibalism



NWACS-MICE Ecopath Inputs – diet compositions

4. MLE diet estimates – weakfish

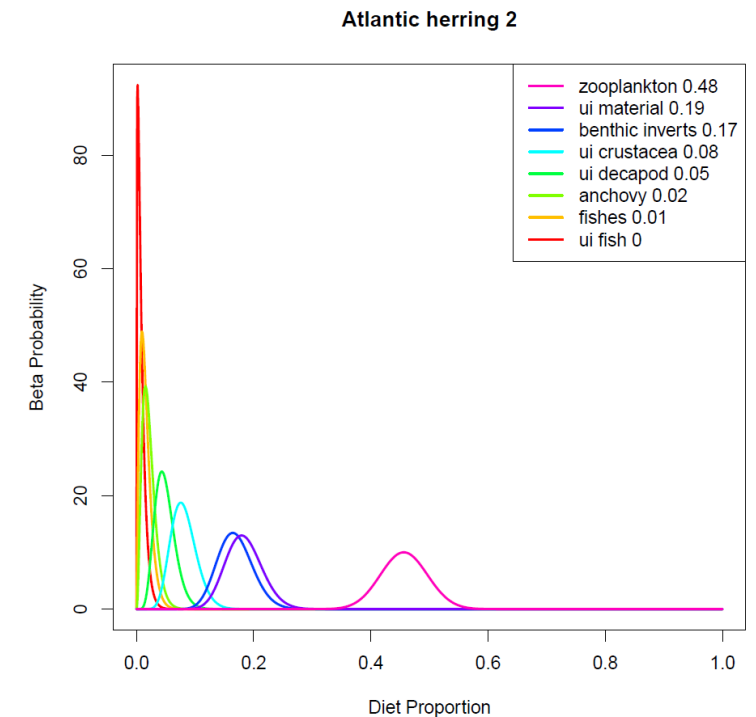
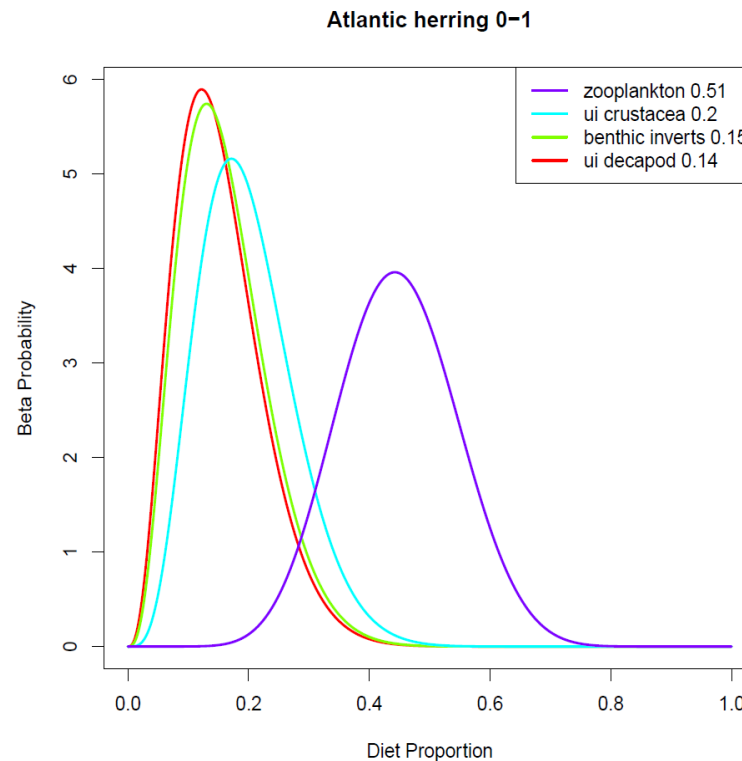
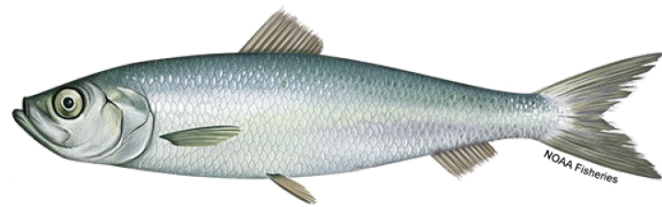
- Consume less menhaden than striped bass, bluefish, and spiny dogfish
- Cannibalism



NWACS-MICE Ecopath Inputs – diet compositions

4. MLE diet estimates – Atlantic herring

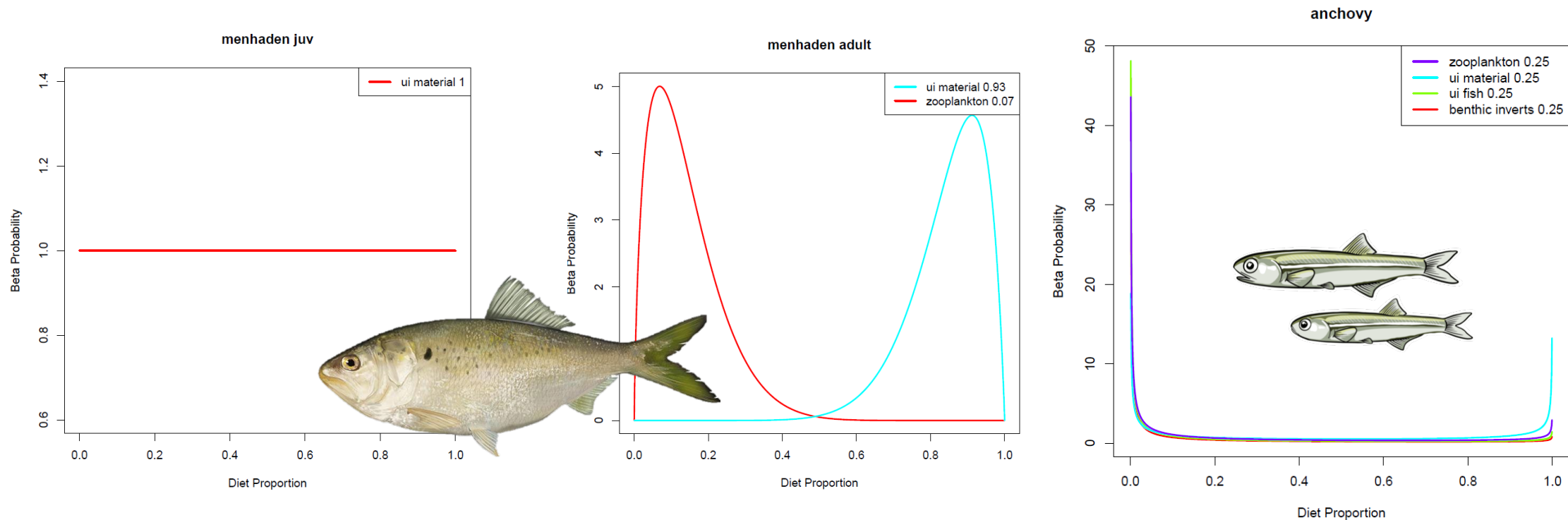
- Primarily planktivorous, Consume mostly zooplankton, small crustaceans, and benthic inverts (opportunistically)



NWACS-MICE Ecopath Inputs – diet compositions

4. MLE diet estimates – menhaden and anchovy

- Not estimable with MLE approach, diet remained unchanged from v2.1



NWACS-MICE Ecopath Inputs – diet compositions

5. Distribute UI Prey

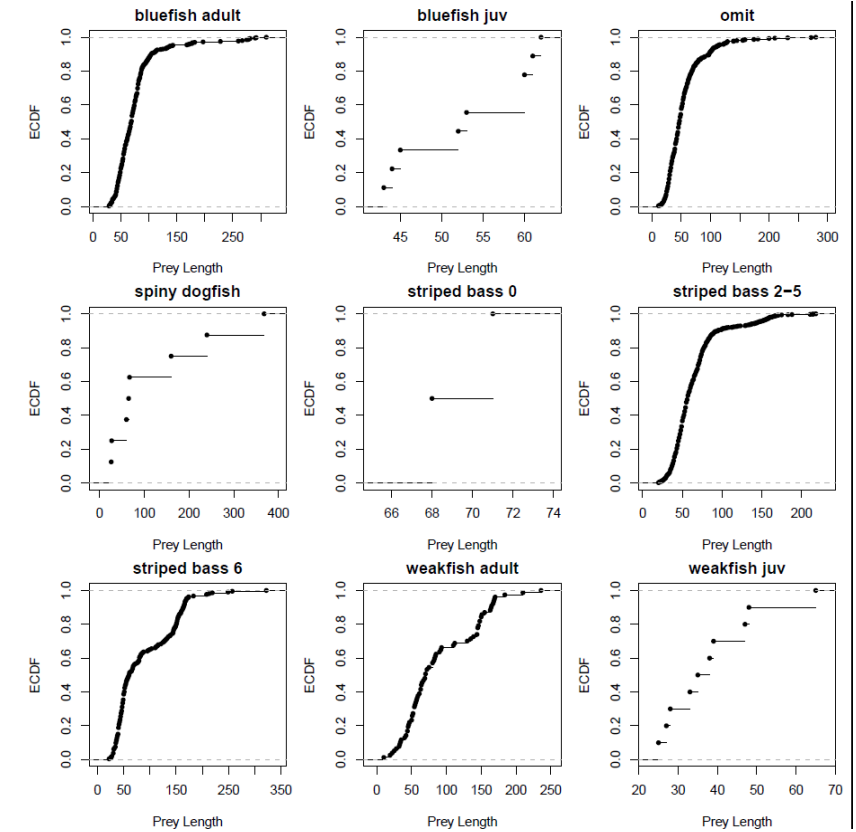
- MLE of diet proportion included the UI categories
- MLE proportions assigned to model groups in order from low to high taxonomic resolution

ui.name	order
ui plantae	1
ui decapod	2
ui crustacea	3
ui clupeid	4
ui elasmobranch	5
ui fish	6
ui animal	7
ui material	8

NWACS-MICE Ecopath Inputs – diet compositions

6. Assign prey to age stanzas

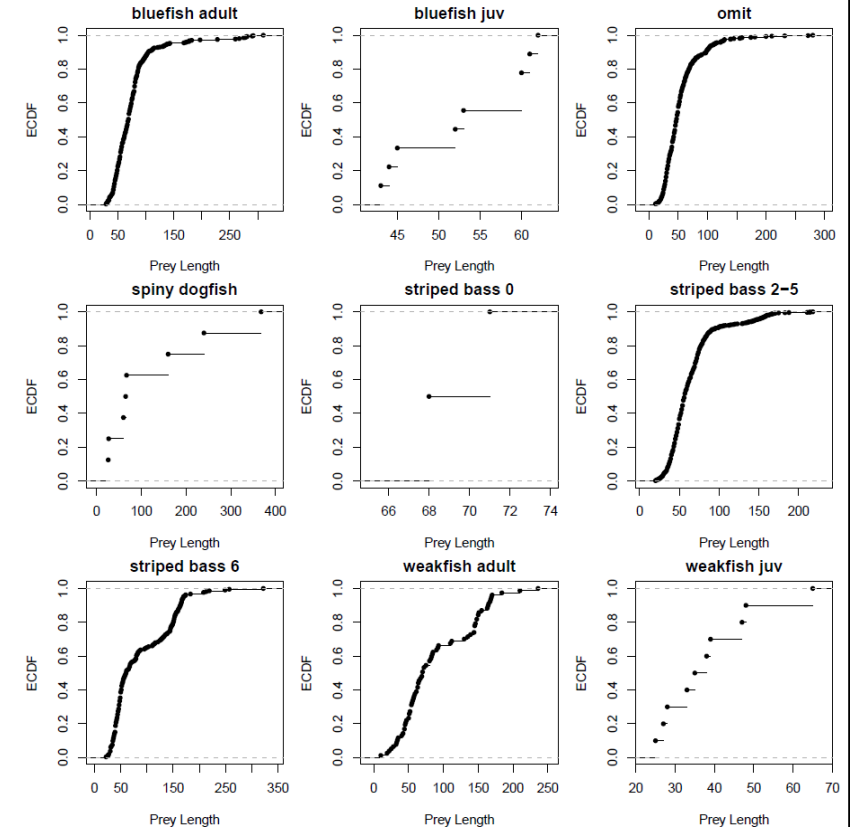
- Use RI predator-prey size data
- Calculate cumulative distribution function of data by prey length for fish prey, by predator
- Represents generalized finfish prey size preferences for each predator
- Apply ECDF to size breaks of multistanza prey species



NWACS-MICE Ecopath Inputs – diet compositions

6. Assign prey to age stanzas

- Use RI predator-prey size data
- Calculate cumulative distribution function of data by prey length for fish prey, by predator
- Represents generalized finfish prey size preferences for each predator
- Apply ECDF to size breaks of multistanza prey species
- This approach created situations where adult stanzas were eating way too much from age-0s
 - Example: $DC_{\text{juv menhaden, striped bass } 6+} = 38\%$
 - Fix: Re-assigned prey to stanzas based on biomass proportion of prey stanzas



predator	Prey with DC _{ij} proportioned by biomass
striped bass 2-5	weakfish
striped bass 6+	menhaden, weakfish, and herring
spiny dogfish	striped bass,
Bluefish adult	menhaden, weakfish
Weakfish adult	menhaden, weakfish

NWACS-MICE Ecopath Inputs – diet matrix

Balanced diet matrix

Pred/Prey	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 stiped bass 0	0.00	0.00	0.00				0.00	0.00	0.00						
2 striped bass 2-5						0.00									
3 striped bass 6+						0.00									
4 menhaden juv	0.05	0.21	0.05			0.01	0.02	0.01	0.00	0.01					
5 menhaden adult		0.01	0.41			0.11		0.10		0.05					
6 spiny dogfish						0.00		0.00							
7 bluefish juv	0.00	0.00	0.00				0.00	0.00		0.00					
8 bluefish adult						0.00		0.02							
9 weakfish juv	0.00	0.00					0.00	0.00	0.00	0.00					
10 weakfish adult	0.00	0.01	0.00			0.00		0.01		0.05					
11 Atlantic herring 0-1		0.01	0.00			0.00	0.00	0.01							
12 Atlantic herring 2+		0.00	0.03			0.02		0.01		0.00					
13 anchovies	0.32	0.14	0.08			0.02	0.52	0.16	0.30	0.27	0.00	0.02			
14 benthic inverts	0.45	0.35	0.11			0.19	0.03	0.02	0.31	0.18	0.23	0.26	0.10	0.09	0.00
15 zooplankton	0.04	0.01	0.00	0.54	0.66	0.10	0.00	0.00	0.20	0.04	0.77	0.71	0.68	0.02	0.26
16 phytoplankton				0.24	0.18								0.16	0.23	0.49
17 Detritus	0.00	0.00		0.22	0.17	0.00	0.00		0.00	0.00			0.06	0.41	0.20
Import	0.14	0.26	0.32			0.53	0.42	0.65	0.19	0.40	0.00	0.01		0.25	0.05

High diet import due to model simplification.

The portion of consumption that is import will remain constant during an Ecosim simulation.

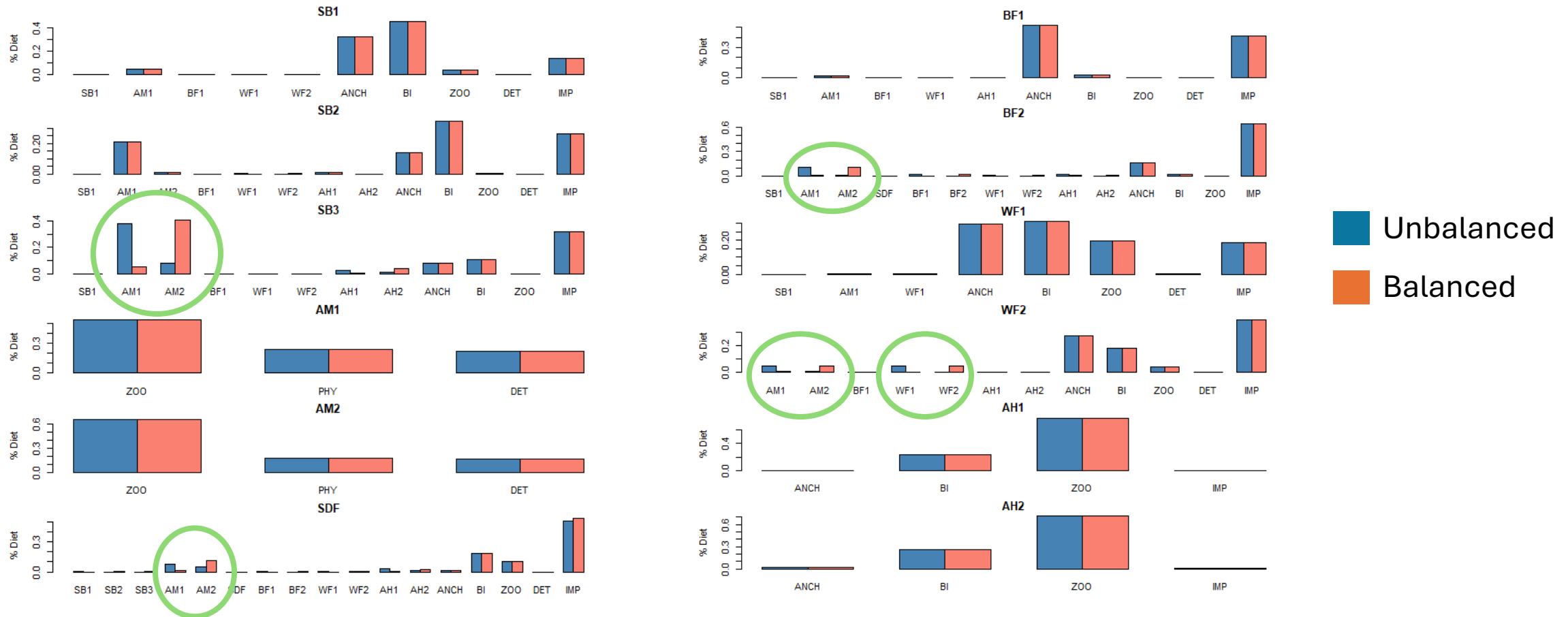
NWACS-MICE Ecopath Balancing - Overview

- Only four groups had ecotrophic efficiencies $EE > 1$, meaning that removals due to predation and fishing exceeded the production of that group.
- Small adjustments to diet had a big effect on predation mortality rates ($M2$), especially for younger stanzas
- Model was also balanced by adjusting biomass accumulation (BA) rates, which had an effect on biomass of non-leading stanzas.

Group name	Biomass		Z or P/B		F		M2		M0		BA		EE	
	U	B	U	B	U	B	U	B	U	B	U	B	U	B
striped bass 0	0.008	0.008	1.040	1.040	0.035	0.035	2.398	0.048	1.005	1.005	0.168	0.168	2.339	0.080
striped bass 2-5	0.041	0.041	0.420	0.420	0.046	0.046		0.221	0.374	0.374	0.168	0.168	0.109	0.636
striped bass 6+	0.040	0.040	0.153	0.153	0.003	0.003		0.112	0.150	0.150	0.168	0.168	0.018	0.750
menhaden juv	0.364	0.313	1.398	1.398	0.031	0.036	1.291	0.296	1.366	1.361	0.223	0.129	0.946	0.238
menhaden adult	2.525	2.525	1.295	1.295	0.312	0.312	0.064	0.212	0.983	0.983	0.223	0.129	0.290	0.405
spiny dogfish	1.668	1.668	0.201	0.201	0.032	0.032	0.000	0.000	0.168	0.168	0.000	0.000	0.163	0.163
bluefish juv	0.007	0.007	0.934	0.934	0.247	0.247	6.185	0.434	0.686	0.686	-0.176	-0.176	6.890	0.730
bluefish adult	0.465	0.465	0.749	0.749	0.250	0.250	0.003	0.094	0.499	0.499	-0.176	-0.176	0.338	0.459
weakfish juv	0.005	0.002	0.726	0.726	0.244	0.677	8.794	0.576	0.482	0.049	0.563	-0.535	12.448	0.990
weakfish adult	0.039	0.039	1.146	1.146	0.613	0.613	0.093	0.842	0.533	0.533	0.563	-0.321	0.616	0.990
Atlantic herring 0-1	0.067	0.023	1.021	1.021	0.131	0.386	1.734	0.559	0.890	0.635	0.983	0.331	1.827	0.925
Atlantic herring 2+	0.318	0.318	0.759	0.759	0.409	0.409	0.114	0.279	0.350	0.350	0.983	0.331	0.689	0.906
anchovies	0.635	0.635	2.200	2.200	0.000	0.000	0.717	0.704	2.200	2.200	0.000	0.000	0.326	0.320
benthic inverts	51.910	51.910	2.432	2.432	0.000	0.000	1.210	1.208	2.432	2.432	0.000	0.000	0.498	0.497
zooplankton	24.470	24.470	45.850	45.850	0.000	0.000	41.513	41.492	45.850	45.850	0.000	0.000	0.905	0.905
phytoplankton	25.450	25.450	186.436	186.436	0.000	0.000	78.797	78.793	186.436	186.436	0.000	0.000	0.423	0.423
Detritus	29.420	29.420	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.234	0.234

NWACS-MICE Ecopath Balancing – diet adjustments

Changes to the diet inputs were minimal. Mostly required moving diet from age-0 to older stanzas.



NWACS-MICE Ecopath Balancing – Weakfish

- The weakfish assessment assumes a low M for juveniles that increases over time. The initial low M was creating balancing issues in Ecopath.
- Weakfish assessment re-run with higher M (Krause assumption)
 - Use biomass and Z from Krause run as Ecopath inputs, keeping all others the same.
 - Still out of balance, but not as bad (EE= 12)
- Manual adjustments made to diets to bring EE<2
- Set EE= 0.99 and solve for biomass accumulation
 - This *should* allow Z to increase in Ecosim if predators increase

species	stanza	biomass _mt	biomass_ mtkm2	F	M	Z
WF	1	4,159	0.0094	0.1272	0.2140	0.3412
WF	2	12,276	0.0278	0.8601	0.1326	0.9926
WF	total	16,435	0.0373	0.6746		
WF_KrauseM	1	12,650	0.029	0.042	0.684	0.726
WF_KrauseM	2	17,012	0.039	0.621	0.525	1.146
WF_KrauseM	total	29,662	0.067	0.374		

NWACS-MICE Ecopath model – Summary

Key input parameters were derived from stock assessments and fisheries independent surveys conducted within the NWACS.

Adjustments made during the balancing process were minor.

The NWACS-MICE Ecopath model serves as initial starting conditions for Ecosim simulations.

num	name	Biomass (mt/km2)	BA rate (/year)	Z or PB (/year)	Q/B (/year)	vbK	Wmat/ Winf	Landings (mt/km2)	EE	Trophic Level
1	stiped bass 0	0.008		1.040	7.573			0.000	0.080	3.500
2	striped bass 2-5	0.041	0.168	0.420	3.122	0.183	0.261	0.002	0.636	3.505
3	striped bass 6+	0.040		0.153	1.869			0.000	0.750	3.789
4	menhaden juv	0.313		1.398	9.521			0.011	0.238	2.722
5	menhaden adult	2.525	0.129	1.295	3.804	0.331	0.379	0.788	0.405	2.883
6	spiny dogfish	1.668	0.000	0.201	1.810			0.054	0.163	3.500
7	bluefish juv	0.007		0.934	10.684			0.002	0.730	3.962
8	bluefish adult	0.465	-0.176	0.749	3.139	0.310	0.112	0.116	0.459	3.845
9	weakfish juv	0.002	-0.535	0.726	11.371			0.001	0.990	3.501
10	weakfish adult	0.039	-0.321	1.146	3.770	0.190	0.041	0.024	0.990	3.622
11	Atlantic herring 0-1	0.023		1.021	10.027			0.009	0.925	3.285
12	Atlantic herring 2+	0.318	0.331	0.759	3.700	0.340	0.277	0.130	0.906	3.292
13	anchovies	0.635		2.200	7.333				0.320	3.027
14	benthic inverts	51.910		2.432	12.469				0.497	2.108
15	zooplankton	24.470		45.850	154.600				0.905	2.337
16	phytoplankton	25.450		186.436					0.423	1.000
17	Detritus	29.420							0.234	1.000

not required

Ecopath Calculated

NWACS EwE

Survey Data

Stock Assessment

Balancing/ Other input

NWACS-MICE:
Ecosim time-dynamic
simulations and model
calibration

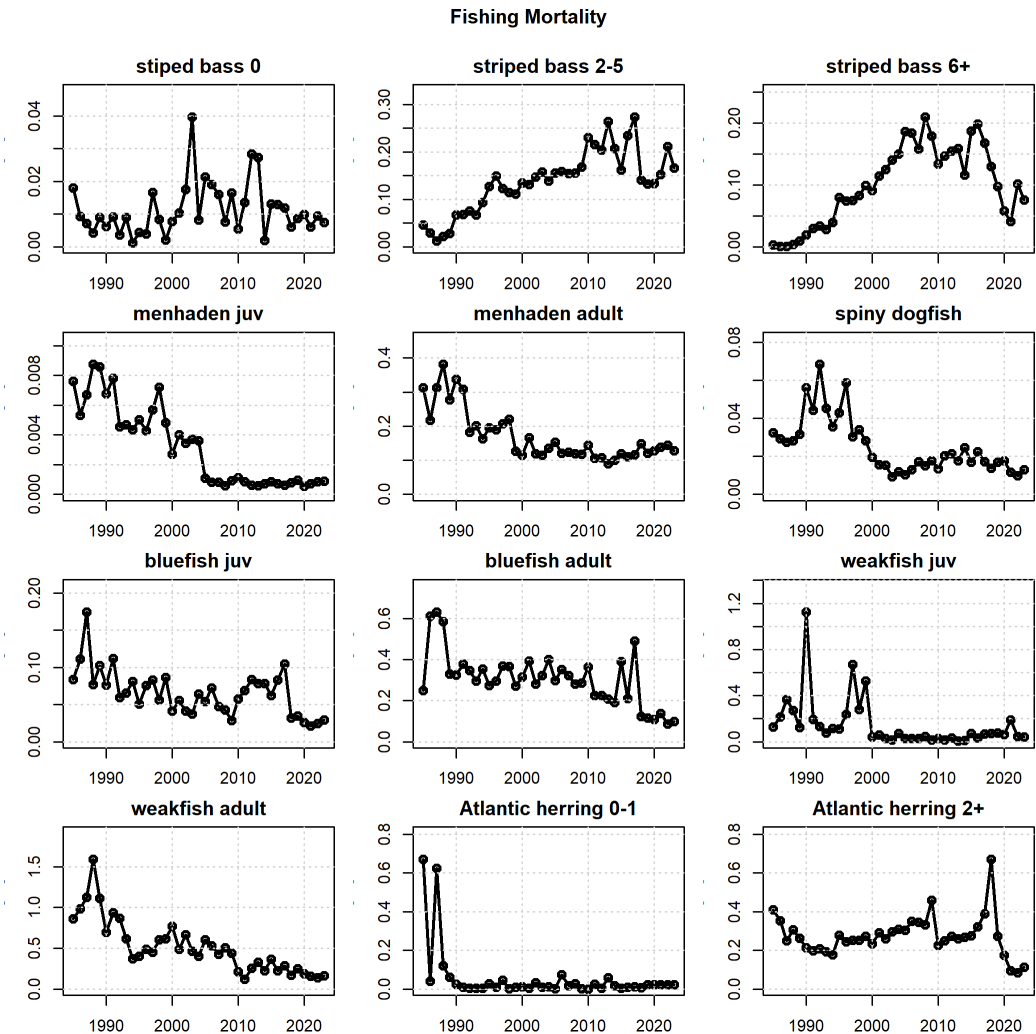
NWACS-MICE Ecosim - Observed Timeseries

- 23 annual relative abundance indices and 12 catch timeseries were extracted from the stock assessment model output files.
 - Relative catch used for non-leading stanzas
 - Stock assessment biomass included, but with 0 weight
- Weighted by the mean of $1/CV$ assumed by the stock assessment models for each index.
- Anchovy and zooplankton timeseries obtained from the SDM analysis and NEFSC plankton cruise, respectively.
- Annual observed timeseries used with monthly forcing scenarios

Species	Timeseries Included
Striped bass	Juv composite index, MRIP, CTLIST, MDSSN
Atlantic menhaden	JAI, NAD, MAD, SAD
Spiny dogfish	NEFSC spring BTS
Bluefish	Composite YOY, MRIP CPUE, NC PSIGNS, NEFSC-A
Weakfish	Composite YOY, MRIP CPUE, DE trawl, NJOT, NC PSIGNS
Atlantic herring	Shrimp surv, Fall Albatross 85, Fall Bigelow

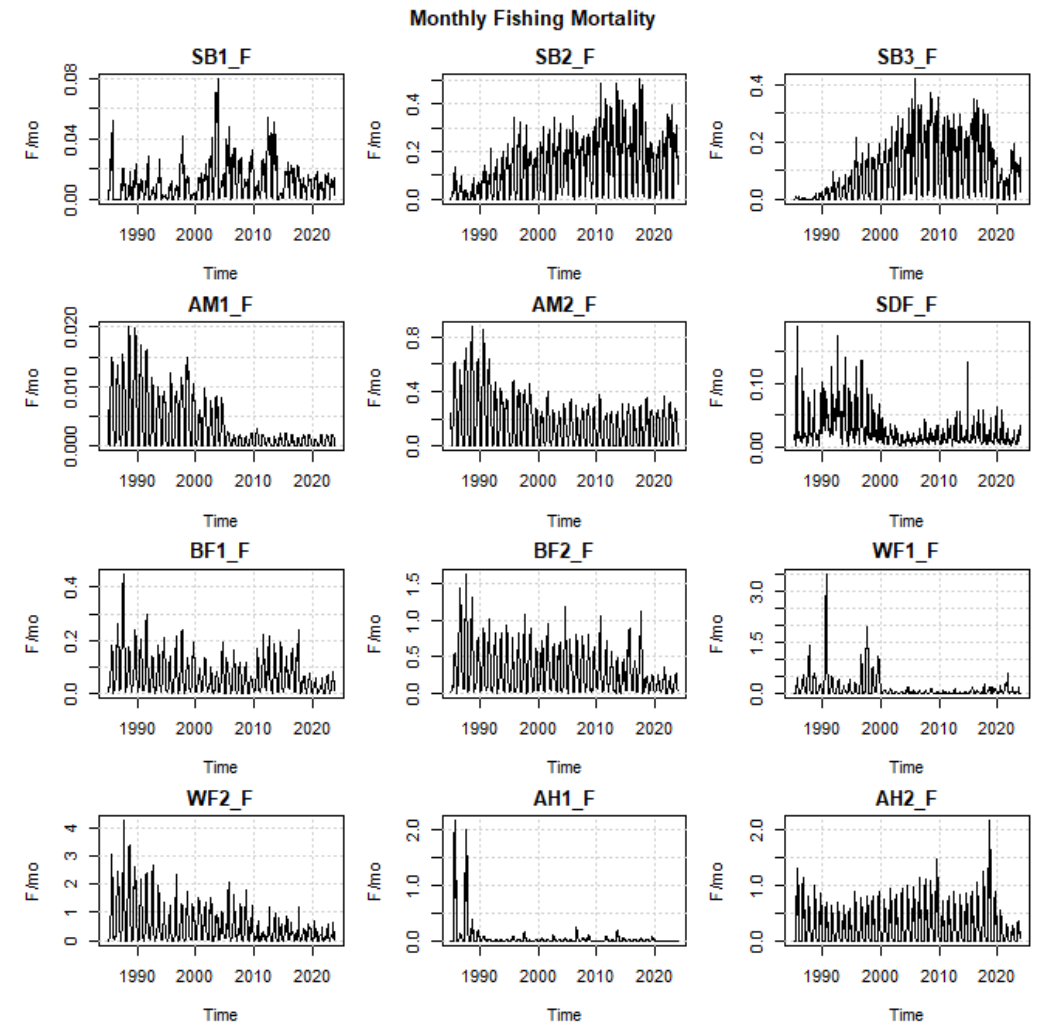
NWACS-MICE Ecosim – Forcing Timeseries

1. Annual F – stock assessment
2. Monthly F – stock assessment * monthly effort or landings proportion
3. Annual Primary Production – from oceanographic reanalysis model
4. Monthly Primary Production – from oceanographic reanalysis model
5. Egg production – histology studies
6. Seasonal vulnerability forcing – pred/prey OI
7. Atlantic herring recruitment deviations – rec devs
8. Atlantic herring survival deviations – NAA devs



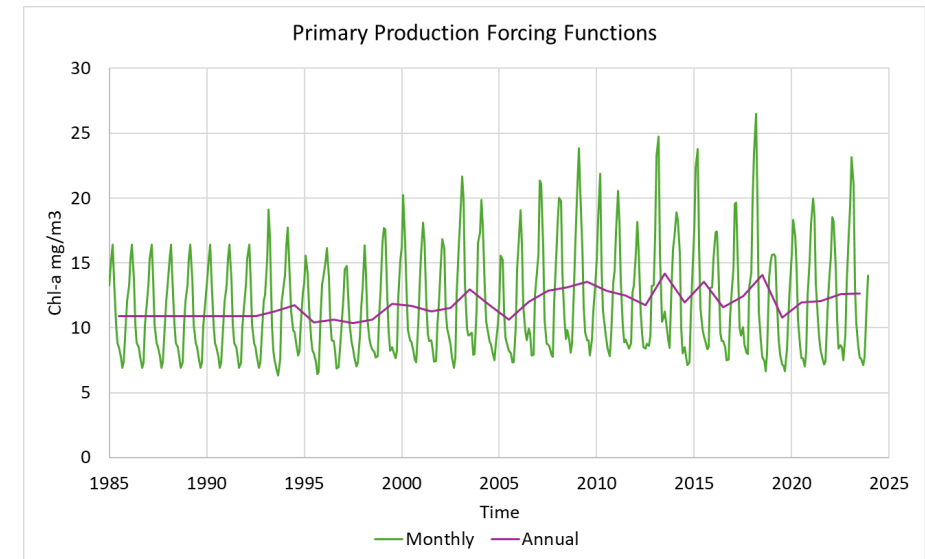
NWACS-MICE Ecosim – Forcing Timeseries

1. Annual F – stock assessment
2. Monthly F – stock assessment * monthly effort or landings proportion
3. Annual Primary Production – from oceanographic reanalysis model
4. Monthly Primary Production – from oceanographic reanalysis model
5. Egg production – histology studies
6. Seasonal vulnerability forcing – pred/prey OI
7. Atlantic herring recruitment deviations – rec devs
8. Atlantic herring survival deviations – NAA devs



NWACS-MICE Ecosim – Forcing Timeseries

1. Annual F – stock assessment
2. Monthly F – stock assessment * monthly effort or landings proportion
3. Annual Primary Production – from oceanographic reanalysis model
4. Monthly Primary Production – from oceanographic reanalysis model
5. Egg production – histology studies
6. Seasonal vulnerability forcing – pred/prey OI
7. Atlantic herring recruitment deviations – rec devs
8. Atlantic herring survival deviations – NAA devs



Chl-a scaled to mean of 1 in first year and applied as multiplier on phytoplankton PB

NWACS-MICE Ecosim – Forcing Timeseries

1. Annual F – stock assessment
2. Monthly F – stock assessment * monthly effort or landings proportion
3. Annual Primary Production – from oceanographic reanalysis model
4. Monthly Primary Production – from oceanographic reanalysis model
- 5. Egg production – histology studies**
6. Seasonal vulnerability forcing – pred/prey OI
7. Atlantic herring recruitment deviations – rec devs
8. Atlantic herring survival deviations – NAA devs

	striped bass	menhaden	bluefish	weakfish	Atlantic herring
Jan	0.00	0.41	0.19	0.00	0.00
Feb	0.00	0.36	0.18	0.00	0.00
Mar	0.05	0.66	0.25	0.00	0.00
Apr	1.00	0.58	0.50	0.10	0.00
May	0.63	0.39	0.56	1.00	0.00
Jun	0.05	0.29	1.00	0.71	0.00
Jul	0.00	0.27	0.75	0.41	0.00
Aug	0.00	0.39	0.25	0.34	0.50
Sep	0.00	0.38	0.13	0.00	1.00
Oct	0.00	1.00	0.08	0.00	1.00
Nov	0.00	0.70	0.13	0.00	0.50
Dec	0.00	0.67	0.15	0.00	0.00

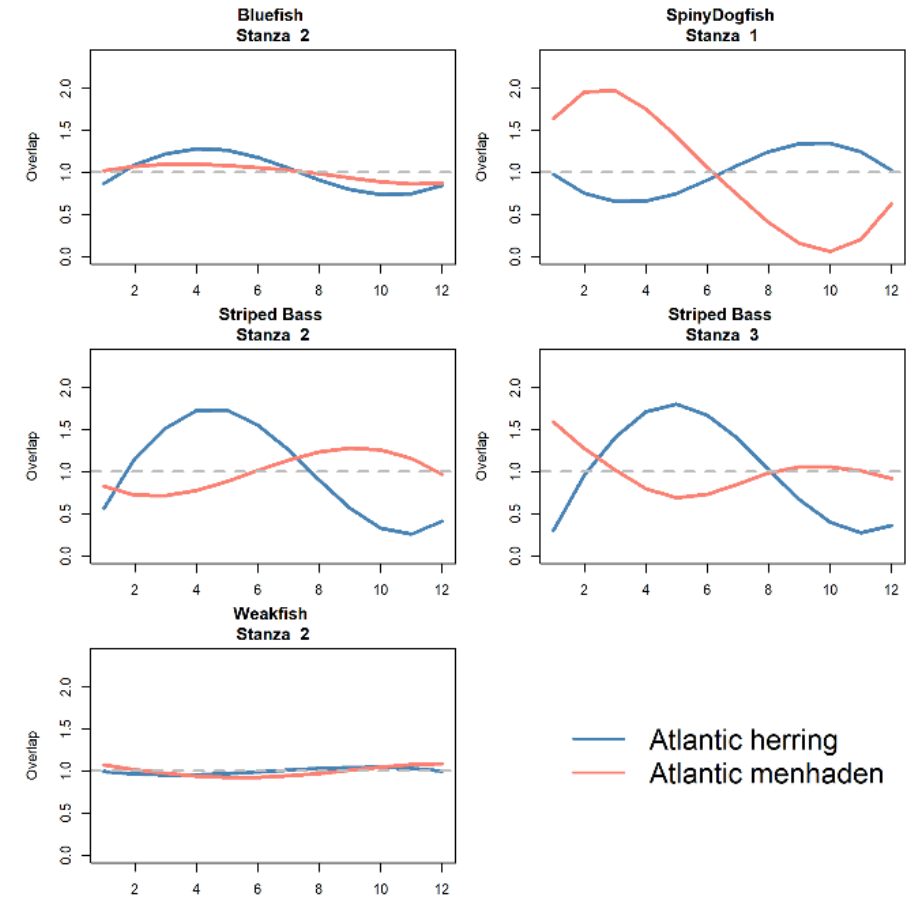
Lowerre-
Barbierie

Source Brown et al. 2024 Latour et al. 2023 Robillard et al. 2008 et al. 1996 Fishbase

Seasonal multiplier on egg production for multistanza groups.

NWACS-MICE Ecosim – Forcing Timeseries

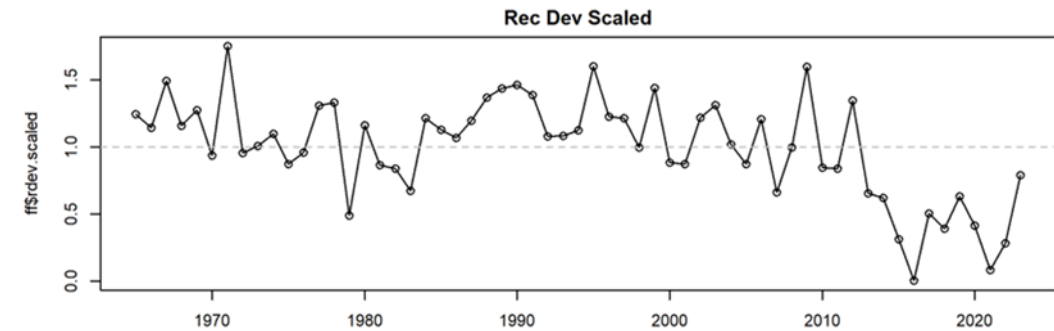
1. Annual F – stock assessment
2. Monthly F – stock assessment * monthly effort or landings proportion
3. Annual Primary Production – from oceanographic reanalysis model
4. Monthly Primary Production – from oceanographic reanalysis model
5. Egg production – histology studies
6. Seasonal vulnerability forcing – pred/prey overlap
7. Atlantic herring recruitment deviations – rec devs
8. Atlantic herring survival deviations – NAA devs



Seasonal predator-prey overlap indices from MSVPA work, smoothed over entire year using spline function

NWACS-MICE Ecosim – Forcing Timeseries

1. Annual F – stock assessment
2. Monthly F – stock assessment * monthly effort or landings proportion
3. Annual Primary Production – from oceanographic reanalysis model
4. Monthly Primary Production – from oceanographic reanalysis model
5. Egg production – histology studies
6. Seasonal vulnerability forcing – pred/prey overlap
7. Atlantic herring recruitment deviations – rec devs
8. Atlantic herring survival deviations – NAA devs

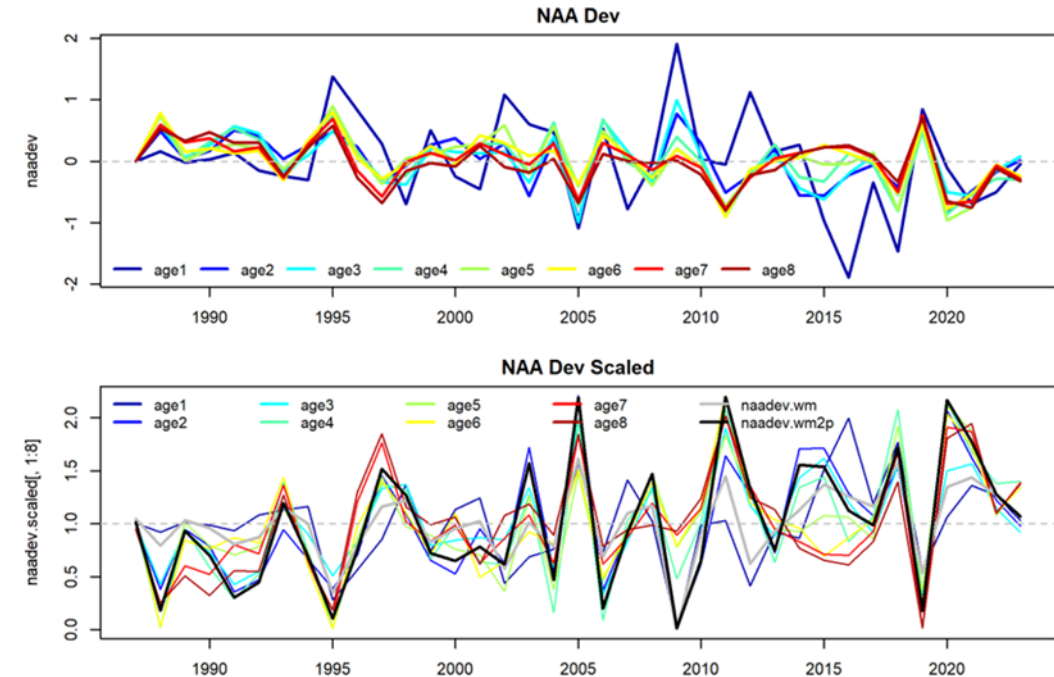


Estimated $\log(Rdev)$ from stock assessment were exponentiated and scaled to 1. Incorporated seasonal component and applied as long-term egg forcing function to Atlantic herring.

Implies that some density independent process is affecting early life history stages

NWACS-MICE Ecosim – Forcing Timeseries

1. Annual F – stock assessment
2. Monthly F – stock assessment * monthly effort or landings proportion
3. Annual Primary Production – from oceanographic reanalysis model
4. Monthly Primary Production – from oceanographic reanalysis model
5. Egg production – histology studies
6. Seasonal vulnerability forcing – pred/prey overlap
7. Atlantic herring recruitment deviations – rec devs
8. Atlantic herring survival deviations – NAA devs



NAA devs from WHAM converted to multiplier on other mortality (M_0). Test alternative hypothesis that survival in older ages is cause for persistent low stock biomass.

NWACS-MICE Ecosim Model Configurations

Forcing functions applied individually and in combinations.

Models were calibrated while changing:

- Initial $k_{ij} = 2$, B/B0, M2/M, TL, random
- Prey switching = 0, 0.5, 1, 1.5, 2
- Max rel PB = 1, 2, 3
- Calibration method = k_j , k_j with timeseries, k_{ij} repeated search

We limited the number of calibrated runs in models 4-13 based on results from models 1-3.

Model Type 12 includes the base run.

Model Type	Annual F	Monthly F	Annual PP	Monthly PP	Monthly vul ff	Monthly egg ff	AH Rdev ff	AH Ndev ff	Number of runs
1	X								30
2	X		X						39
3	X			X					32
4	X					X			7
5	X				X				6
6		X							6
7		X		X	X	X			6
8	X			X	X	X			4
9	X		X		X				2
10	X			X	X				3
11	X				X	X			4
12	X				X	X	X		6
13	X				X	X		X	5

NWACS-MICE Ecosim Calibration – Initializing k_{ij}

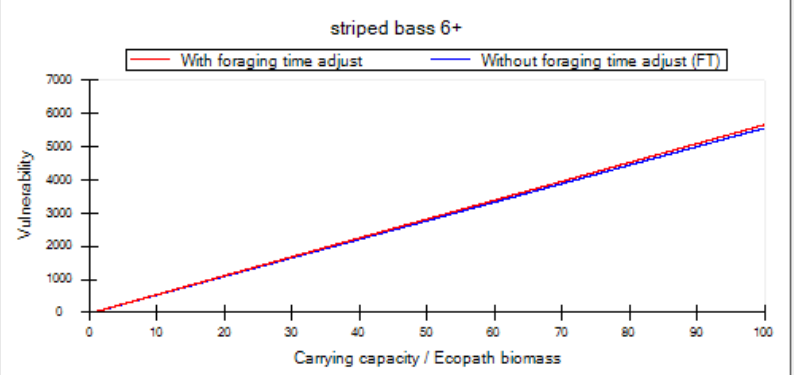
Alternative starting values for vulnerability multipliers (k_{ij})

1. $k_{ij}=2$: default
2. k_j scaled to B_0/B_{1985} : carrying capacity assumption
3. k_j scaled to trophic level: range 1.2-100
4. k_{ij} set to $vulcap = 0.75M_2_{ij}/M_i$
5. k_{ij} random starting values ($n=5$)

Estimate Vulnerabilities

Estimate Vulnerabilities from: —

- Bo (Ecopath) / B unfished
- B unfished / Bo (Ecopath)
- F max / M
- Predation mort (rel) / Bo/Bunf



Select which computed vulnerabilities to transfer to Ecosim:

	Group name	Poten. growth (Bunf/Bo)	Vulnerability w/o FT	Vulnerability w. FT	FMax	Vulnerability w/o FT	Vulnerability w. FT
1	striped bass 0	15.65	425.603	36.124	0.0379	301.511	13.976
2	striped bass 2-5	10.06	74.167	84.227	0.134	92.862	81.862
3	striped bass 6+	13.81	714.049	727.859	0.210	6.300	5.207
4	menhaden juv	1.618	23.101	24.719	0.0294	384.800	373.788
5	menhaden adult	2.142	3.599	5.741	0.349	42.515	31.515
6	spiny dogfish	2.256	6.503	8.759	0.212	62.775	51.775
7	bluefish juv	2.149	3.190	5.339	0.396	38.766	27.767
8	bluefish adult	2.149	2.293	4.442	0.551	30.956	19.956
9	weakfish juv	1.877	3.599	5.476	1.276	2.205	
10	weakfish adult	1.877	2.561	4.438	0.790	4.002	2.236
11	Atlantic herring 0-1	4.770	6.197	10.967	0.669	27.438	16.438
12	Atlantic herring 2+	10.97	8.536	19.506	1.285	19.562	8.562
13	anchovies				1.200	1.833	
14	benthic inverts				1.200	1.833	
15	zooplankton				1.200	1.833	
16	phytoplankton				1.200		

Cancel OK

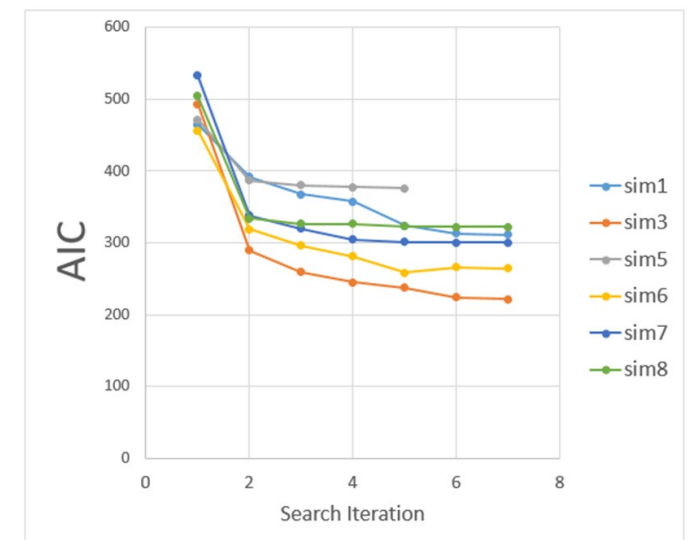
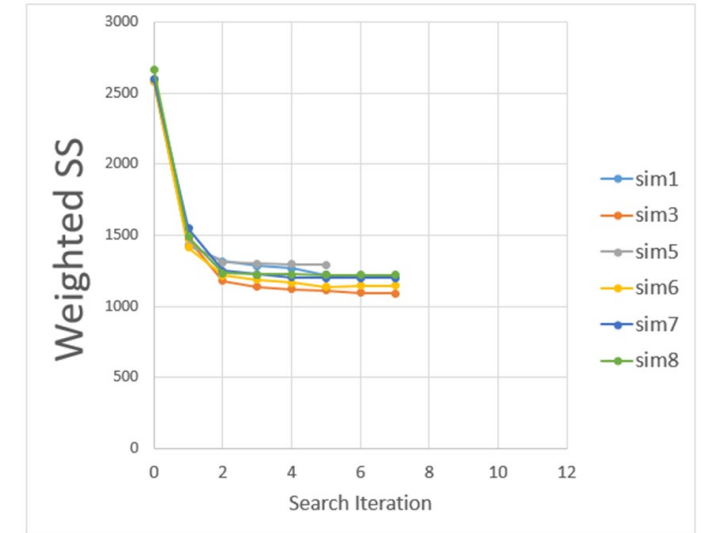
NWACS-MICE Ecosim Calibration Procedure

We considered 3 approaches for model calibration

- Estimate a single k_j for all consumer groups
- Estimate a single k_j for all consumer groups with obs
- Estimate N most sensitive k_{ij} , repeated

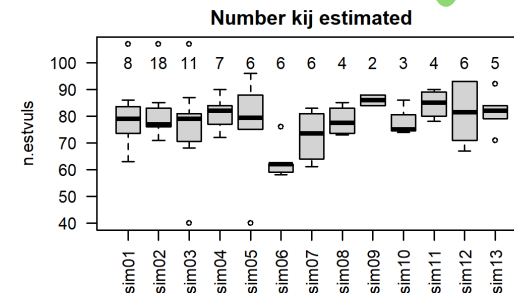
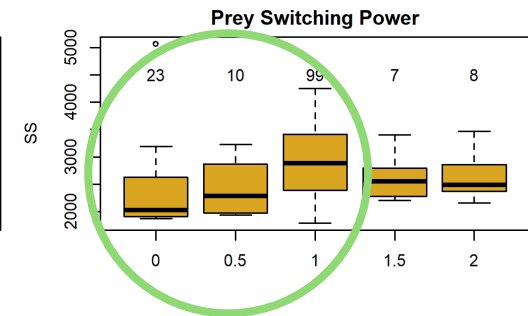
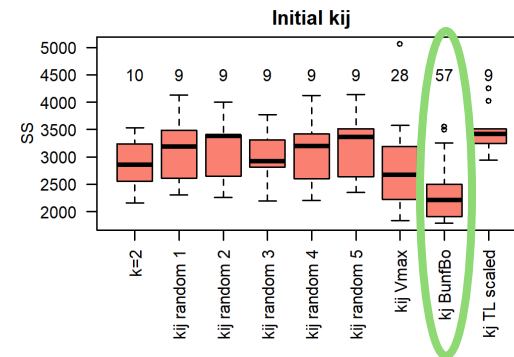
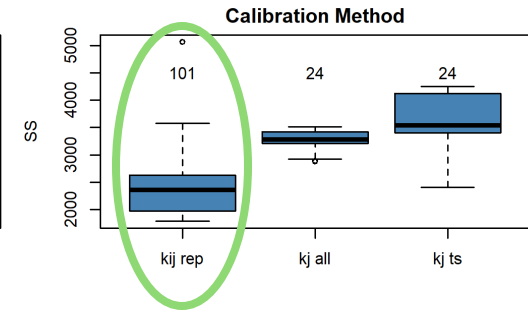
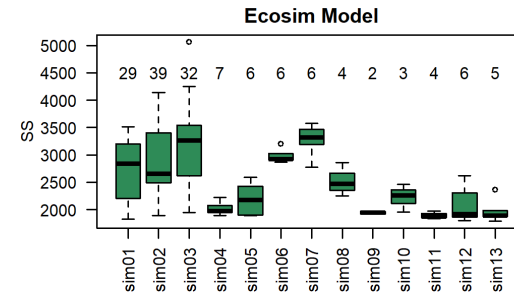
The repeated k_{ij} approach produced the best model fits

- Step 1: Search for K most sensitive k_{ij} , where K is number of reference timeseries-1
- Step 2: Estimate the K most sensitive k_{ij}
- Step 3: Repeat 1-2 until no further improvements in SS (~ 5)
- Usually results in about $3 \times K$ parameters estimated



NWACS-MICE Summary of Calibrated Models

- A total of 150 calibrated Ecosim runs.
- Initializing with $k_{ij}=B_0/B_{1985}$, $P_j < 1$, and using the repeated k_{ij} search produced best fitting models (low SS)
- Equally good fits in models 1-5, and especially those with egg production (model 4)
- Monthly fishing effort models (6-7) resulted in poor fits to the data
- The number of k_{ij} estimated from repeated search runs varied from 60-110.



Model Type	Annual F	Monthly F	Annual PP	Monthly PP	Monthly vul ff	Monthly egg ff	AH Rdev ff	AH Ndev ff	Number of runs
1	X								30
2	X		X						39
3	X			X					32
4	X					X			7
5	X				X				6
6		X							6
7		X		X	X	X			6
8	X			X	X	X			4
9	X		X		X				2
10	X			X	X				3
11	X				X	X			4
12	X				X	X	X		6
13	X				X	X		X	5

NWACS-MICE Summary of Calibrated Models

The lowest SS was achieved in runs with Atlantic herring forcing functions

- Run 145 did not improve fit to AH biomass and conversion of NAA devs to M0 forcing is questionable.

Top 10% of runs (SS <= 1,895)

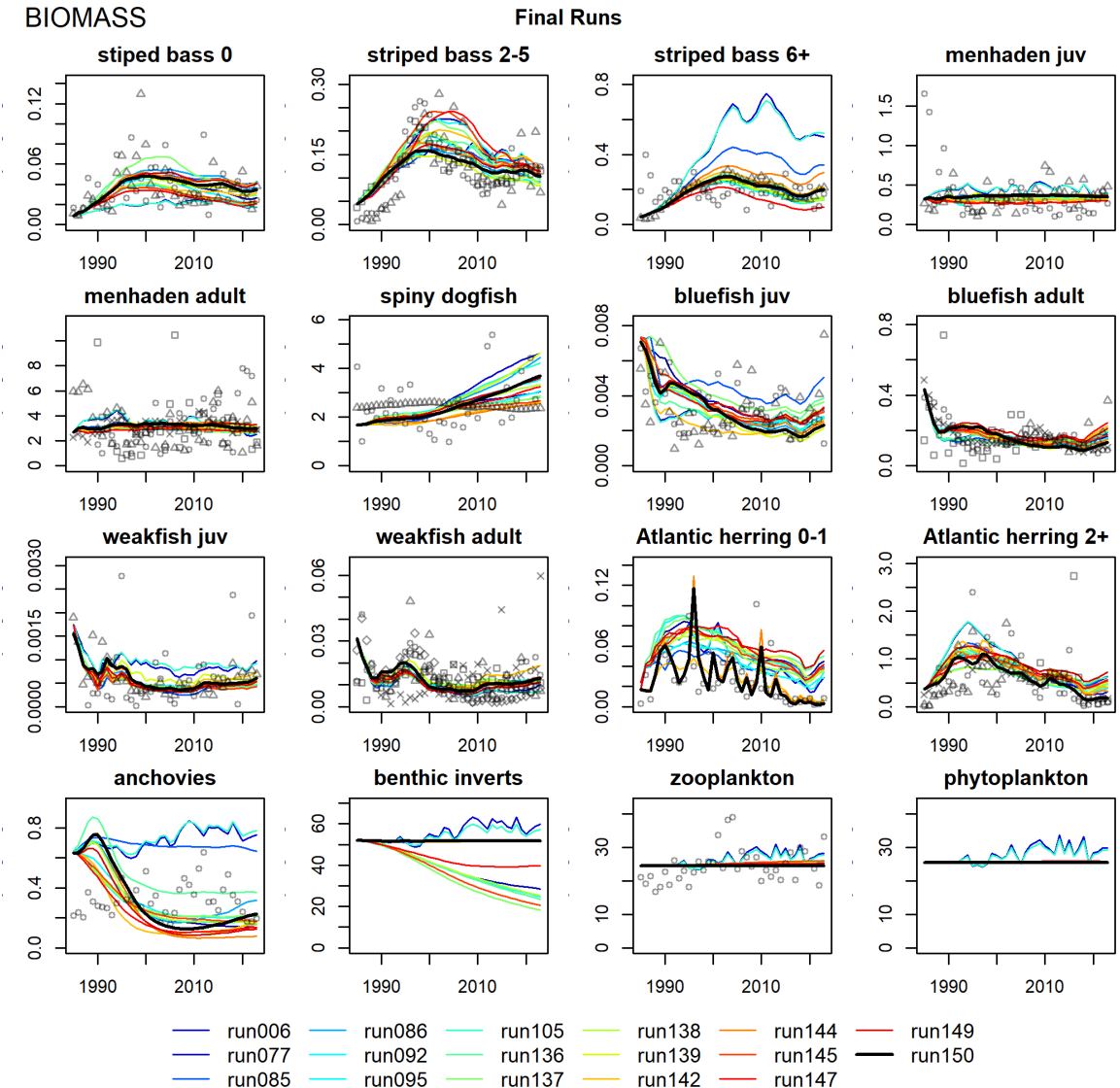
- No runs with monthly PP or F were in top 10%
- N estimated kij 63-95 (mean = 81.33), 2-4 parameters per timeseries with 1,720 data points
- N estimated on bounds ranged from 13-43 (mostly lower bound 1.0)

Run num	Model num	Model label	Initi Kij	Max Rel PB	Pj	Final SS	Final AIC	N est kij	N low	N high
145	13	seasonal eggs, vuls, AH NAAdev	BunfBo	2	1	1791	151	82	24	6
144	12	seasonal eggs, vuls, AH Rdev	BunfBo	2	mix	1800	160	93	13	2
6	1	continuity	BunfBo	2	1	1824	183	78	20	2
137	11	seasonal eggs and vuls	Vmax	2	1	1837	NA	78	19	9
136	11	seasonal eggs and vuls	BunfBo	2	1	1860	217	82	19	7
142	12	seasonal eggs, vuls, AH Rdev	BunfBo	2	1	1864	220	67	12	1
95	1	continuity	Vmax	2	1	1865	222	63	15	3
147	13	seasonal eggs, vuls, AH NAAdev	BunfBo	2	1	1872	276	84	21	11
150	12	seasonal eggs, vuls, AH Rdev	BunfBo	2	mix	1874	167	93	12	2
138	11	seasonal eggs and vuls	BunfBo	2	mix	1884	NA	88	17	3
92	5	seasonal vuls	BunfBo	2	1	1888	242	88	17	3
105	2	PP annual	BunfBo	3	0	1890	244	79	21	22
149	13	seasonal eggs, vuls, AH NAAdev	BunfBo	2	1	1892	246	92	12	2
85	4	seasonal eggs	BunfBo	2	0	1892	246	76	17	7
77	2	PP annual	BunfBo	2	0	1895	249	77	19	9
86*	4	seasonal eggs	BunfBo	2	0.5	1934	284	85	11	3
139*	11	seasonal eggs and vuls	BunfBo	2	NA	1971	NA	90	9	2

NWACS-MICE

Biomass

- Biomass trajectories were consistent across runs for most species.
 - Striped bass age 6+ biomass higher in PP models (77, 105)
 - Spiny dogfish and juv bluefish diverged across model runs
 - Anchovies and benthic inverts differed in PP models
 - Zooplankton and phytoplankton were flat unless PP forcing was included
- Only the Atlantic herring Rdev models were able to capture variable recruitment for herring and low biomass in recent years
- Ecosim was unable to fit high variability in the individual indices because it doesn't estimate annual recruitment parameters



Fits to individual indices available in the report.

NWACS-MICE

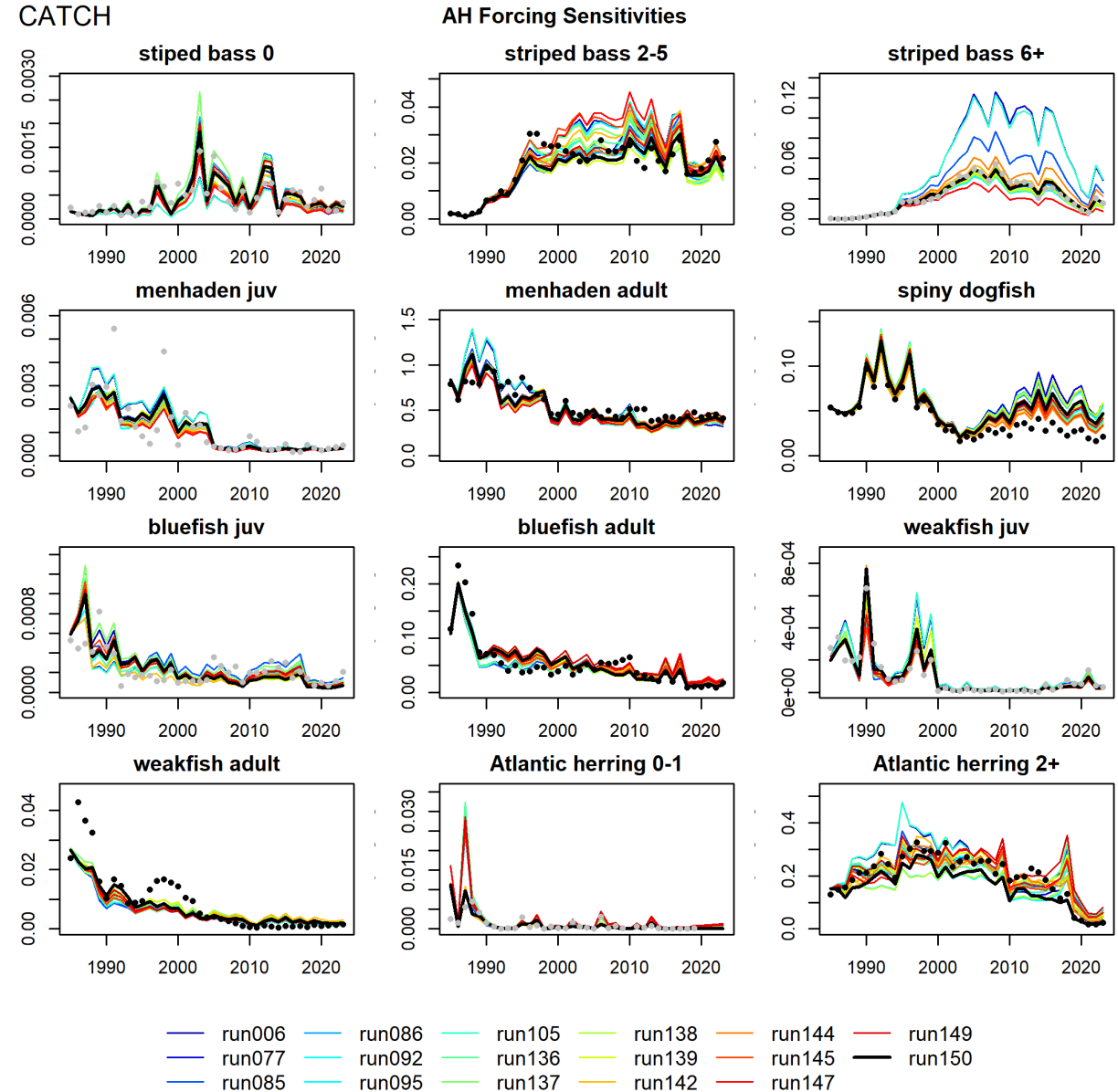
Catch

Obs catch = landings and dead discards

Est catch = est B * F forcing

Predicted catch was consistent across models and fit the data well

- Striped bass and spiny dogfish overestimated catch when k_{ij} is high and biomass is overestimated
- Atlantic herring catch is poorly fit in recent years

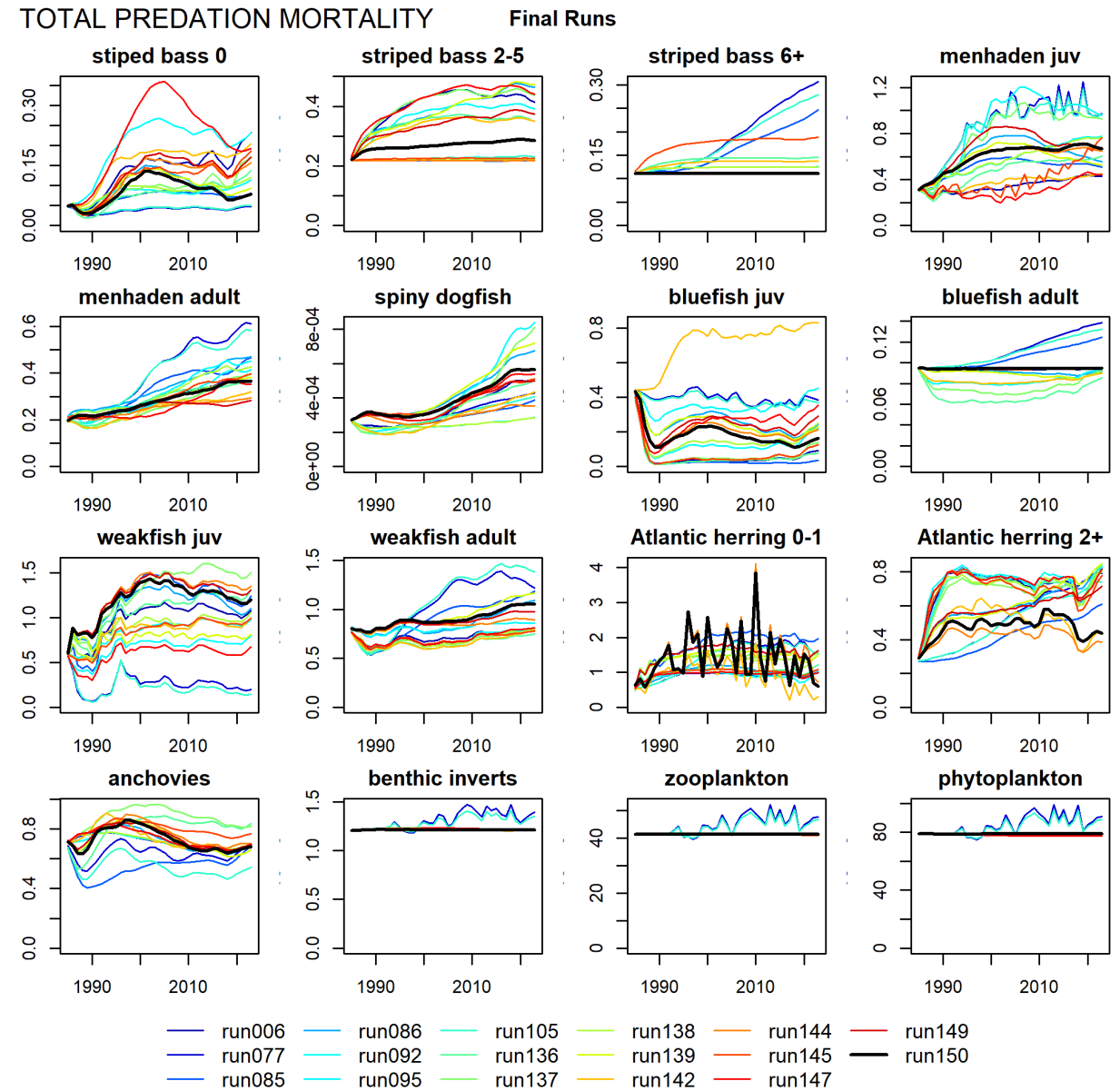


NWACS-MICE

Predation Mortality

Total predation mortality varied considerably across model runs for most species, owing to the direct relationship between the vulnerability parameters and consumption rates

Higher k_{ij} allows biomass of predators (i.e. striped bass and spiny dogfish) to increase in some scenarios, leading to higher predation mortalities.



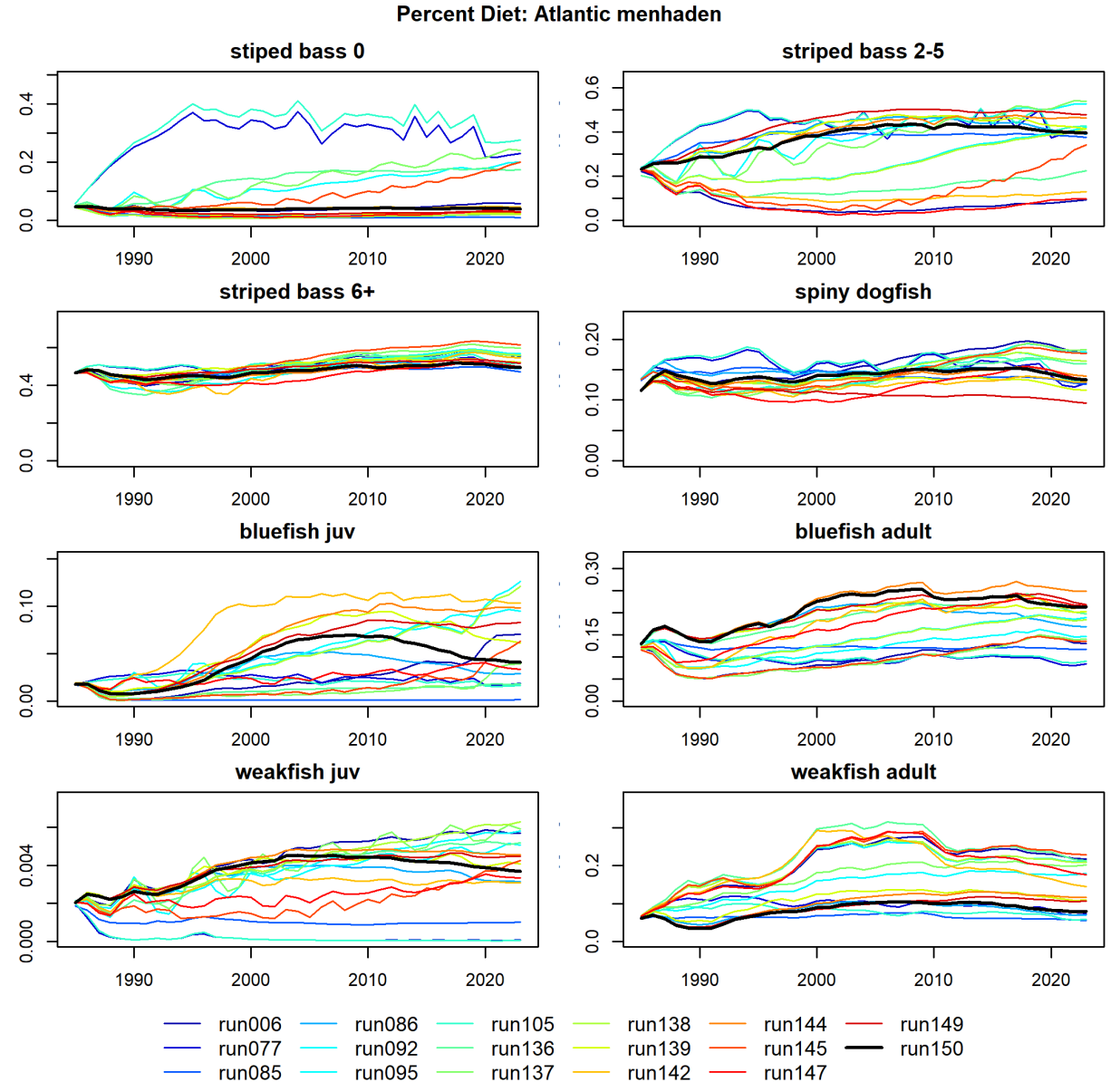
NWACS-MICE

Diet Compositions

Diet % is predicted based on diet matrix, predator-prey biomasses, and foraging arena parameters

The percent of menhaden in predator diets (all ages) varied over time and across model runs.

- High variability across model runs for striped bass age-0 and 2-5, bluefish, and weakfish
- Striped bass age 6+ and spiny dogfish diets remain relatively constant at around 45% and 15% menhaden, respectively



NWACS-MICE

Diet Compositions

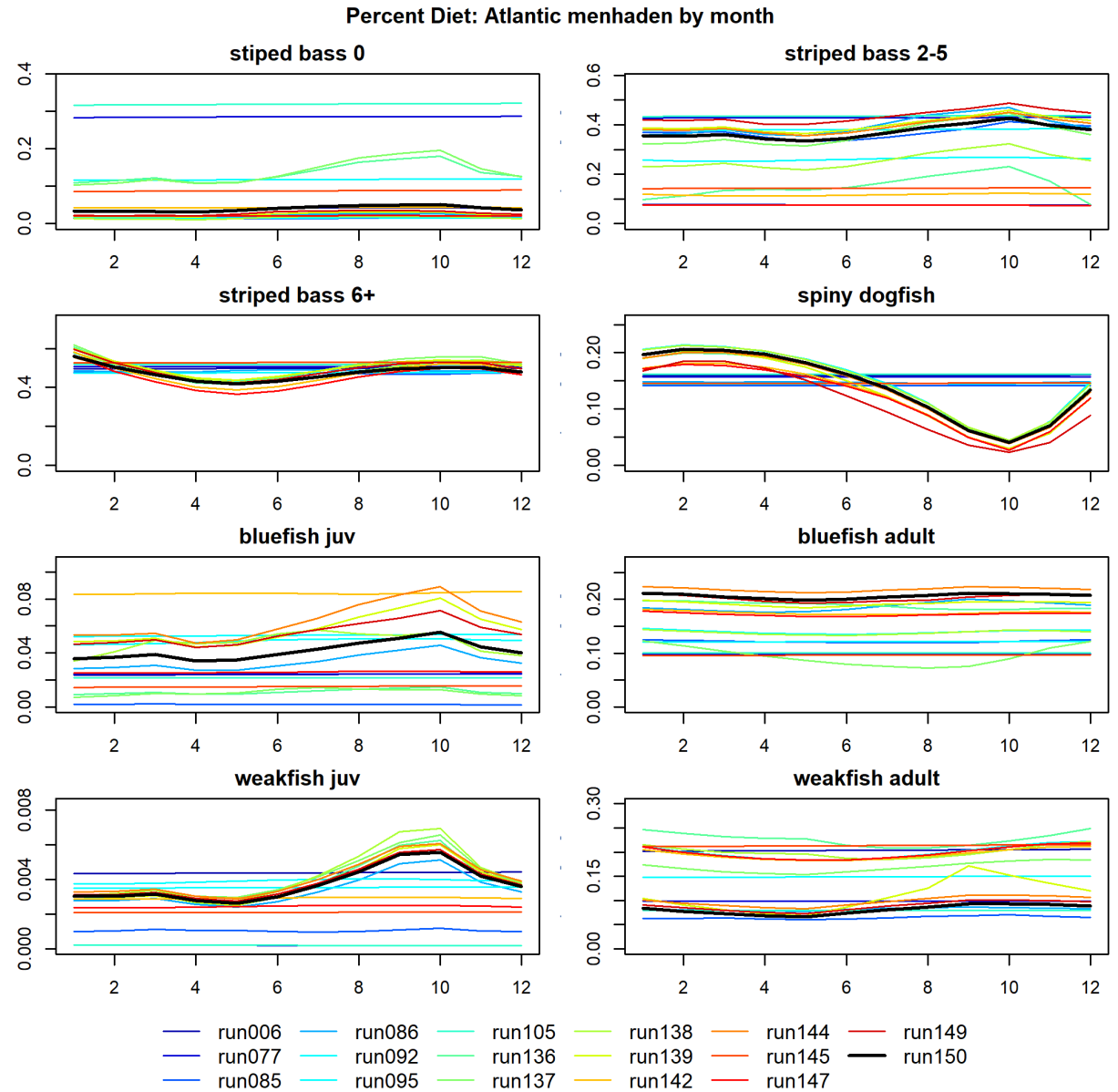
Diet % is predicted based on diet matrix, predator-prey biomasses, and foraging arena parameters

The percent of menhaden in predator diets (all ages) varied over time and across model runs.

- High variability across model runs for striped bass age-0 and 2-5, bluefish, and weakfish
- Striped bass age 6+ and spiny dogfish diets remain relatively constant at around 45% and 15% menhaden, respectively

Runs with seasonal vul FF allowed menhaden consumption to vary monthly

- Striped bass eat less menhaden during the spring than fall and winter
- Bluefish and weakfish consume more menhaden during the fall
- Spiny dogfish consume more menhaden during spring than during fall



NWACS-MICE

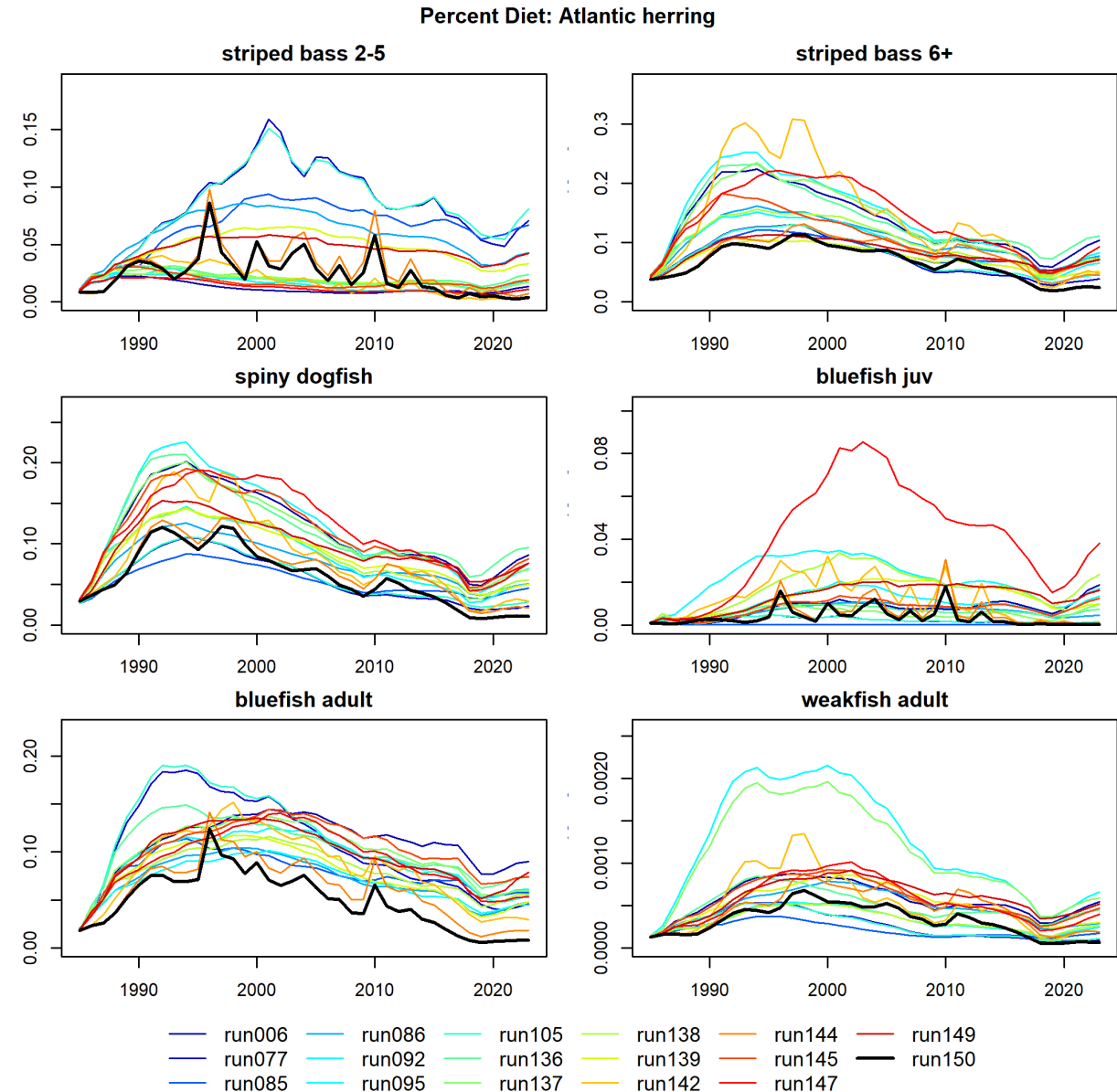
Diet Compositions

Striped bass, spiny dogfish, and bluefish were the primary consumers of Atlantic herring in the model.

- Percent diet tracked biomass history of Atlantic herring

Run 150 estimated lower diet % than other runs.

- Atlantic herring dynamics driven by Rdevs and not predation



NWACS-MICE

Diet Compositions

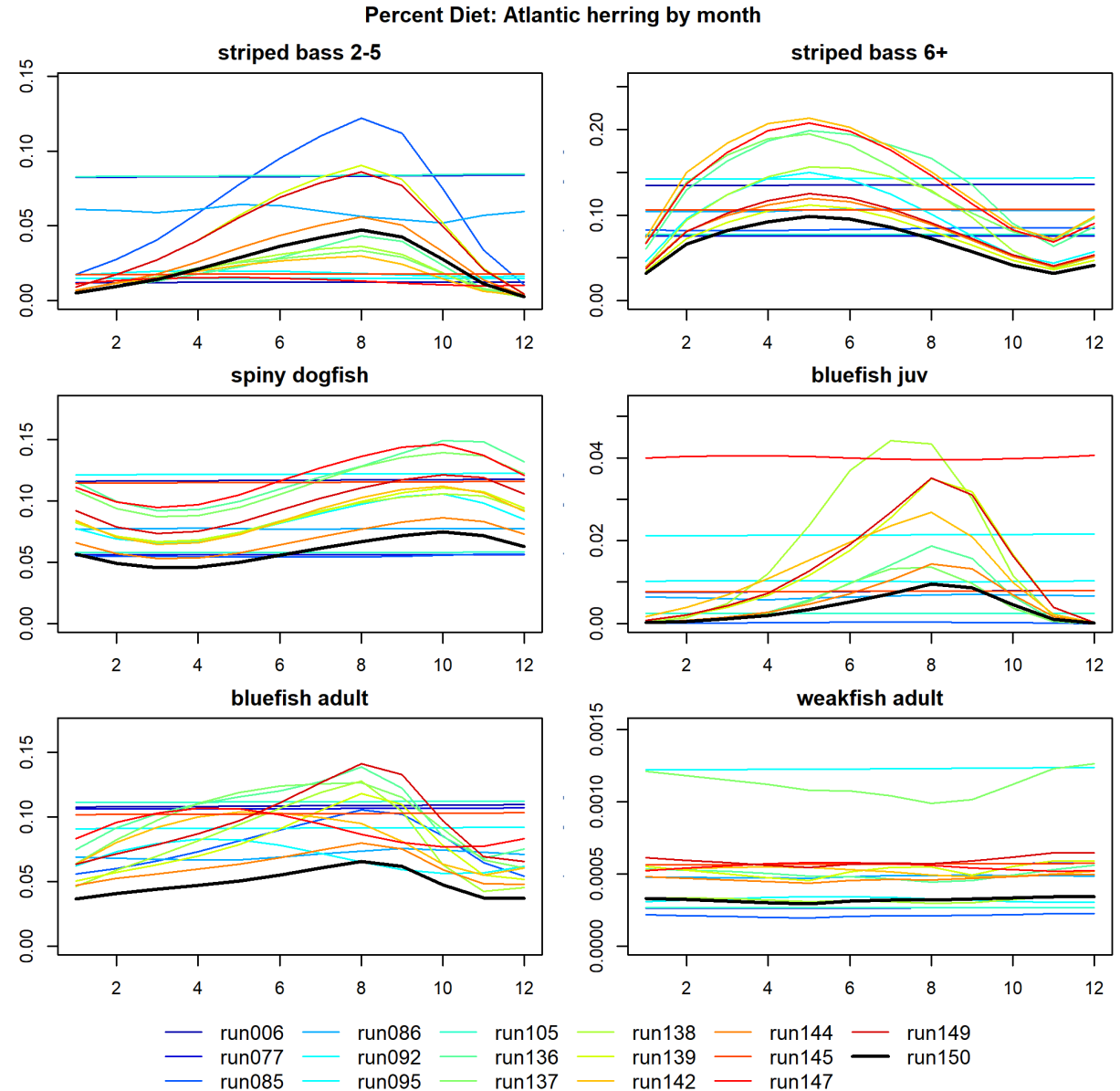
Striped bass, spiny dogfish, and bluefish were the primary consumers of Atlantic herring in the model.

- Percent diet tracked biomass history of Atlantic herring

Run 150 estimated lower diet % than other runs.

- Atlantic herring dynamics driven by Rdevs and not predation

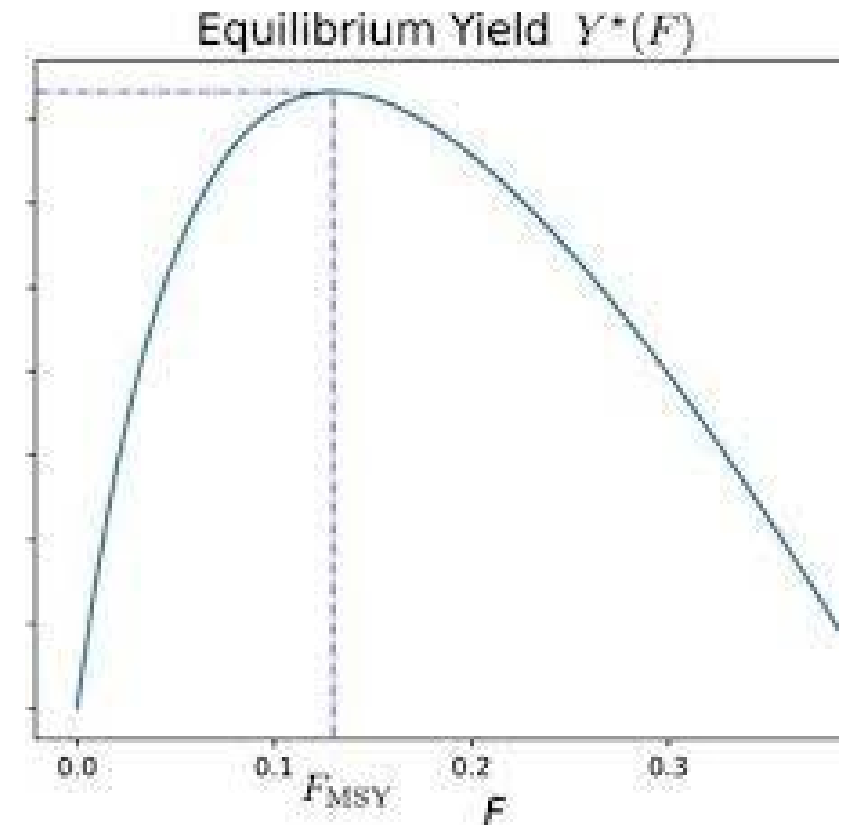
The seasonal effect was more evident for Atlantic herring than menhaden.



NWAC-MICE Equilibrium Analysis

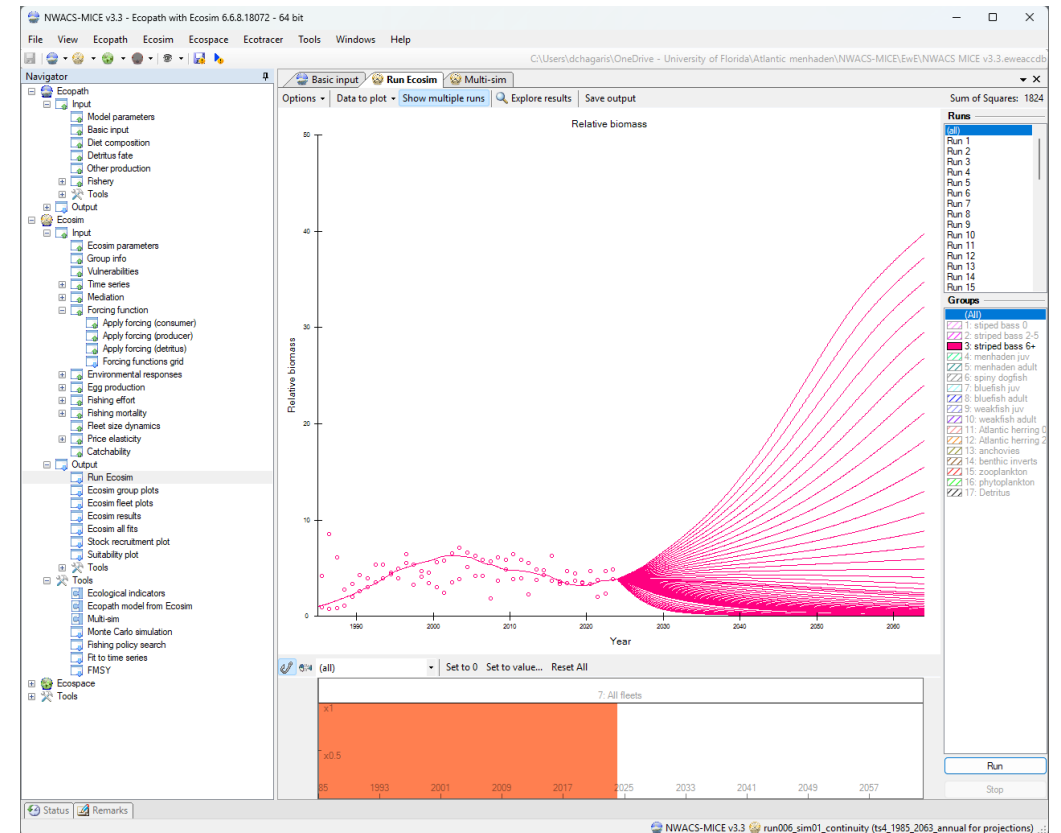
Equilibrium analysis conducted as a model diagnostic for ERP species

- Do they respond to F in a way that is consistent with the stock assessment?
- Do species reach their B_{target} when fished at the single species F target?



NWAC-MICE Equilibrium Analysis

- 40-year projections from the terminal year (2024-2063) while iterating over F rates
 - $F = [0, 2 * M]$
- Evaluate one species at a time, holding others constant at status quo F
- Automated using the Multisim plugin

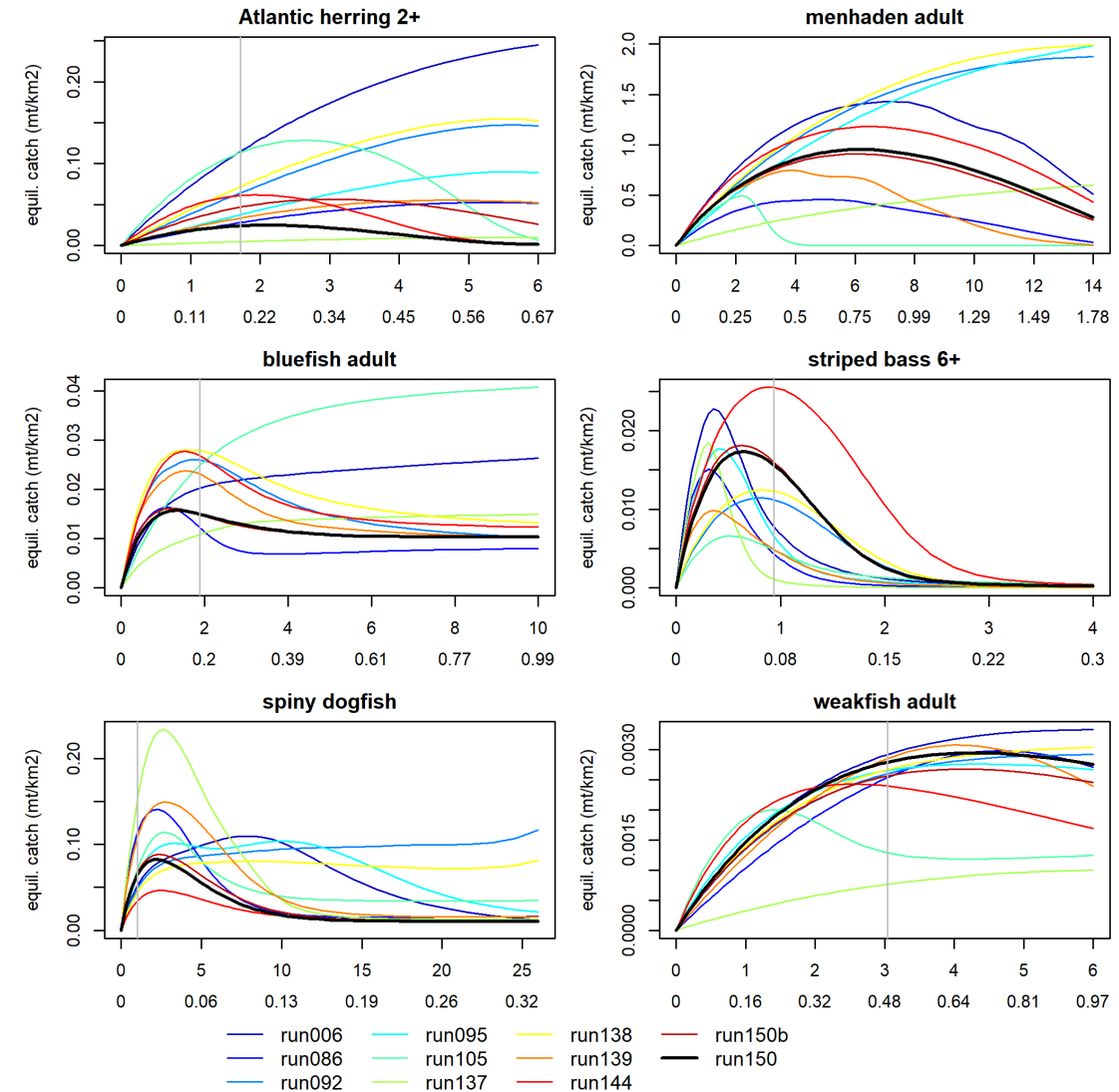


NWAC-MICE Equilibrium Analysis

Equilibrium yield curves usually exhibited one of 3 patterns:

1. Asymptotic
2. Broad dome-shaped, species can tolerate high levels of F
3. Dome-shaped, clear indication of F_{msy} near the single species value

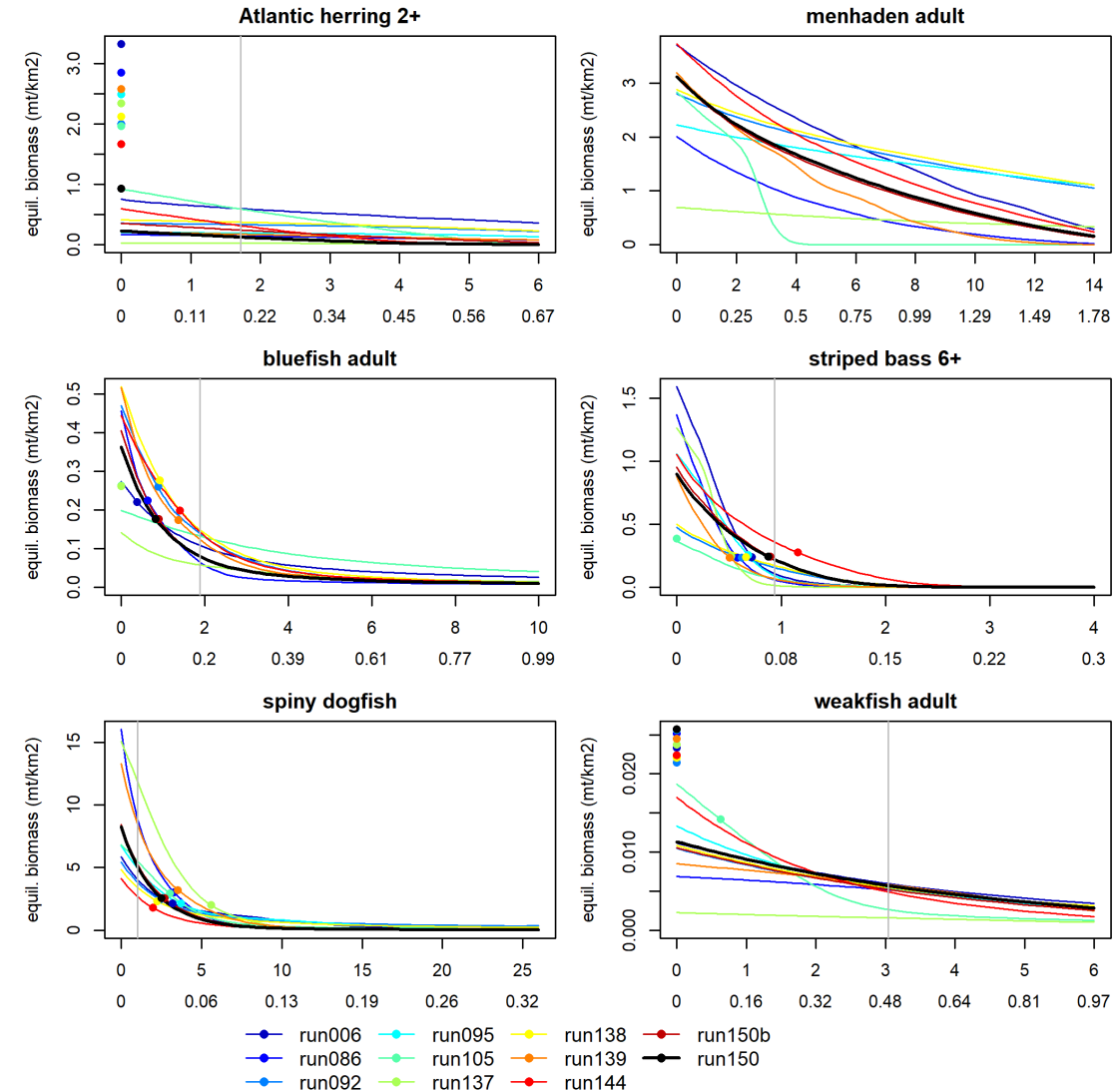
The equilibrium analysis will also detect dynamic instability at high F , and reveal other issues in the model (earlier runs, not shown).



NWAC-MICE Equilibrium Analysis

Equilibrium biomass

- Most species do not reach their B target exactly, when fished at their F target
 - Striped bass approximates B target when fished at F target in several runs.
 - Bluefish B target is reached at lower F
 - Spiny dogfish B target achieved at higher F
- Atlantic herring and weakfish never reach their Btarget, even at F=0
 - Low AH Rdevs assumed in projections
 - Predation on weakfish



NWAC-MICE Base Run

Sum-of squared residuals

Number of parameters estimated and on bounds

Equilibrium diagnostics

Few manual adjustments

Run num	Model num	Model label	Final SS	N est kij	N low	N high	SB	Equilibrium Analysis				
								AM	SDF	BF	WF	AH
144	12	seasonal eggs, vuls, AH Rdev	1800	93	13	2	2	2	2	2	2	2
6	1	continuity	1824	78	20	2	2	2	1	1	1	0
137	11	seasonal eggs and vuls	1837	78	19	9	2	1	2	1	1	1
95	1	continuity	1865	63	15	3	2	1	2	2	1	1
150	12	seasonal eggs, vuls, AH Rdev	1874	93	12	2	2	2	2	2	2	2
138	11	seasonal eggs and vuls	1884	88	17	3	2	1	1	2	1	1
92	5	seasonal vuls	1888	88	17	3	2	1	0	2	1	1
105	2	PP annual	1890	79	21	22	2	1	2	1	2	2
77	2	PP annual	1895	77	19	9	2	1	2	2	2	2
86*	4	seasonal eggs	1934	85	11	3	2	2	2	2	2	2
139*	11	seasonal eggs and vuls	1971	90	9	2	2	2	2	2	2	2

NWAC-MICE Base Run

Early model runs with seasonal k_{ij} and egg production forcing had better diagnostics.

These were applied together in later models, but still didn't capture declines in Atlantic herring.

- Run 139 low SB productivity

Long-term egg production (Rdev) forcing applied to Atlantic herring in model 12.

- Run 144 high SB productivity

Run num	Model num	Model label	Final SS	N est kij	N low	N high	Equilibrium Analysis					
							SB	AM	SDF	BF	WF	AH
144	12	seasonal eggs, vuls, AH Rdev	1800	93	13	2	2	2	2	2	2	2
6	1	continuity	1824	78	20	2	2	2	1	1	1	0
137	11	seasonal eggs and vuls	1837	78	19	9	2	1	2	1	1	1
95	1	continuity	1865	63	15	3	2	1	2	2	1	1
150	12	seasonal eggs, vuls, AH Rdev	1874	93	12	2	2	2	2	2	2	2
138	11	seasonal eggs and vuls	1884	88	17	3	2	1	1	2	1	1
92	5	seasonal vuls	1888	88	17	3	2	1	0	2	1	1
105	2	PP annual	1890	79	21	22	2	1	2	1	2	2
77	2	PP annual	1895	77	19	9	2	1	2	2	2	2
86*	4	seasonal eggs	1934	85	11	3	2	2	2	2	2	2
139*	11	seasonal eggs and vuls	1971	90	9	2	2	2	2	2	2	2

NWAC-MICE Base Run

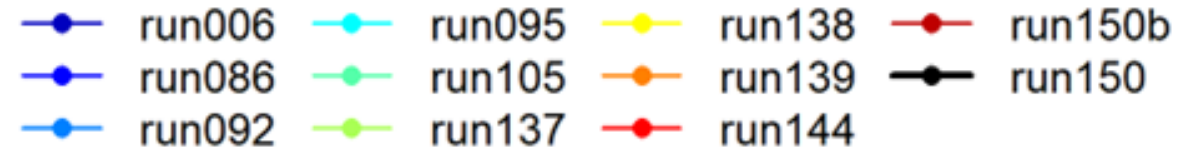
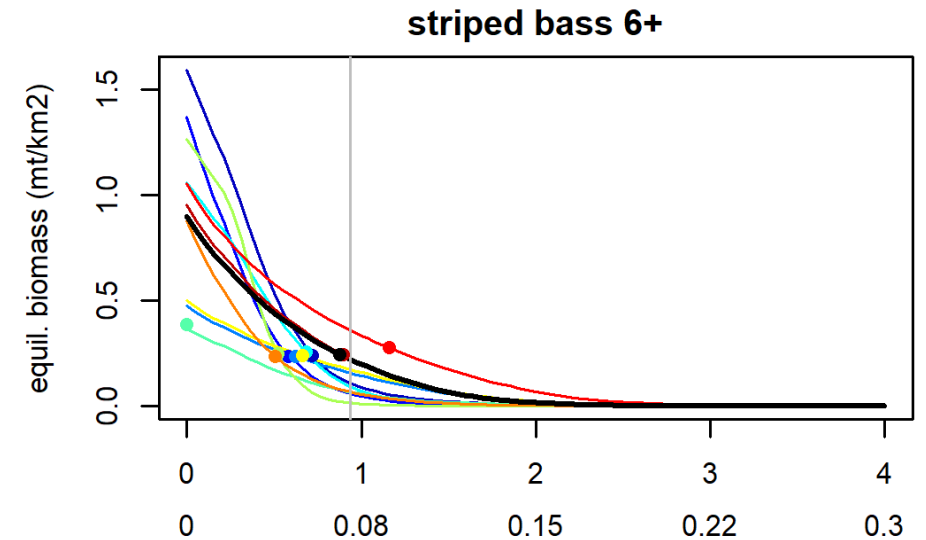
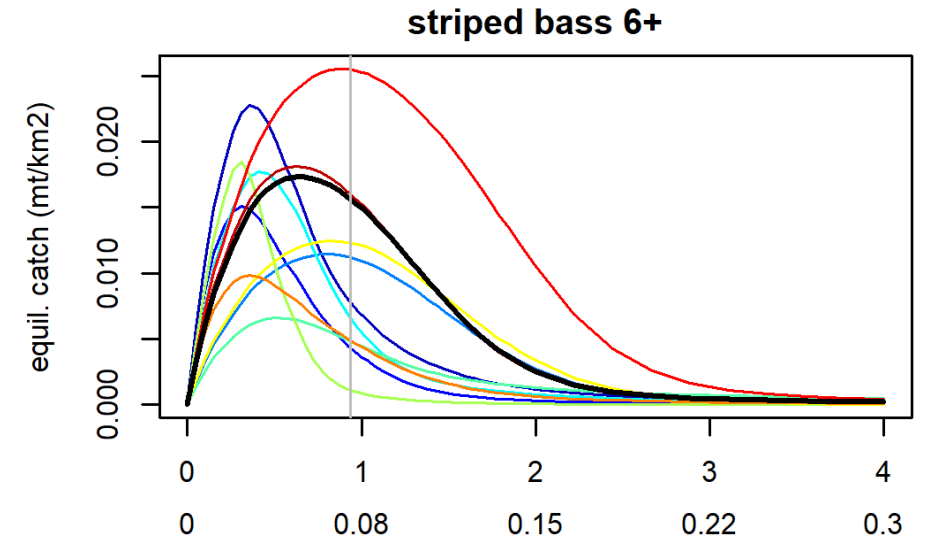
Early model runs with seasonal k_{ij} and egg production forcing had better diagnostics.

These were applied together in later models, but still didn't capture declines in Atlantic herring.

- Run 139 low SB productivity

Long-term egg production (Rdev) forcing applied to Atlantic herring in model 12.

- Run 144 high SB productivity



NWAC-MICE Base Run

Early model runs with seasonal k_{ij} and egg production forcing had better diagnostics.

These were applied together in later models, but still didn't capture declines in Atlantic herring.

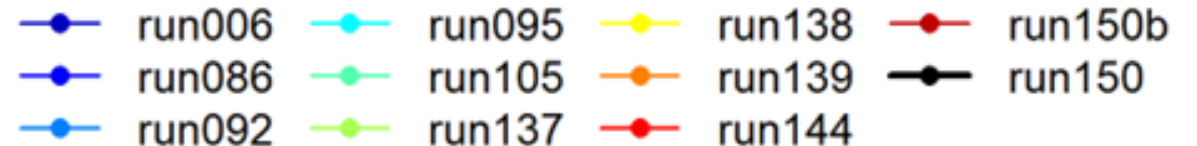
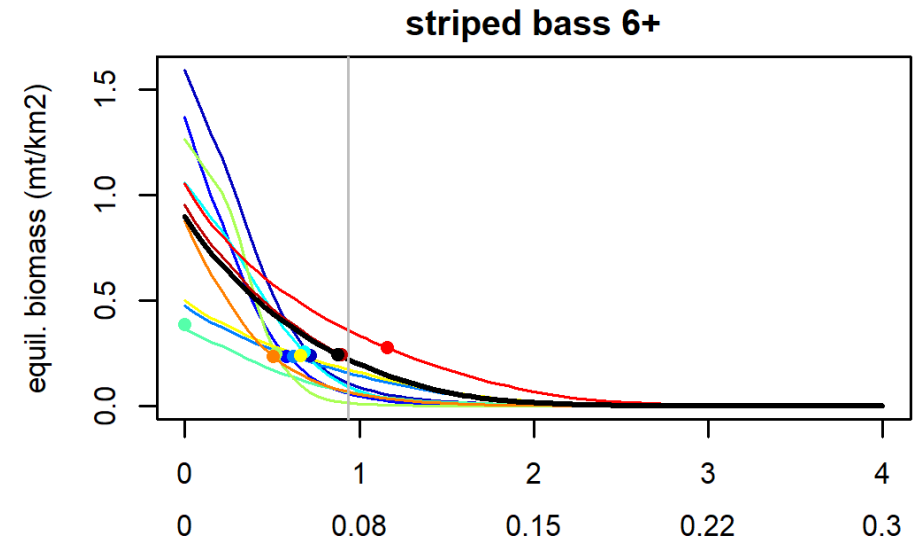
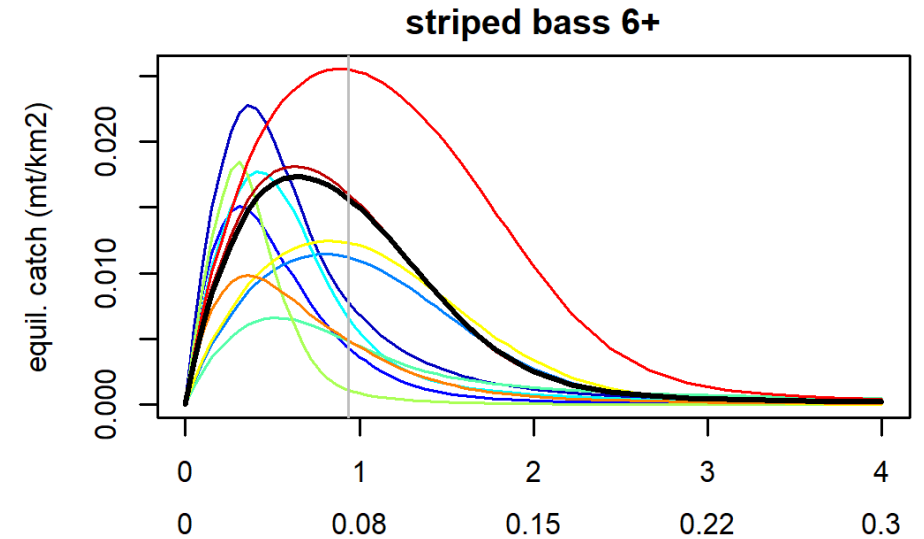
- Run 139 low SB productivity

Long-term egg production (Rdev) forcing applied to Atlantic herring in model 12.

- Run 144 high SB productivity

k_{ij} for spiny dogfish consuming striped bass age 2-5.

- Run 139 $k_{ij} = 3.47$
- Run 144 $k_{ij} = 1.001$



NWAC-MICE Base Run

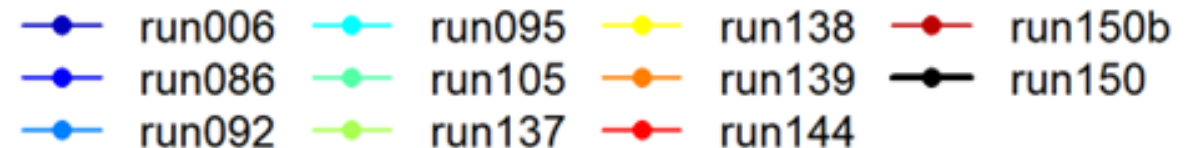
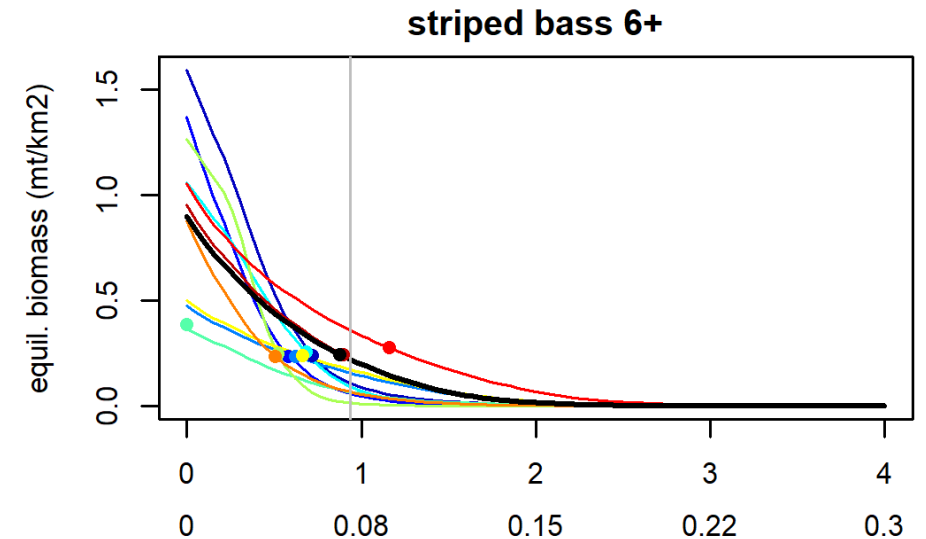
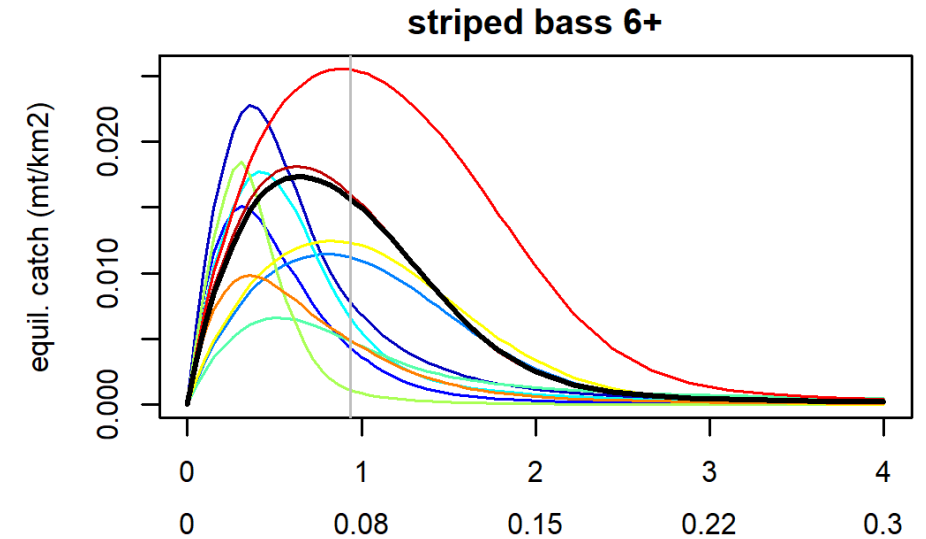
The preferred base run (**150**) is run 144, with $k_{ij} = 1.5$ for spiny dogfish and striped bass age 2-5.

$K_{ij} = 1.5$ selected based on iterative runs aiming for striped bass to approximate B_{target} when fished at F_{target} .

- A prerequisite before running menhaden F simulations?

Baseline M2 is already high, not much scope to increase, thus a low k_{ij} is reasonable.

Run 150 - 5th lowest SS, 93 k_{ij} estimated, and good equilibrium diagnostics.



NWAC-MICE Base Run

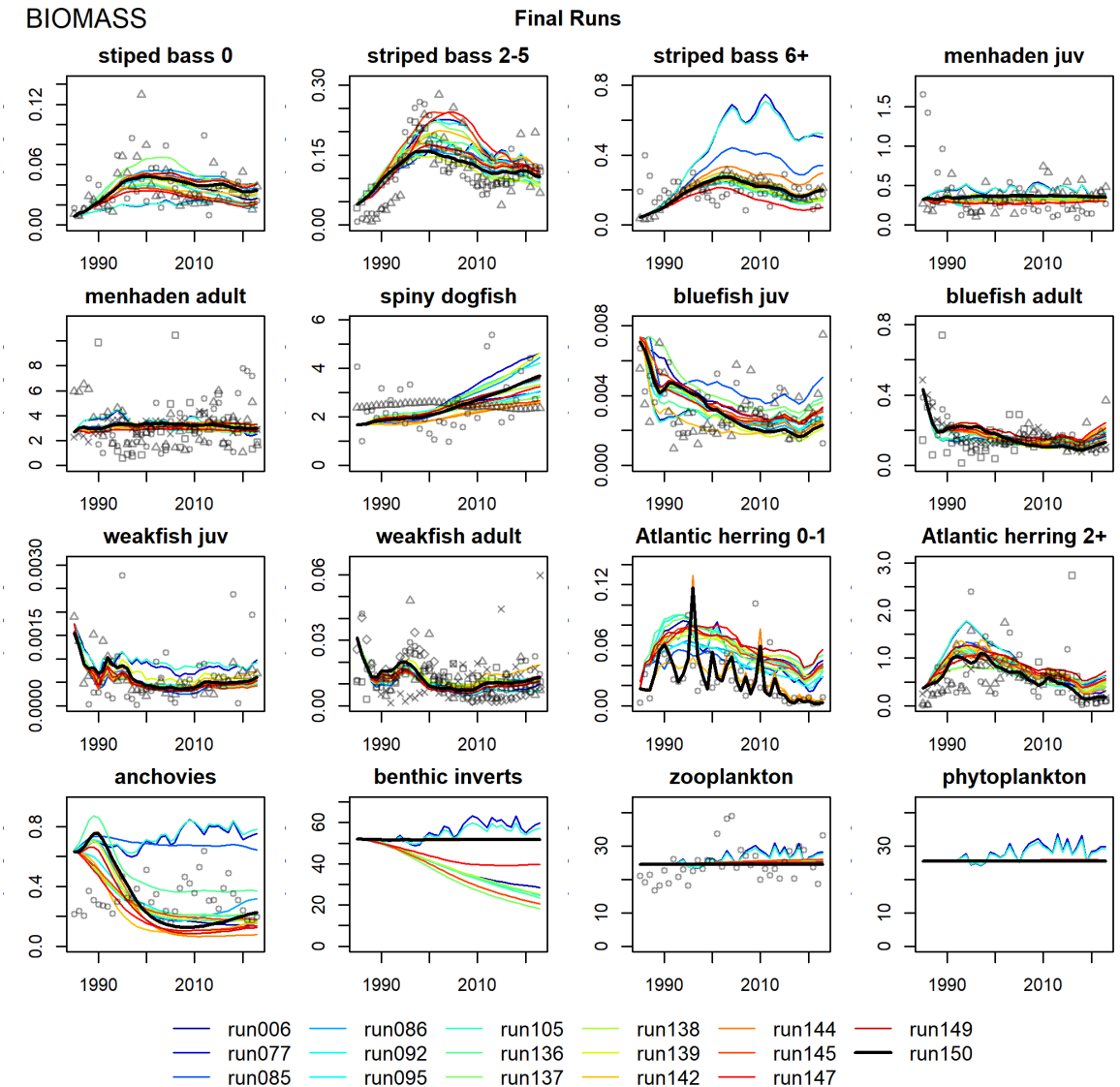
The preferred base run (**150**) is run 144, with $k_{ij} = 1.5$ for spiny dogfish and striped bass age 2-5.

$K_{ij} = 1.5$ selected based on iterative runs aiming for striped bass to approximate B_{target} when fished at F_{target} .

- A prerequisite before running menhaden F simulations?

Baseline M2 is already high, not much scope to increase, thus a low k_{ij} is reasonable.

Run 150 - 5th lowest SS, 93 k_{ij} estimated, and good equilibrium diagnostics.



NWACS-MICE Summary

Model updates are considered improvements and address key uncertainties from the previous ERP assessment.

- Inputs based on most recent stock assessments
- Lower M and B for menhaden resulted in higher EE
- Diet data updated and reanalyzed
- Seasonal and long-term forcing functions included
- Exhaustive calibration effort
- Improved efficiency and reproducibility

Core challenges of ecosystem modeling remain.

- Structural uncertainties, misspecification
- Tradeoffs in model fits
- Infinite parameter combinations
- Prone to local minima
- Model inference and diagnostics

NWACS-MICE Summary

Spiny dogfish were a dominant predator in the model.

- Biomass from recent assessment is ~3x higher than previous.
- Higher diet proportions for menhaden and striped bass based on updated reanalysis of diet data
- K_{ij} for spiny dogfish prey were usually estimated to be high, resulting in large biomass gains and overestimation of catch.
 - The model wanted to use spiny dogfish as a lever to drive down herring biomass.
 - High k_{ij} had consequences for striped bass productivity.
 - Difficult to fit spiny dogfish, striped bass, and Atlantic herring simultaneously