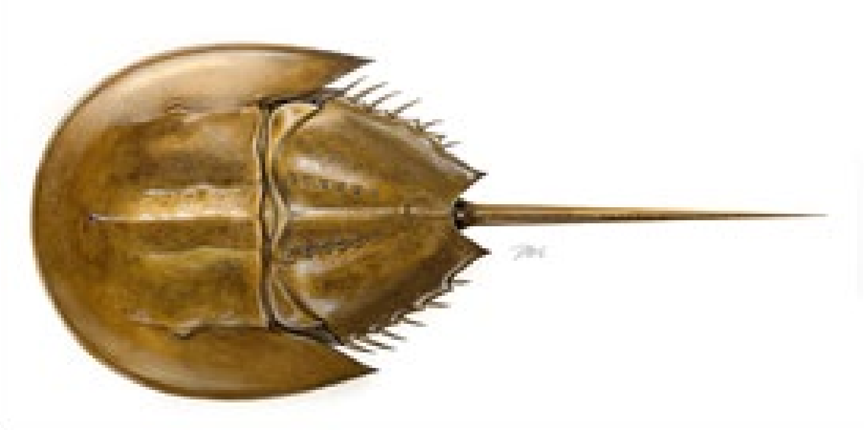
2024 Stock Assessment Update

Management Board

April 30, 2024



HSC Stock Assessment Schedule

- 2019: Coastwide benchmark stock assessment
- 2022: Delaware Bay ARM Revision, Addendum VIII
  - Annual updates of the ARM Framework
- 2024: Stock assessment update
- *2029: Coastwide benchmark stock assessment*

Committee Membership

SAS

- Katherine Rodrigue (RI, Chair)
- Derek Perry (MA)
- Linda Barry (NJ)
- Margaret Conroy (DE)
- Jeffrey Dobbs (NC)
- Daniel Sasson (SC)
- John Sweka (USFWS)
- Kristen Anstead, Caitlin Starks (ASMFC)

With additional support from:

- Josh Newhard (USFWS)

TC

- Katherine Rodrigue (RI)
- Derek Perry (MA)
- Kelli Mosca (CT)
- Jennifer Lander (NY)
- Joanna Burger (Rutgers)
- Samantha MacQuesten (NJ)
- Jordan Zimmerman (DE)
- Steve Doctor (MD)
- Ingrid Braun (PRFC)
- Ethan Simpson (VMRC)
- Jeffrey Dobbs (NC)
- Jeff Brunson (SC)
- Eddie Leonard (GA)
- Claire Crowley (FL)
- Chris Wright (NOAA)
- Caitlin Starks (ASMFC)

Bait Landings

- ACCSP data validation for 1998-2022

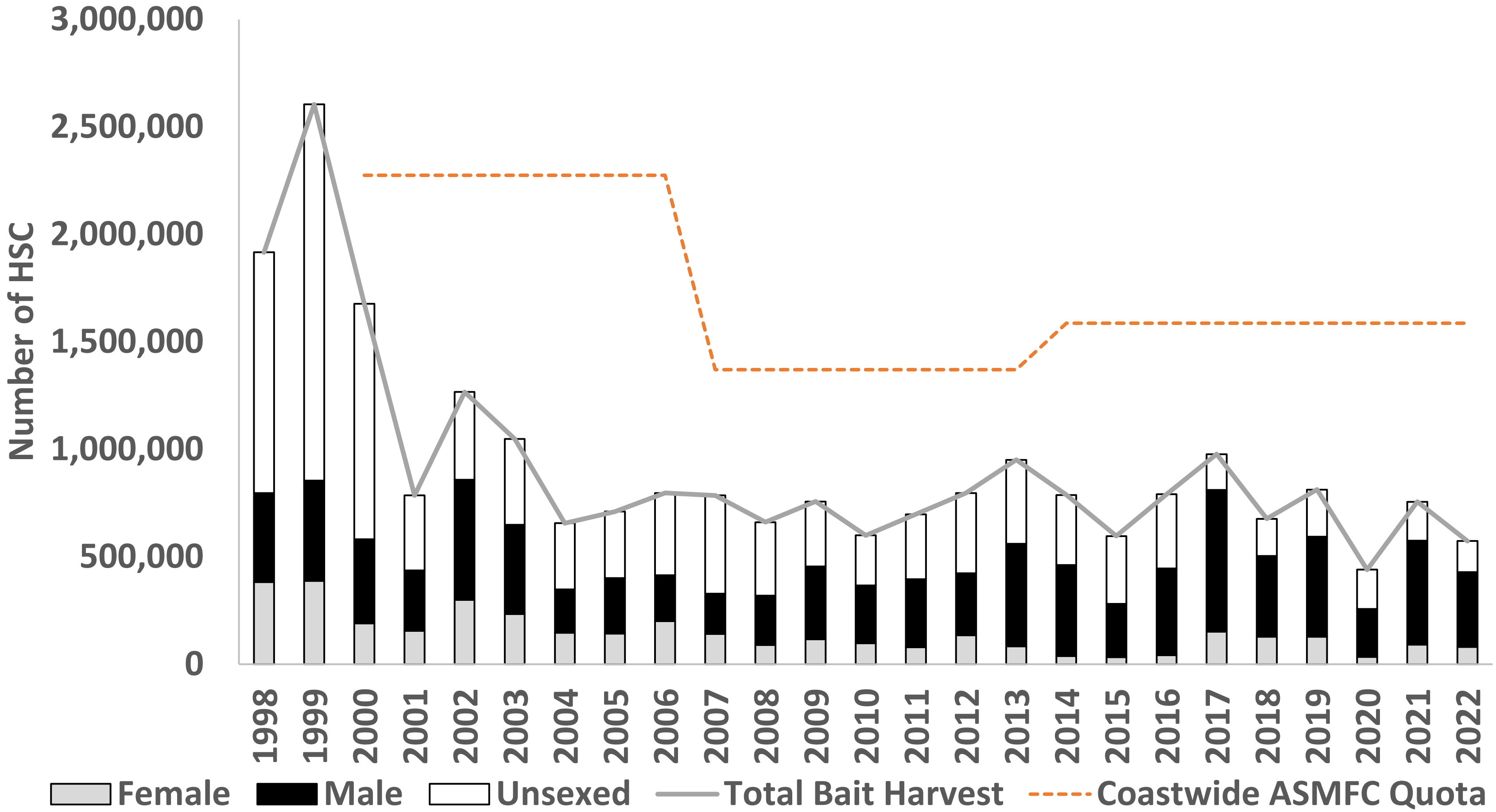
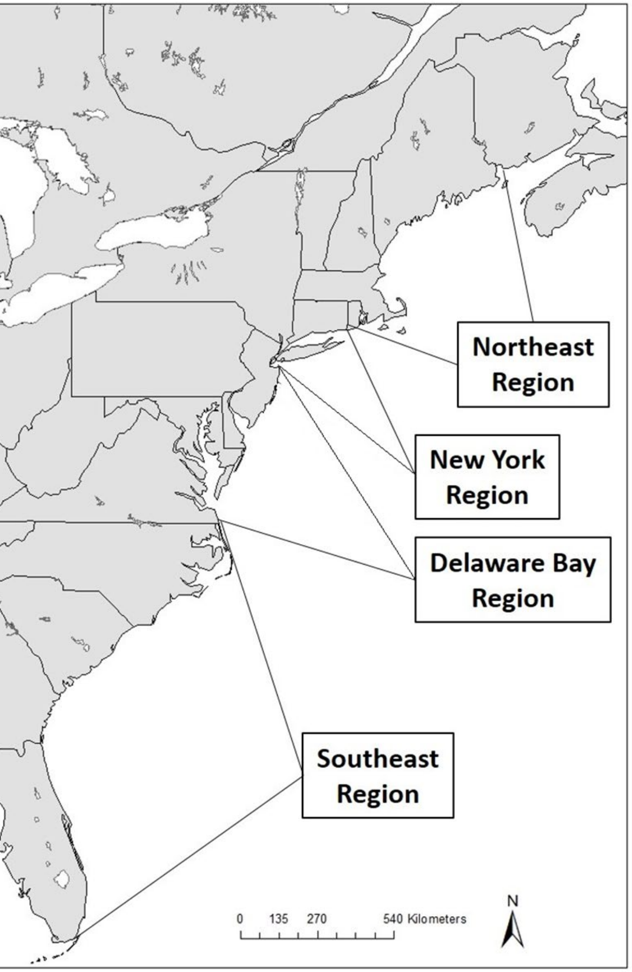
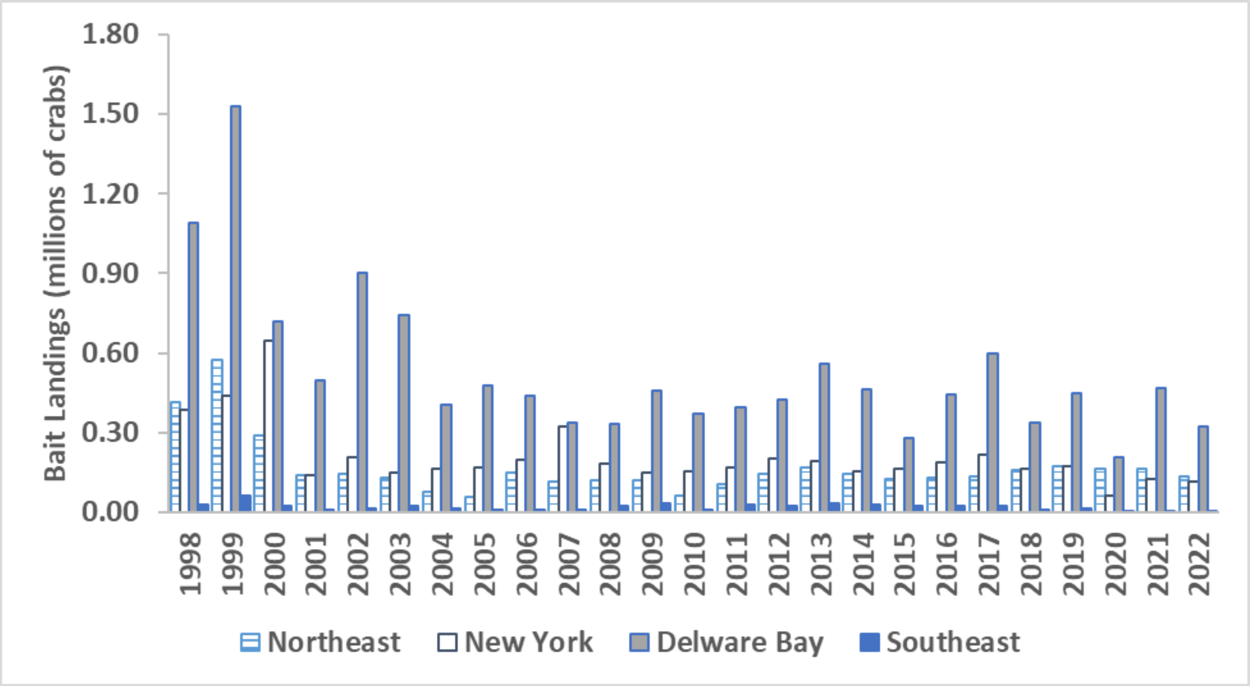


Figure 1. Coastwide horseshoe crab bait landings, 1998-2022, by sex where available. Coastwide ASMFC quota indicated in orange. Source: ACCSP.

Bait Landings





Biomedical Harvest & Mortality

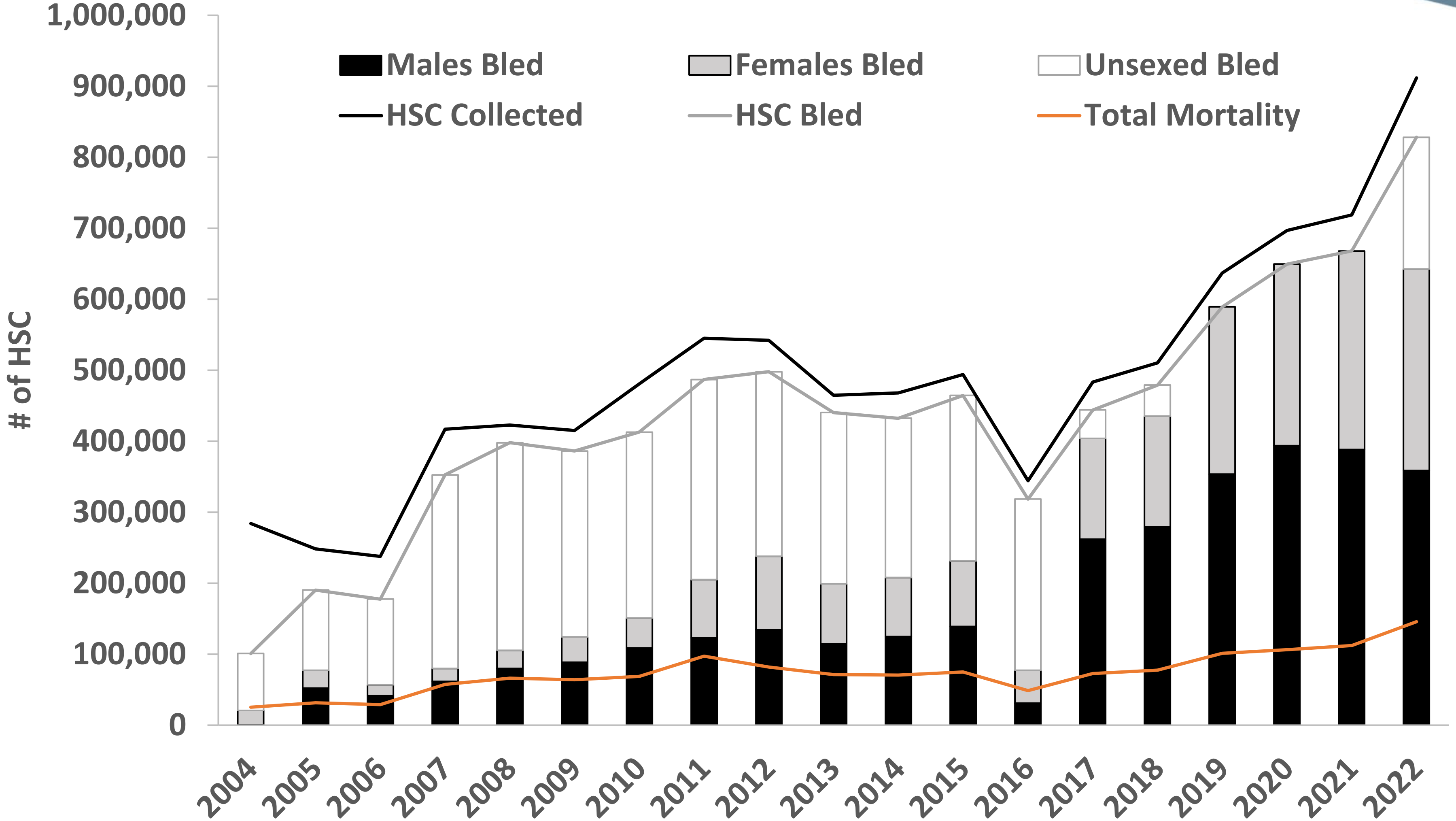


Figure 5. Coastwide number of horseshoe crabs collected and bled by the biomedical industry and the total resulting mortality (observed mortality during the bleeding process plus 15% of those bled and released alive).

Dead Discards

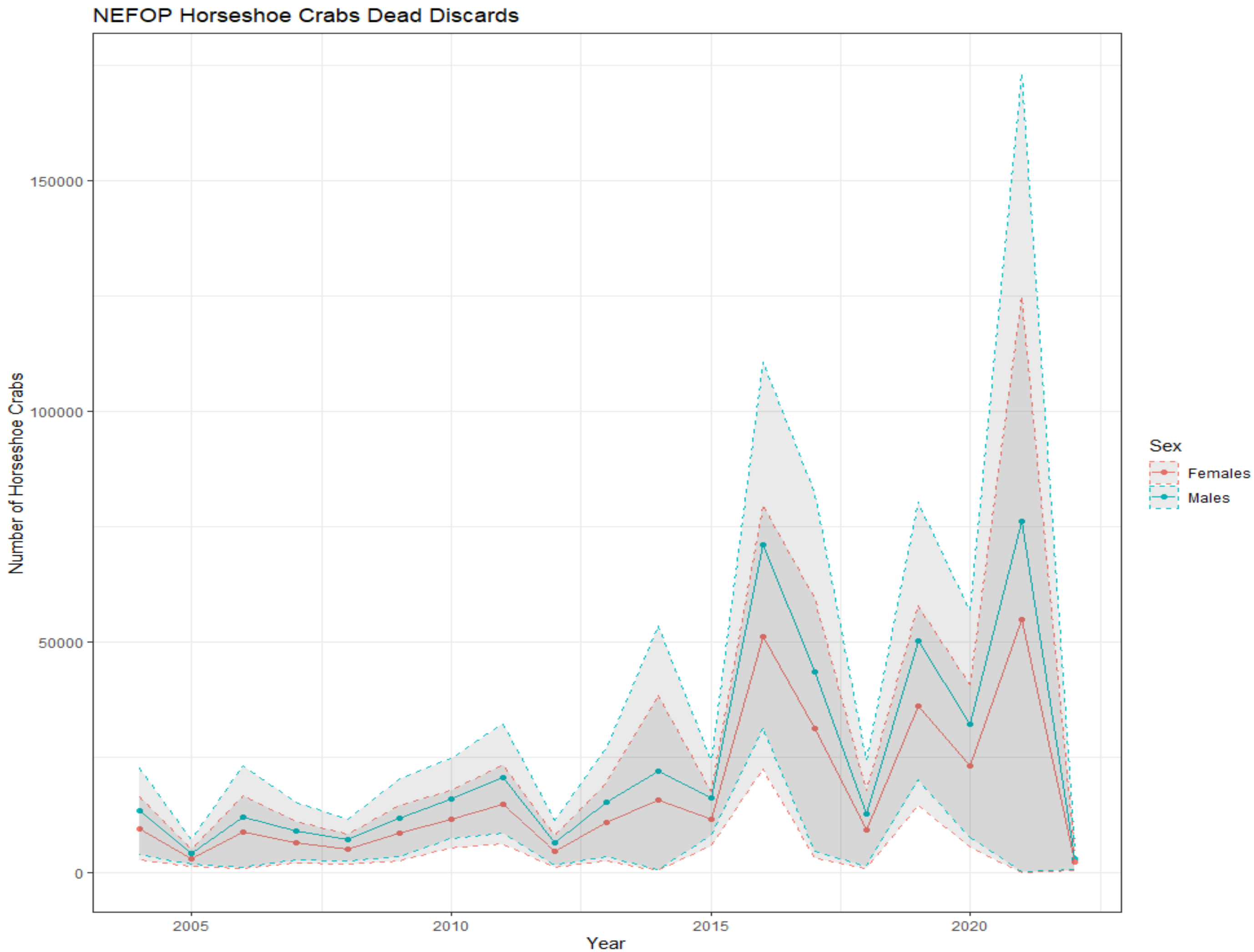


Figure 6. Estimated number of dead horseshoe crabs discarded in the Delaware Bay region from commercial fisheries, 2004-2022, by sex with 95% confidence intervals. Source: NEFOP.

Index Calculation Changes

- ASMFC 2019: SAS explored nominal, standardized indices
  - Delta distribution for the mean and variance used for all indices due to high prop. of zeros
- ASMFC 2022 Peer review: fixed station surveys should be standardized
- This update: fixed station surveys were standardized, all others delta mean

NE Region Indices

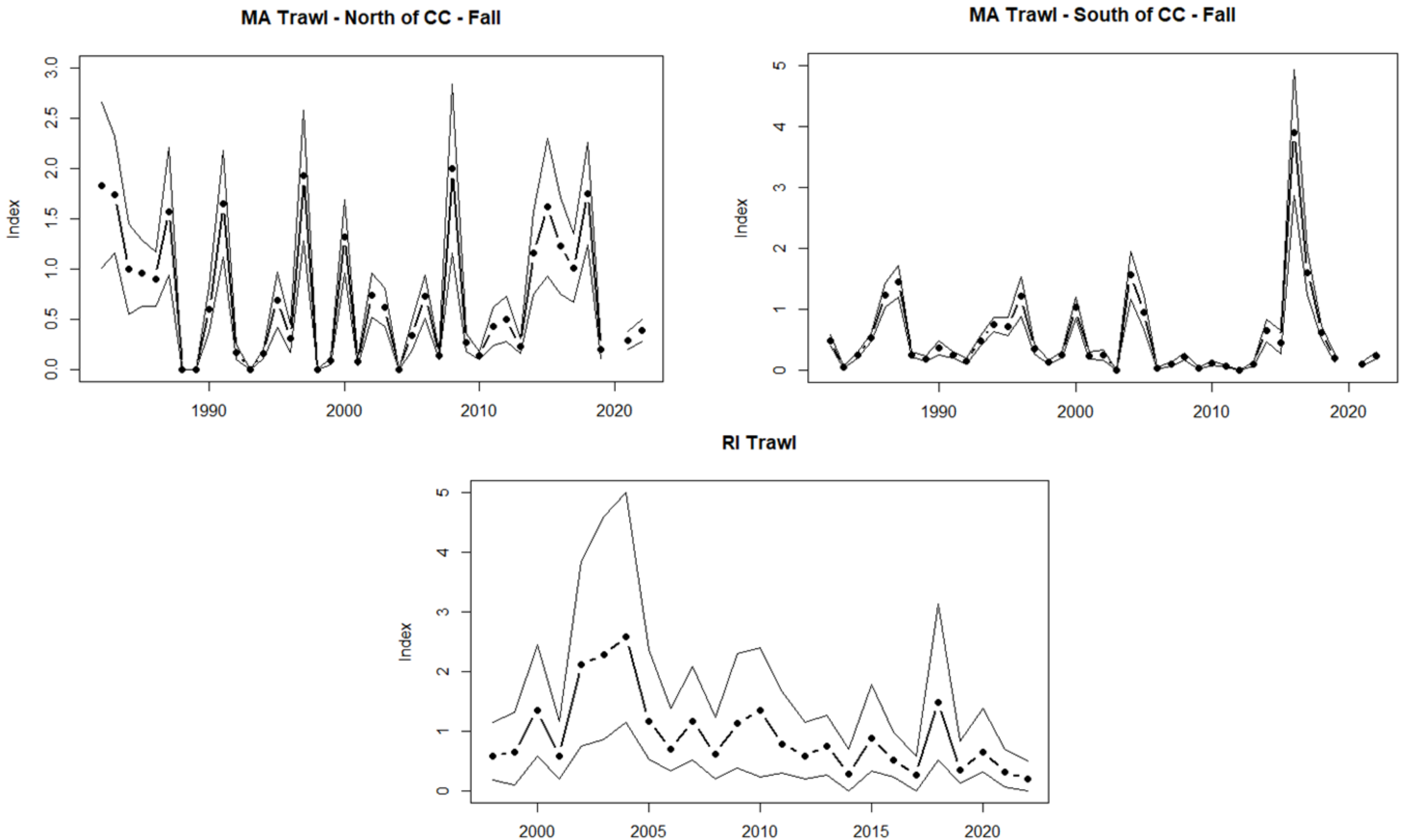


Figure 7. Indices of relative abundance of horseshoe crabs developed from the Massachusetts Trawl Survey for north and south of Cape Cod (CC) in the fall months and the Rhode Island Monthly Trawl Survey with 95% confidence intervals.

NE Region Indices

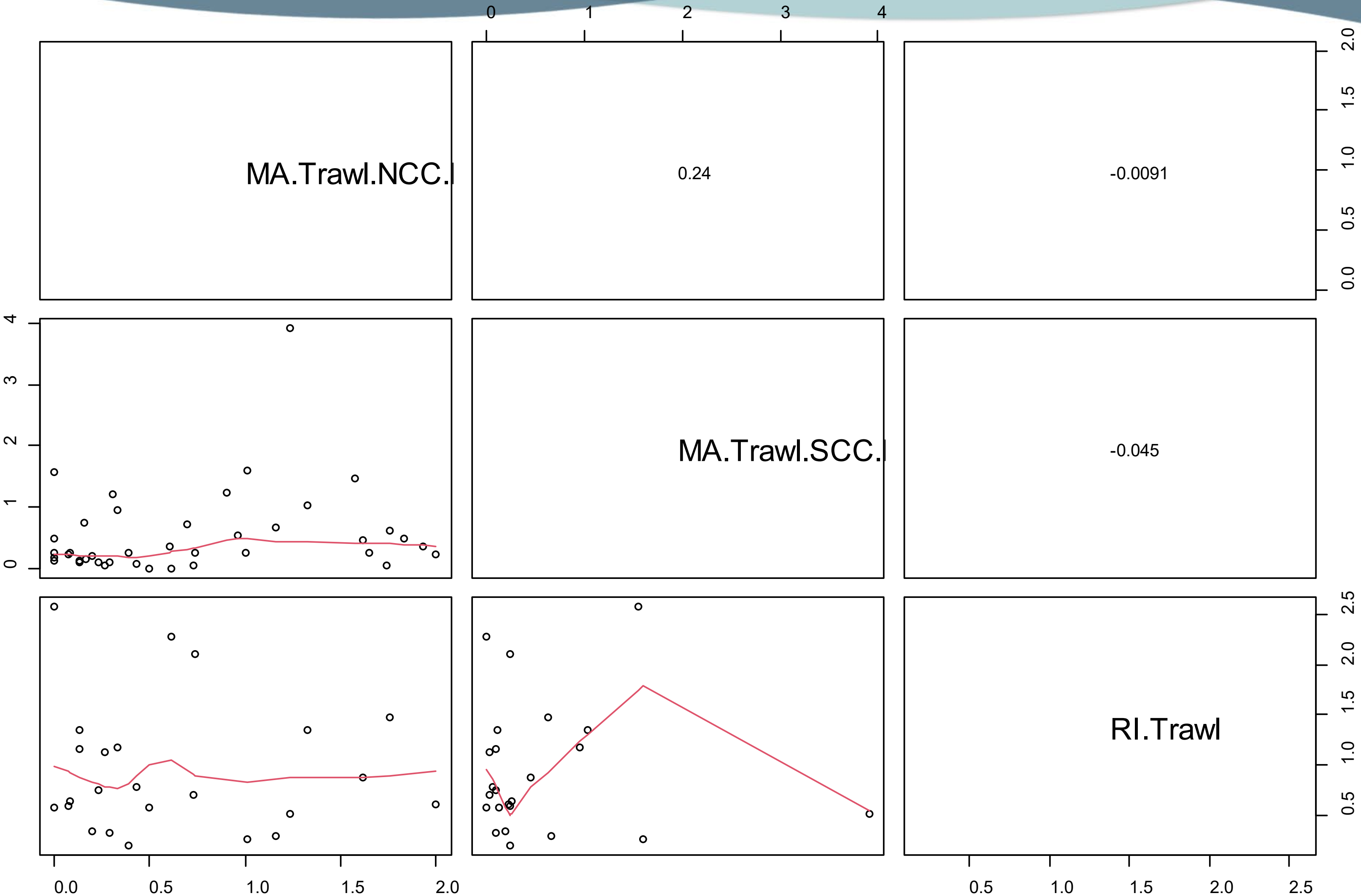


Figure 15. Correlation coefficients and scatter plots for the horseshoe crab abundance indices in the Northeast Region. None of the correlations were significant (P<0.05).

NY Region Indices

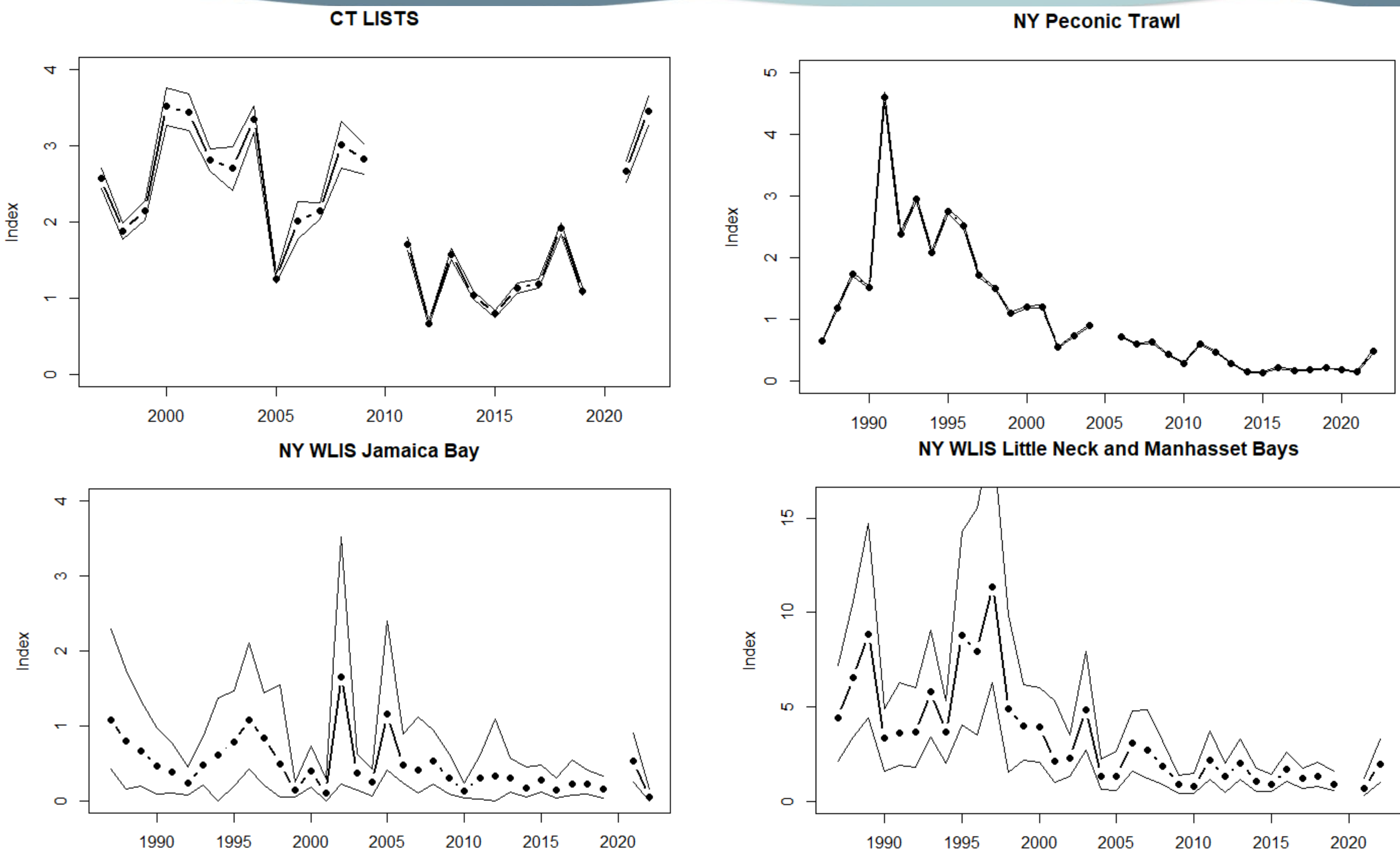


Figure 8. Indices of relative abundance of horseshoe crabs developed from the Connecticut Long Island Sound Trawl (CT LISTS), New York Peconic Bay Trawl, and New York Western Long Island Sound (WLIS) Surveys with 95% confidence intervals.

NY Region Indices

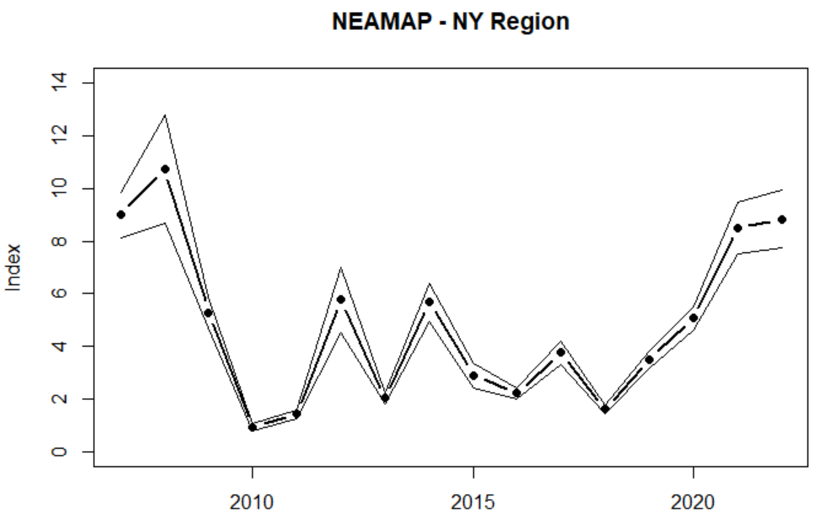


Figure 9. Indices of relative abundance of horseshoe crabs developed from the Northeast Area Monitoring and Assessment Program (NEAMAP) and Maryland Coastal Bays Surveys with 95% confidence intervals.

NY Region Indices

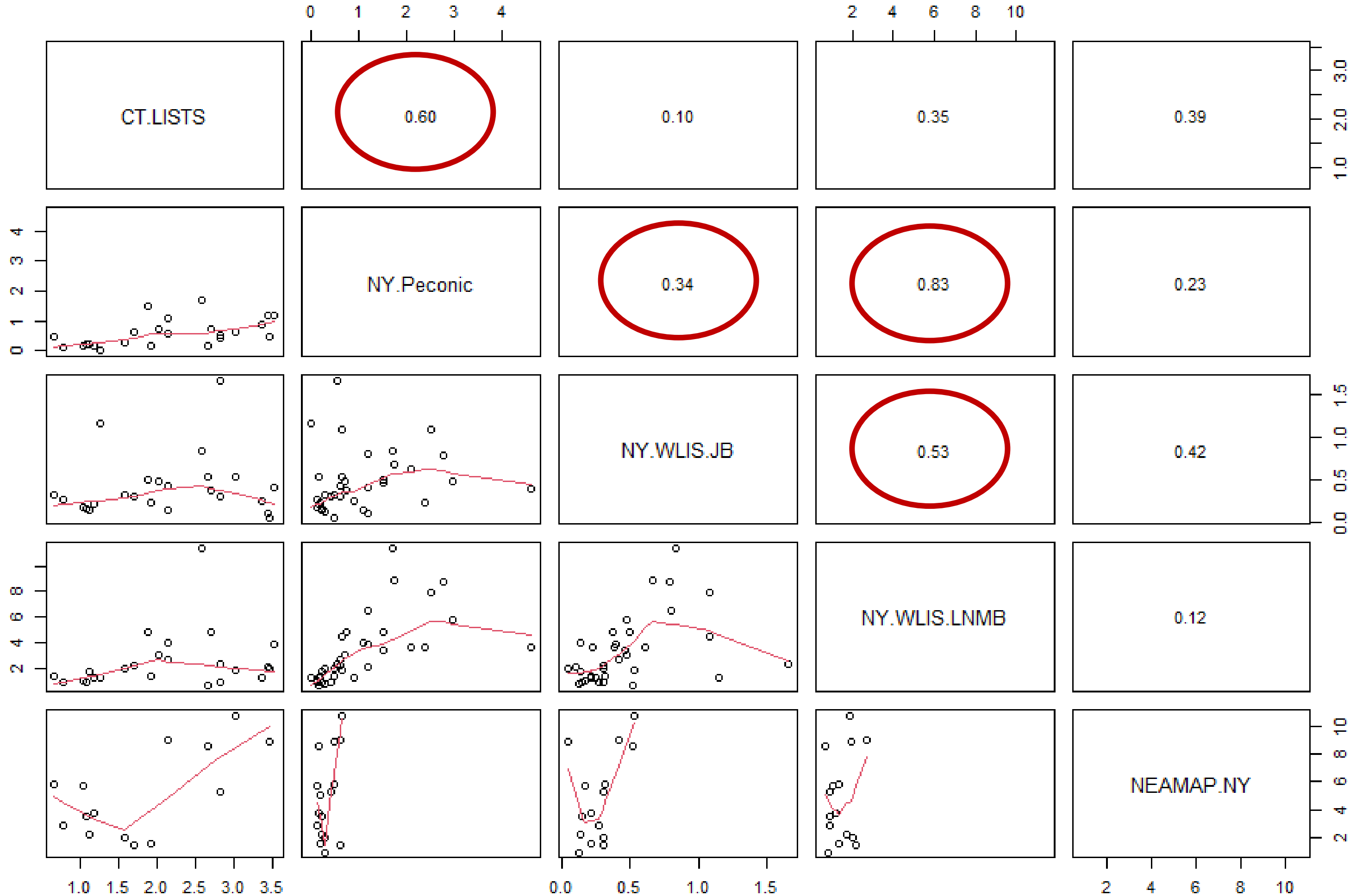


Figure 16. Correlation coefficients and scatter plots for the horseshoe crab abundance indices in the New York Region. Significant correlations (P<0.05) are circled in red.

DB Region Indices

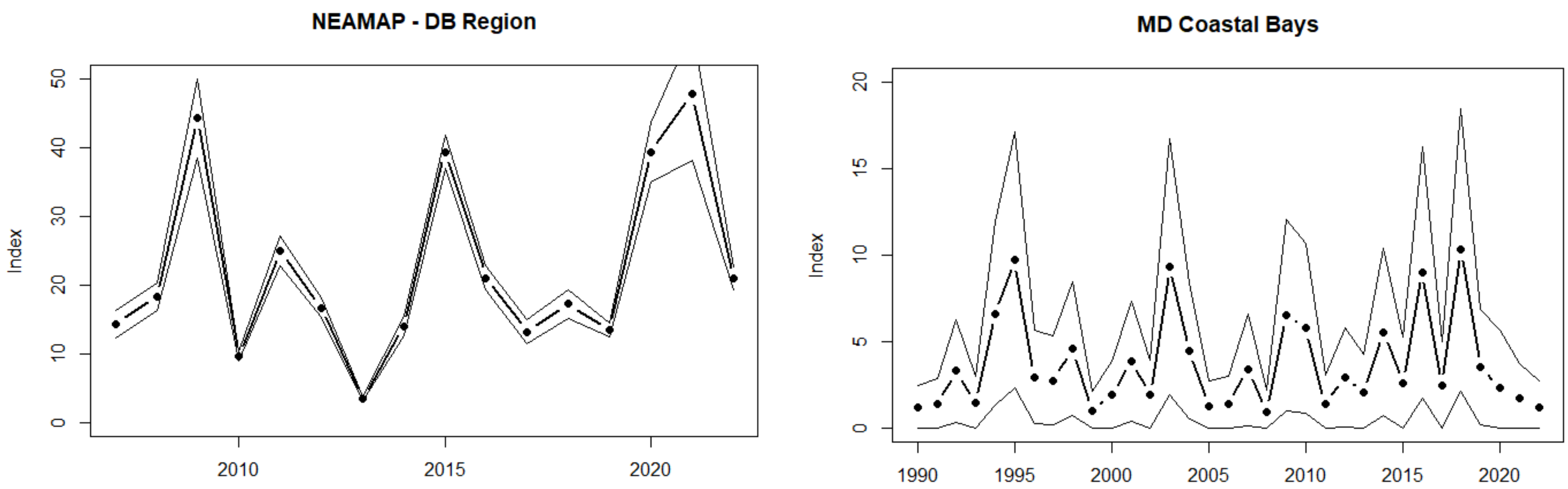


Figure 9. Indices of relative abundance of horseshoe crabs developed from the Northeast Area Monitoring and Assessment Program (NEAMAP) and Maryland Coastal Bays Surveys with 95% confidence intervals.

DB Region Indices

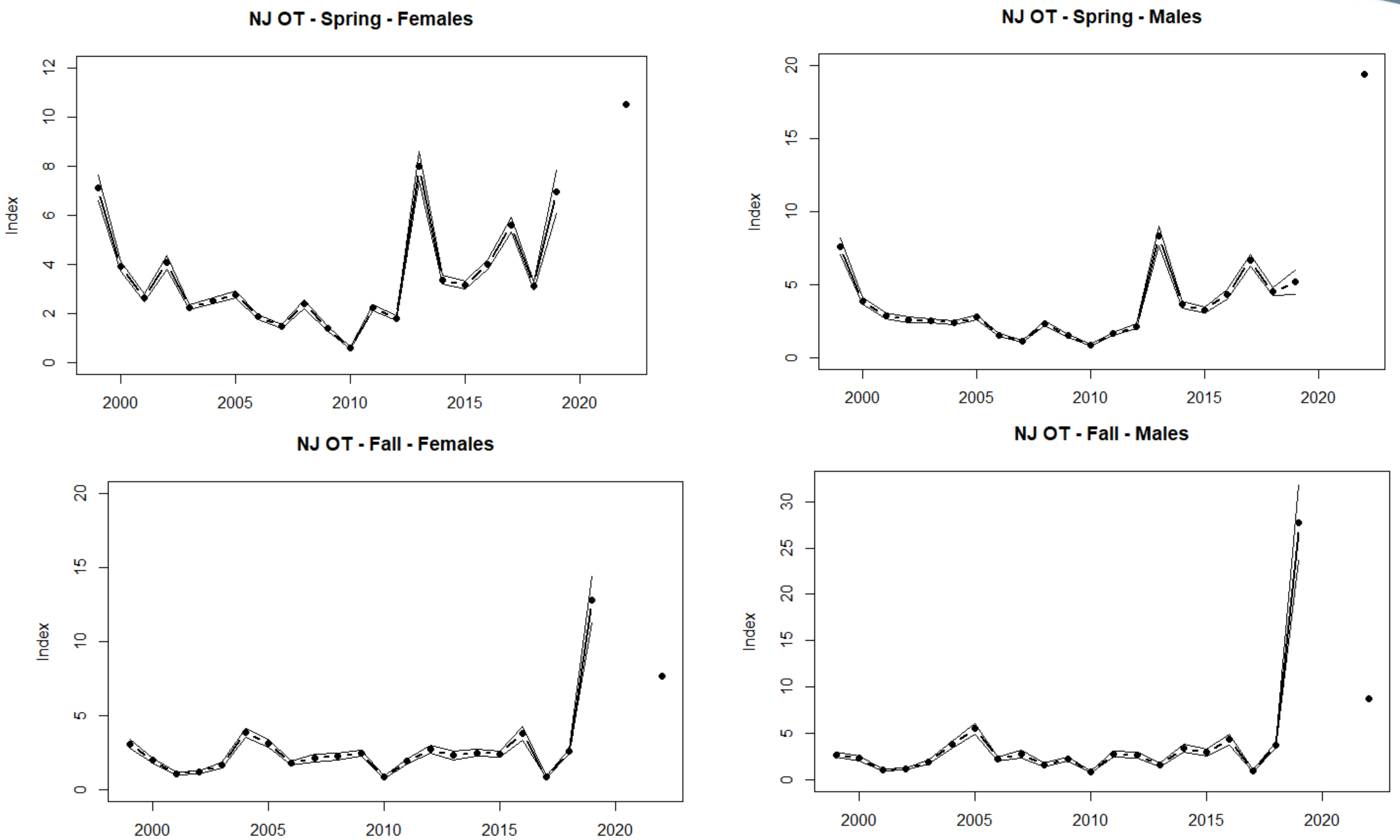


Figure 10. Indices of relative abundance of horseshoe crabs developed from the New Jersey Ocean Trawl (NJ OT) Survey by sex and season with 95% confidence intervals.

DB Region Indices

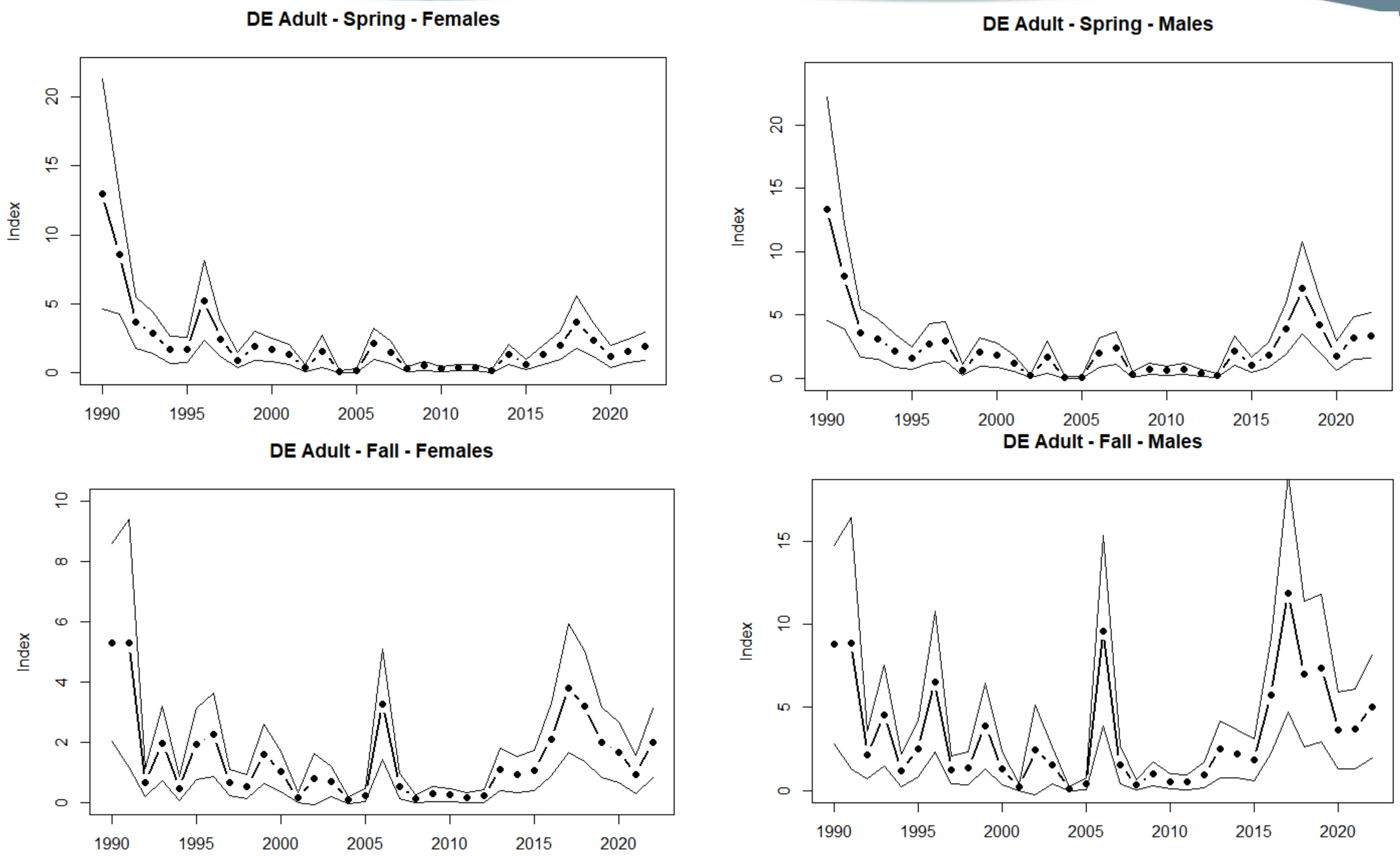


Figure 11. Indices of relative abundance of horseshoe crabs developed from the Delaware 30' Adult Trawl Survey by sex and season with 95% confidence intervals.

DB Region Indices

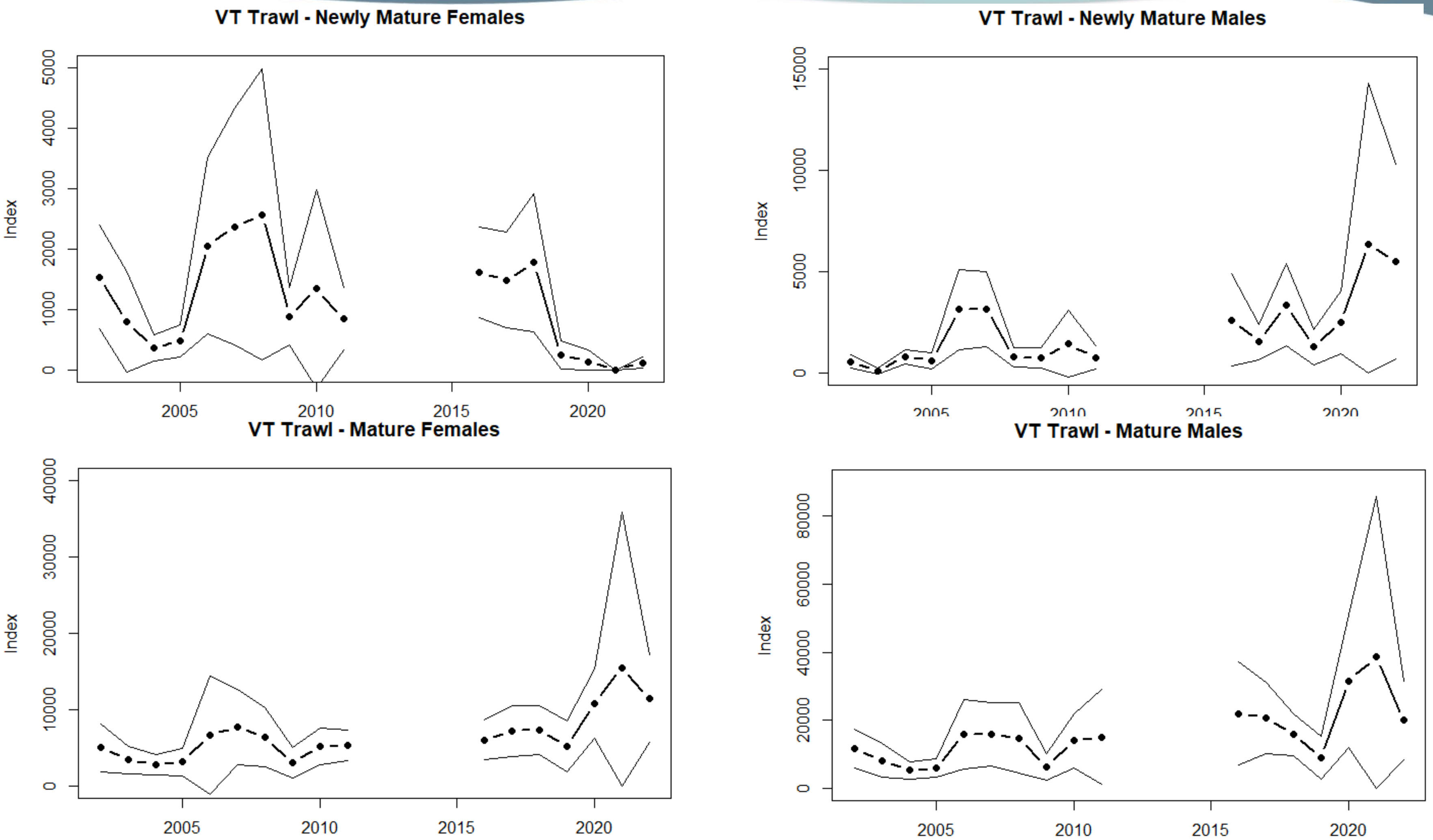


Figure 12. Indices of relative abundance of horseshoe crabs developed from the Virginia Tech Trawl Survey by sex and maturity stage with 95% confidence intervals.

DB Region Indices

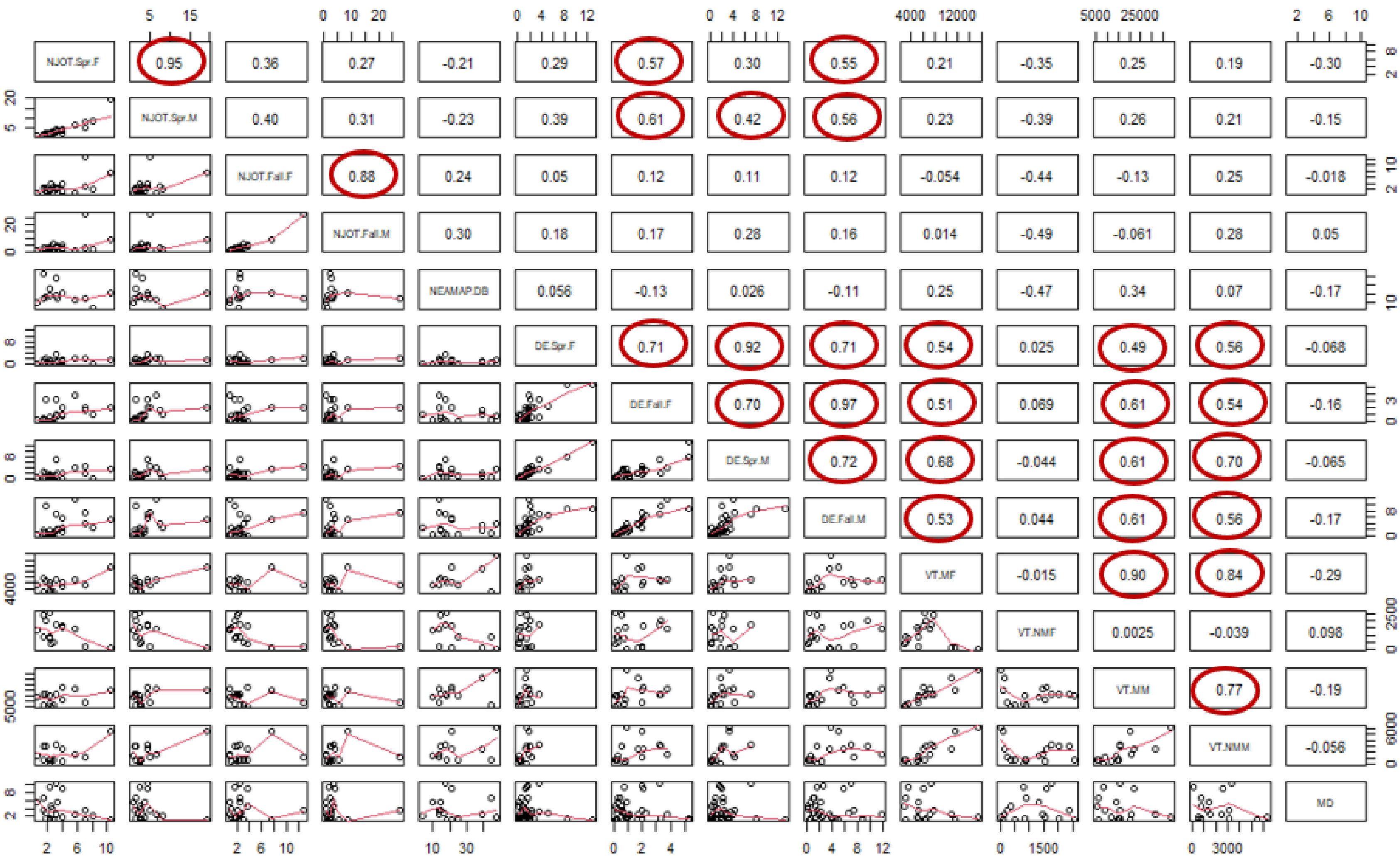


Figure 17. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the Delaware Bay Region. Significant correlations (*P*<0.05) are circled in red.

DB Region Indices

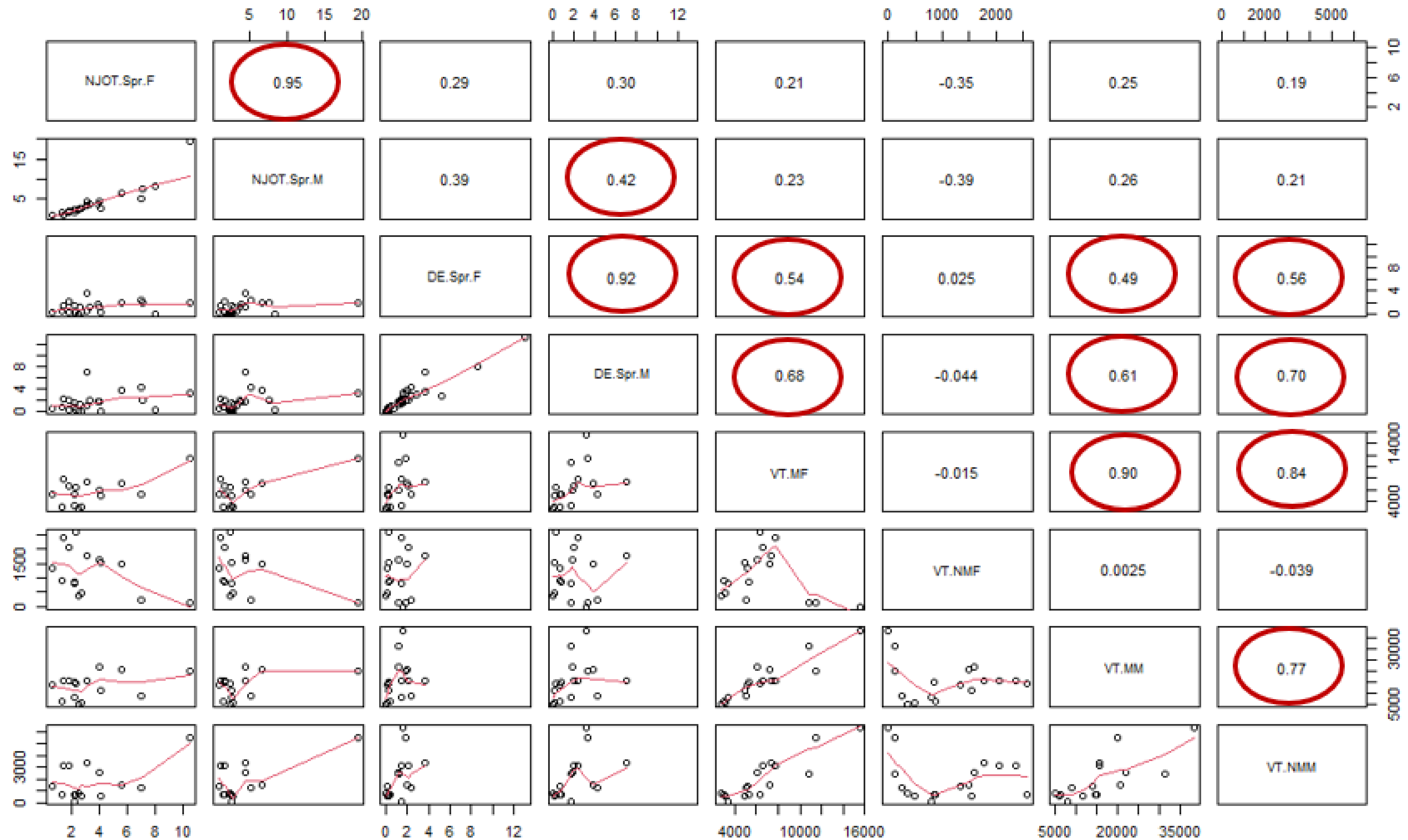


Figure 18. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the Delaware Bay Region used in the ARM Framework, 2003-2022, where the Virginia Tech Trawl Survey has been lagged forward one year as it is in the CMSA. Significant correlations (P<0.05) are circled in red.

SE Region Indices

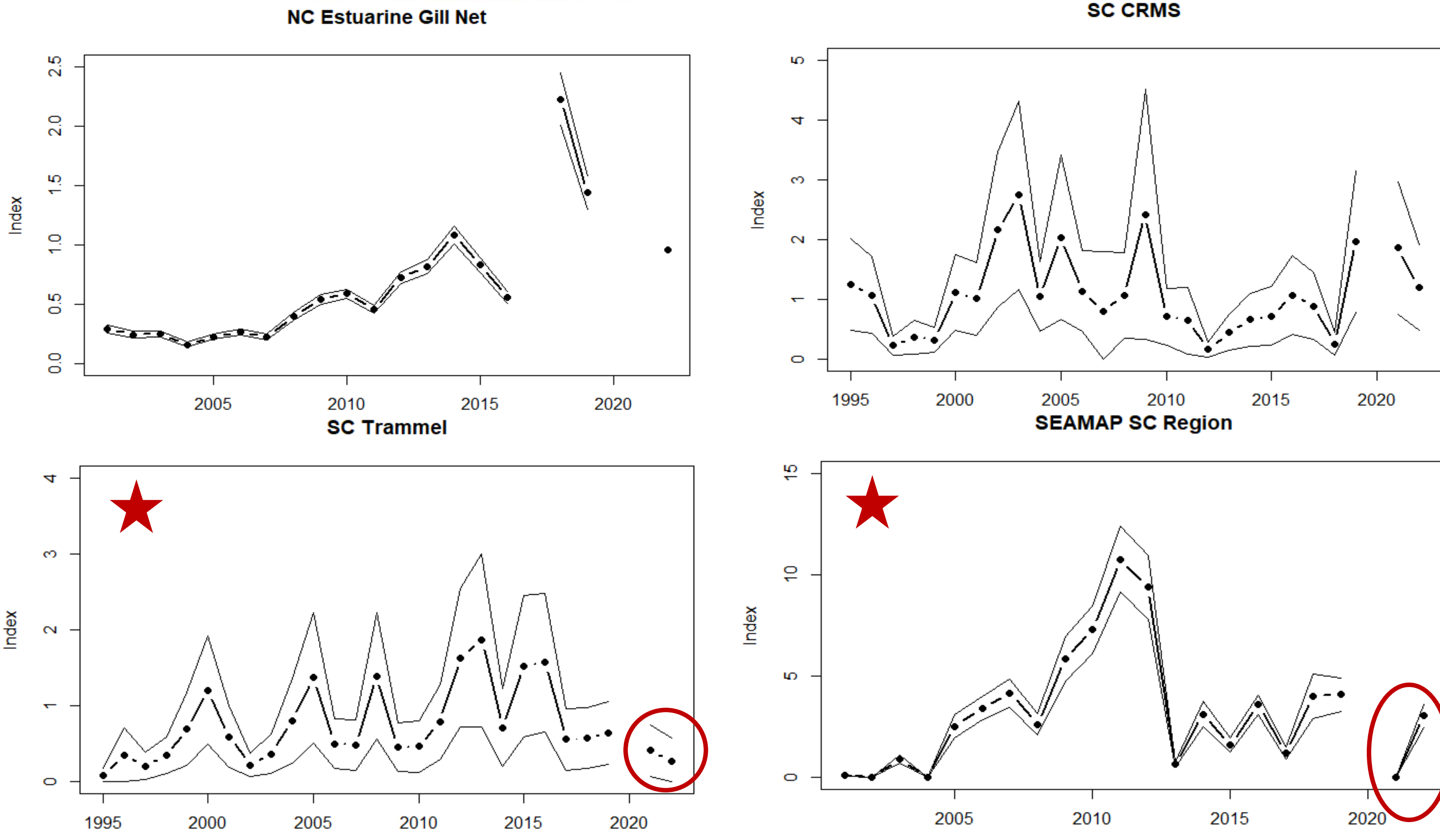
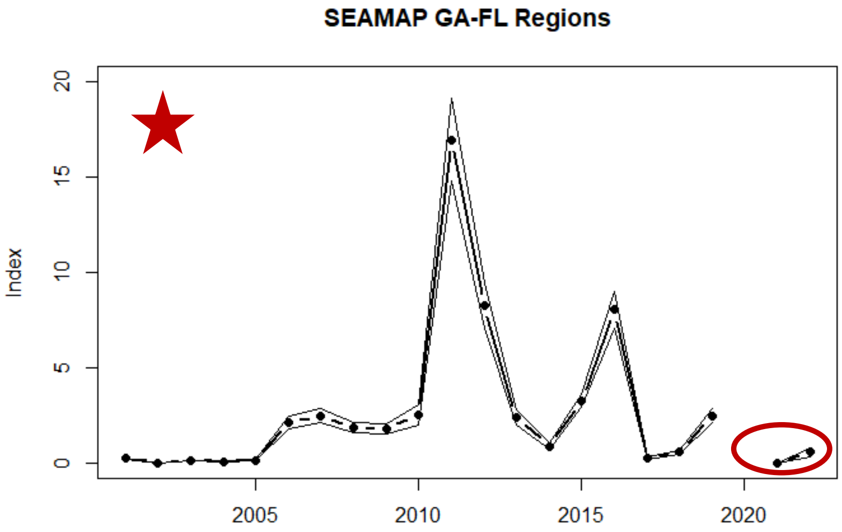


Figure 13. Indices of relative abundance of horseshoe crabs developed from the North Carolina Estuarine Gill Net, South Carolina Crustacean Research and Monitoring (CRMS; recently renamed as Estuarine Trawl Survey), South Carolina Trammel, and Southeast Area Monitoring and Assessment Program (SEAMAP) Surveys with 95% confidence intervals. Both the SC Trammel and SEAMAP had reduced sampling in the strata used in the index in 2021-2022 and therefore those trends should be interpreted cautiously.

SE Region Indices



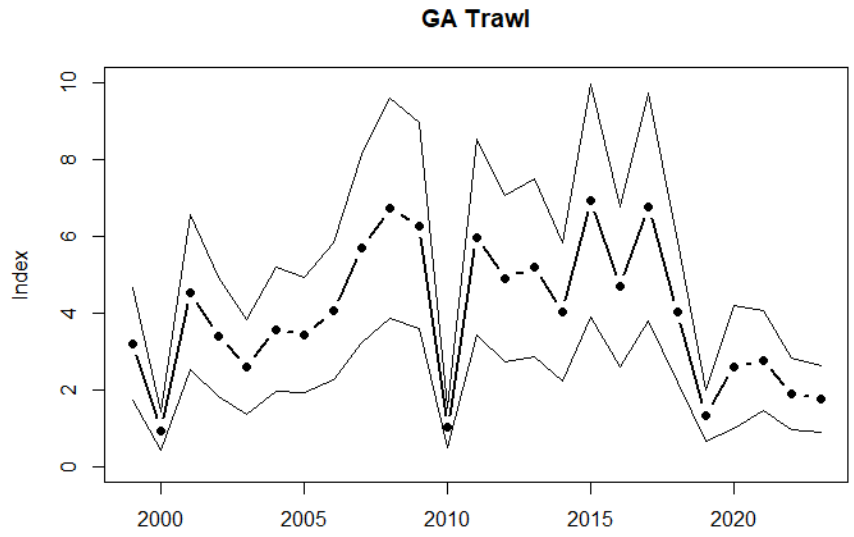


Figure 14. Indices of relative abundance of horseshoe crabs developed from the Southeast Area Monitoring and Assessment Program (SEAMAP) and Georgia Ecological Monitoring Trawl Surveys with 95% confidence intervals. SEAMAP had reduced sampling in the strata used in the index in 2021-2022 and therefore those trends should be interpreted cautiously.

SE Region Indices

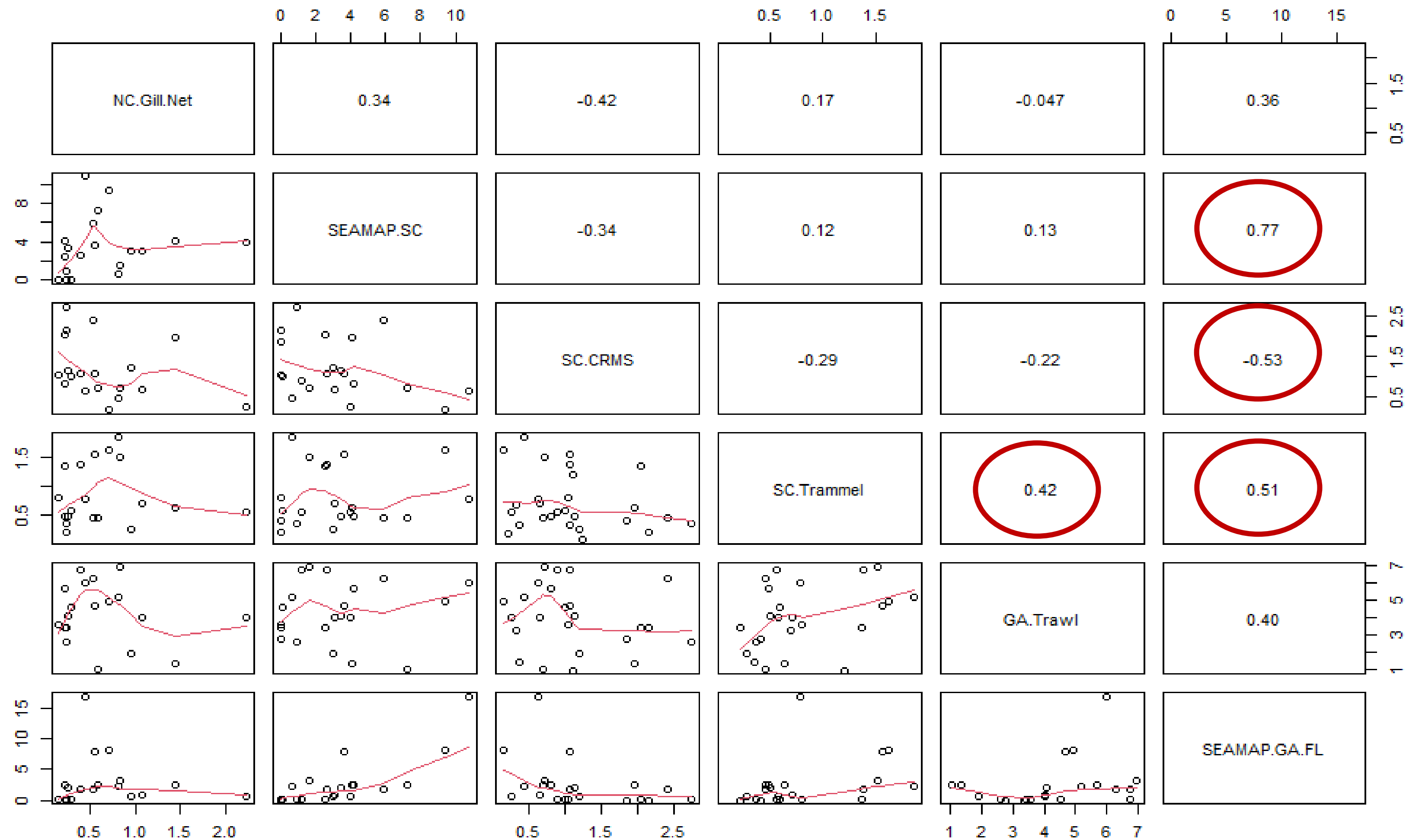


Figure 19. Correlation coefficients and scatter plots for the horseshoe crab abundance indices in the Southeast Region. Significant correlations (P<0.05) are circled in red.

Tagging Data and Analysis

- US FWS tagging database
- Regional recapture rates
- Regional survival estimates from mark-recapture analysis
- Regions different from the management regions
  - Northeast (MA, NH, RI, CT)
  - Coastal NY-NJ
  - Delaware Bay
  - Coastal DE-VA
  - Southeast (SC, GA, FL Atlantic coast)
  - Other regions not included here: Chesapeake Bay and Gulf of Mexico

Mark-Recapture Analysis

- Survival is "apparent survival"
  - Model cannot distinguish between emigration and mortality
- Decreased survival, increased error may be due to reduced tagging/recapture effort in recent years

Region	2019 Benchmark		2024 Update	
	Survival Rate (CI)	SE	Survival Rate (CI)	SE
Northeast	67% (66 - 68%)	0.006	63% (51 - 73%)	0.057
Coastal NY-NJ	62% (59 - 65%)	0.016	63% (46 - 76%)	0.079
Delaware Bay	76% (73 - 78%)	0.014	67% (48 - 81%)	0.087
Coastal DE-VA	71% (69 - 73%)	0.012	60% (40 - 74%)	0.100
Southeast	63% (55 - 69%)	0.035	41% (17 - 62%)	0.129

Table 10. Regional apparent annual survival rates and associated 95% confidence intervals (CI) and standard errors (SE), averaged among years 2009-2022.

Mark-Recapture Analysis

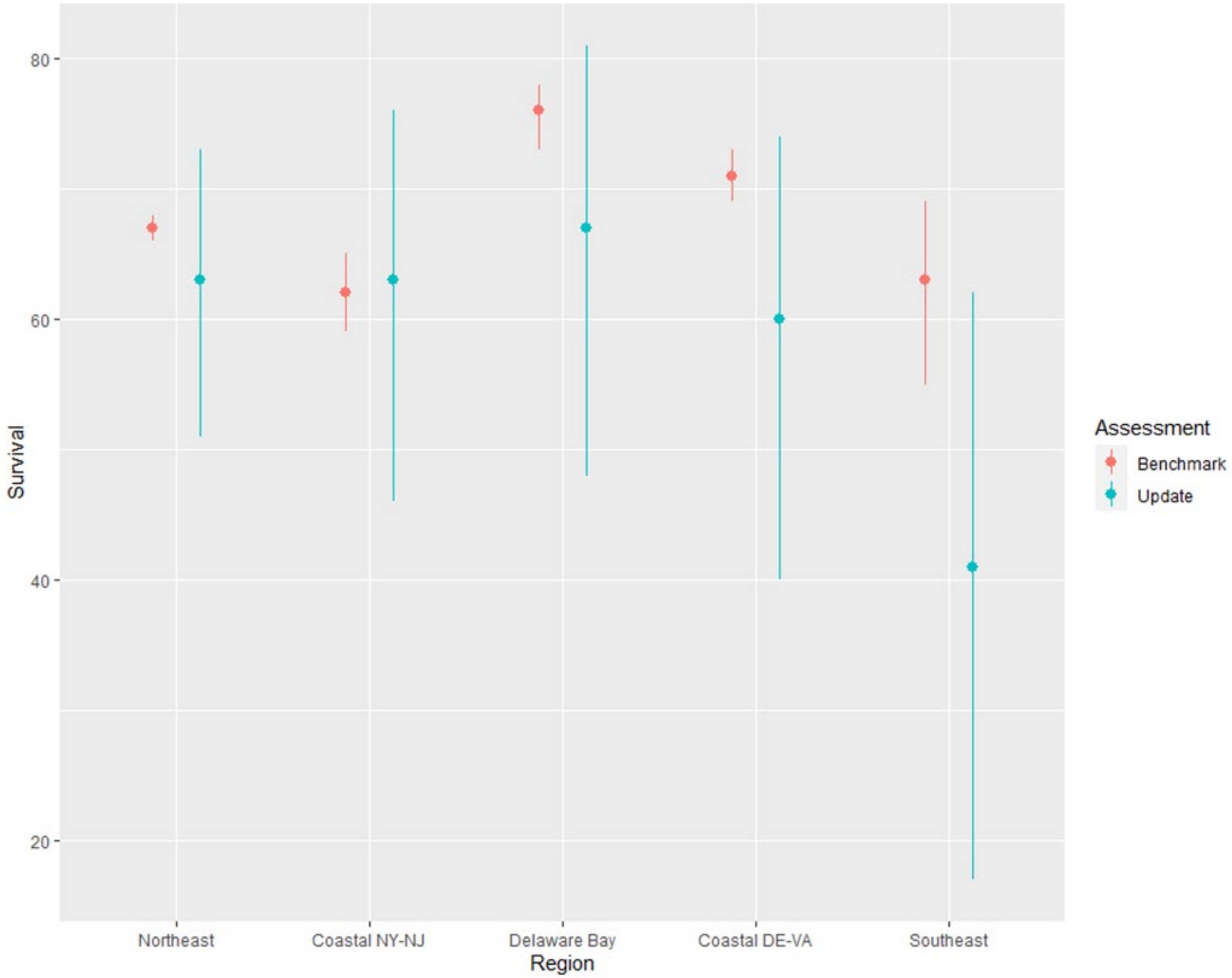


Figure 22. Comparison between the benchmark stock assessment (2019) and update (2024) estimates for survival rate (%) with 95% confidence intervals by region.

Change in Tagging Effort

RELEASES															2009-2019 Average Releases	2020 Difference from Average	2021 Difference from Average	2022 Difference from Average
Region	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022				
Northeast	14,954	17,197	16,487	11,154	7,616	3,802	3,726	3,964	1,869	2,937	2,275	1,345	1,225	1,174	7,816	-83%	-84%	-85%
Coast NY-NJ	3,331	2,194	2,130	7,075	4,568	2,913	3,868	4,343	4,570	4,850	5,435	2,560	4,645	5,617	4,116	-38%	13%	36%
Delaware Bay	546	1,976	3,625	2,277	1,314	4,222	4,231	5,625	5,597	5,640	4,966	30	2,784	4,937	3,638	-99%	-23%	36%
Coast DE-VA	4,721	5,413	6,844	9,873	6,813	4,237	3,574	4,170	5,193	5,018	5,897	4,042	6,166	7,382	5,614	-28%	10%	31%
Southeast	325	2,588	957	442	412	1,757	2,015	1,865	418	502	608	65	1,206	773	1,081	-94%	12%	-28%

RECAPTURES															2009-2019 Average Recaps	2020 Difference from Average	2021 Difference from Average	2022 Difference from Average
Region	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022				
Northeast	2,208	3,533	3,901	1,593	2,268	1,050	1,086	1,108	784	877	1,092	1,001	756	627	1,773	-44%	-57%	-65%
Coast NY-NJ	215	440	481	615	818	1,030	657	554	589	629	1,083	612	926	1,438	646	-5%	43%	122%
Delaware Bay	660	553	962	541	944	594	776	673	926	962	1,415	748	800	775	819	-9%	-2%	-5%
Coast DE-VA	431	327	435	1,040	630	604	474	507	411	738	404	268	505	815	546	-51%	-7%	49%
Southeast	11	51	138	94	49	355	245	195	38	71	75	25	60	49	120	-79%	-50%	-59%

Table 11. Number of tag releases (top) and recaptures (bottom) from 2009-2022 and the percent change of tagging effort during the COVID years (2020-2022).

Natural Mortality

- Delaware Bay survival rate from tagging model used to estimate natural mortality (*M*) for catch survey model
- ASMFC 2019: M=0.274
- ASMFC 2022: M=0.3
- ASMFC 2024 (this update): M=0.4

Catch Multiple Survey Analysis

- ASMFC 2019: Developed CMSA for female HSC
- ASMFC 2022: Addressed peer review comments, developed male model
- This update reflects model from ASMFC 2022
- Input data:
  - Bait, biomedical (coastwide and zero), dead discards
  - Three surveys (NJ Ocean Trawl, DE Adult Trawl, VT Trawl)
  - Natural mortality from tagging data

Catch Multiple Survey Analysis

- CMSA is a stage-based model, 2003-2022
  - Newly mature (*R*) + mature (*N*) – harvest (*C*) – natural mortality (*M*) to predict the next year's population (N_{y+1})

$$N_{y+1} = \left(\left(N_y + R_y\right)e^{-Mt} - C_y\right)e^{-M(1-t)}$$

- Unchanged from the model presented to the Board in October 2023 (ARM)
  - Will be updated again (through 2023) as part of the ARM in October 2024
- Coastwide stock status is not based on CMSA

CMSA Female Population Estimates

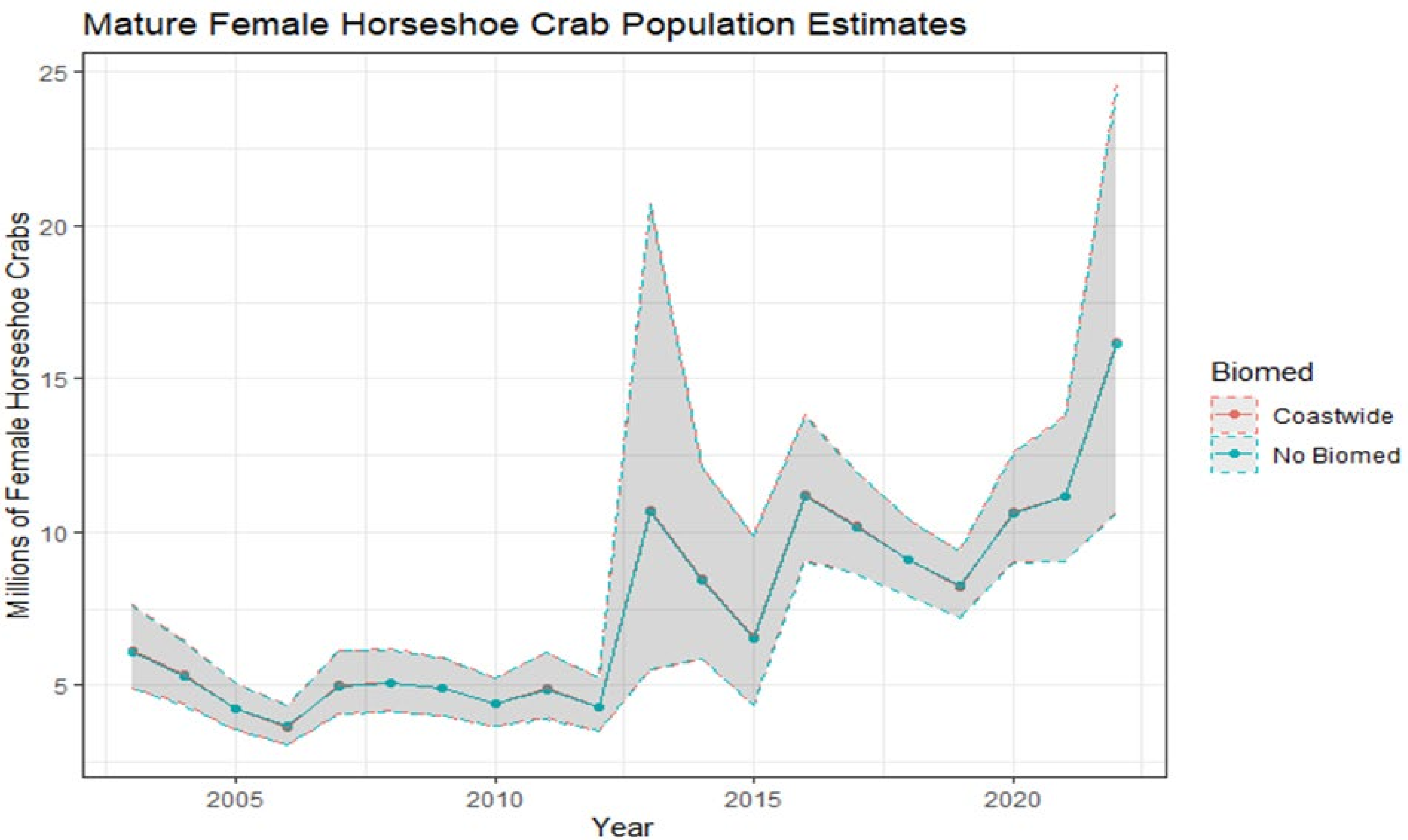


Figure 23. Population estimates from the CMSA for mature female horseshoe crabs with 95% confidence intervals. Delaware Bay biomedical data is confidential so population estimates using coastwide and zero biomedical data provide upper and lower bounds, although there is very little difference between the two and the time series overlap on the figures.

CMSA Male Population Estimates

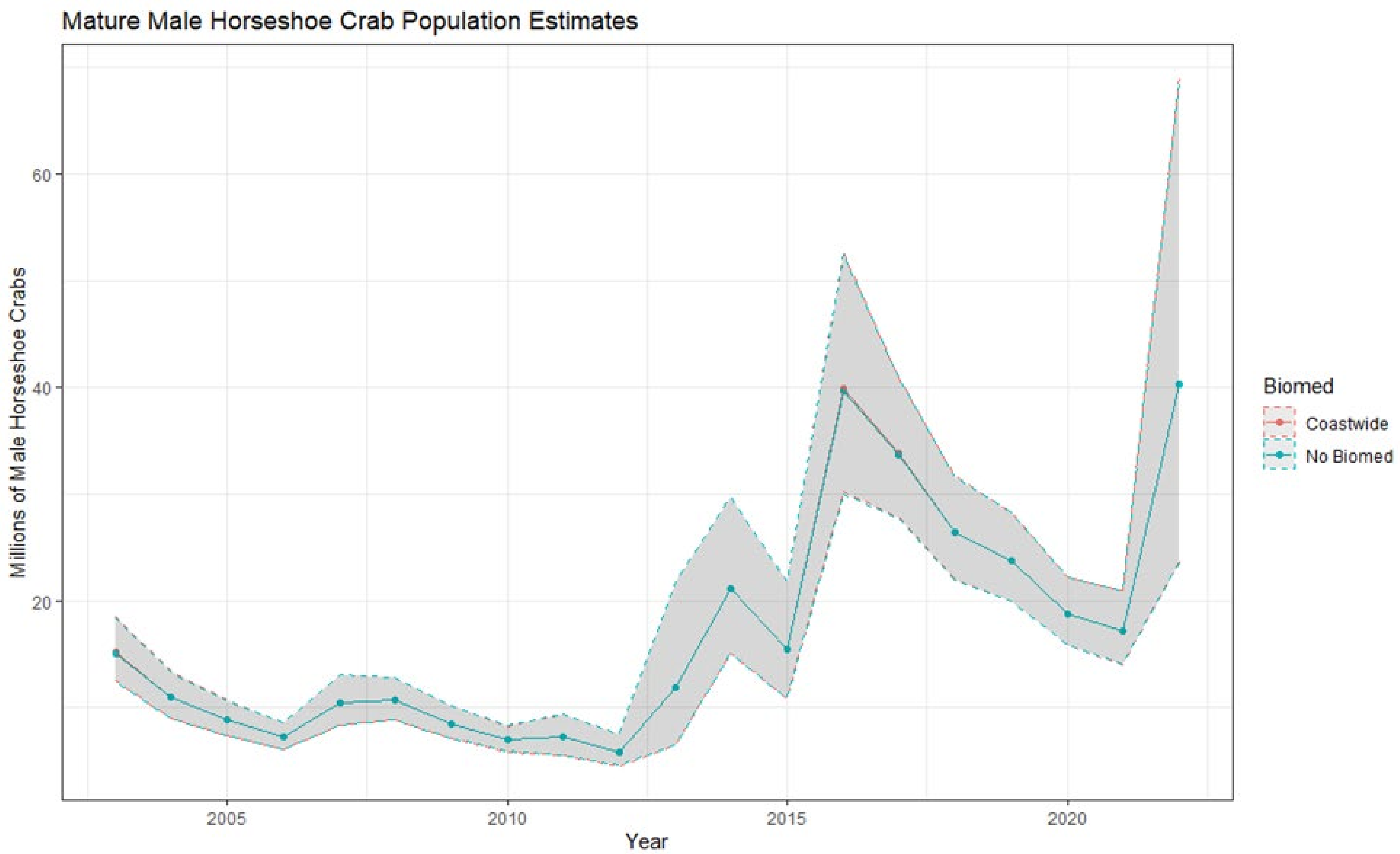
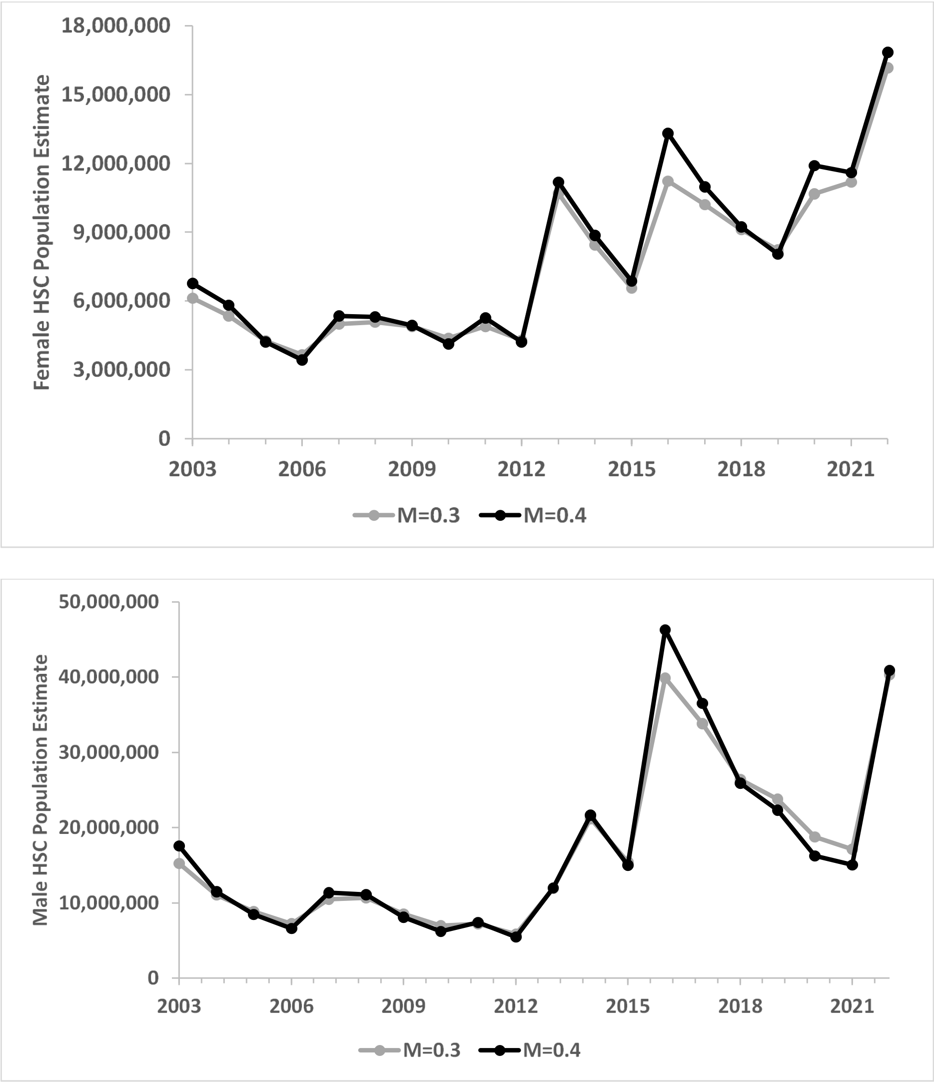


Figure 24. Population estimates from the CMSA for male horseshoe crabs with 95% confidence intervals. Delaware Bay biomedical data is confidential so population estimates using coastwide and zero biomedical data provide upper and lower bounds, although there is very little difference between the two and the time series overlap on the figures.

Sensitivity Run



- Used *M*=0.3 (2022 ARM) in base run, sensitivity run with 0.4 (2024 update)

Figure 25. Comparison between population estimates from the CMSA for mature females (top) and males (bottom) using two natural mortality estimates and coastwide biomedical data.

ARIMA Models

- Autoregressive Integrated Moving Average (ARIMA) models
- Fit to time series of HSC abundance indices
- Estimates the probability that the terminal year of an index is less than reference points with **80%** confidence levels
- Reference points:
  - Q_{25} – bootstrapped lower quartile of fitted index values
  - 1998 – bootstrapped fitted index value for 1998, when harvest restrictions implemented

[NOTE: the Q_{25} reference point can change through time as the length of the time series of abundance estimates increases]

ARIMA Models - Northeast

Survey	i_f	i_{1998}	$P(i_f<i_{1998})$	Q_{25}	$P(i_f<Q_{25})$	Trend since 2017	Trend since 2012
Northeast Region							
MA Trawl North of Cape Cod - Fall Combined Sexes	-0.99	-1.07	35%	-1.19	21%	No Trend	⬆
MA Trawl South of Cape Cod - Fall Combined Sexes	-1.49	-1.47	37%	-1.63	21%	No Trend	⬆
RI Monthly Trawl - Fall Combined Sexes	-1.09	-0.34	96%	-0.70	67%	⬇	⬇

Table 13. Reference points from the ARIMA model for each survey and the probability (P) that the terminal year's fitted index (i_f) is below the reference point. The 1998 reference is i_{1998} and the lower quartile reference is Q_{25}. Reference points are based on ln transformed index values. Relative trends since the last benchmark assessment (trend since 2017) and last stock assessment update (trend since 2012) are indicated.

ARIMA Models – New York

Survey	i_f	i_{1998}	$P(i_f<i_{1998})$	Q_{25}	$P(i_f<Q_{25})$	Trend since 2017	Trend since 2012
New York Region							
CT Long Island Sound Trawl - Fall Combined Sexes	1.02	0.89	37%	0.35	11%	No Trend	↑
NY Jamaica Bay Beach Seine - Spring Combined Sexes	-1.73	-1.00	99%	-1.52	70%	↓	↓
NY Little Neck and Manhasset Bay Beach Seine - Spring Combined Sexes	0.19	1.43	100%	0.26	62%	No Trend	↓
NY NEAMAP - Fall Combined Sexes	2.03			1.02	4%	↑	No Trend
NY Peconic Trawl - Fall Combined Sexes	-1.43	0.15	100%	-1.39	55%	↑	No Trend

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ARIMA Models – DE Bay

Survey	i_f	i_{1998}	$P(i_f<i_{1998})$	Q_{25}	$P(i_f<Q_{25})$	Trend since 2017	Trend since 2012
Delaware Bay Region							
DE 30 ft Trawl - Fall Combined Sexes	1.96	1.05	2%	0.82	0%	No Trend	↑
DE 30 ft Trawl - Fall Female	0.49	-0.25	5%	-0.82	0%	No Trend	↑
DE 30 ft Trawl - Fall Male	1.54	0.52	1%	0.13	0%	No Trend	↑
DE 30 ft Trawl - Spring Combined Sexes	1.73	1.15	9%	0.41	1%	No Trend	↑
DE 30 ft Trawl - Spring Female	0.53	0.35	35%	-0.76	1%	No Trend	↑
DE 30 ft Trawl - Spring Male	1.13	0.26	6%	-0.50	0%	No Trend	↑
Delaware bay NEAMAP - Fall Combined Sexes	2.93			2.83	5%	No Trend	No Trend
MD Coastal Bays - Spring Combined Sexes	1.05	0.75	0%	0.74	0%	No Trend	↑
NJ Ocean Trawl - Fall All Crabs Combined Sexes	2.36	1.88	16%	1.67	10%	No Trend	↑
NJ Ocean Trawl - Fall Female	1.49			0.79	9%	No Trend	↑
NJ Ocean Trawl - Fall Male	1.88			0.88	8%	No Trend	↑
NJ Ocean Trawl - Spring All Crabs Combined Sexes	3.09	2.33	8%	1.67	5%	No Trend	↑
NJ Ocean Trawl - Spring Female	2.09			0.77	8%	No Trend	↑
NJ Ocean Trawl - Spring Male	2.79			0.66	7%	No Trend	↑

ARIMA Models – DE Bay

Survey	i_f	i_{1998}	$P(i_f < i_{1998})$	Q_{25}	$P(i_f < Q_{25})$	Trend since 2017	Trend since 2012
Delaware Bay Region (continued)							
VA Tech Trawl - All Crabs	4.76			4.48	21%	⬆	⬆
VA Tech Trawl - Immature Female	2.94			2.82	19%	⬇	⬇
VA Tech Trawl - Immature Male	2.55			2.38	18%	⬇	⬇
VA Tech Trawl - Multiparous Female	3.34			2.43	18%	⬆	⬆
VA Tech Trawl - Multiparous Male	3.99			3.31	19%	⬆	⬆
VA Tech Trawl - Primiparous Female	-1.62			-0.48	92%	⬇	⬇
VA Tech Trawl - Primiparous Male	2.36			0.90	17%	⬆	⬆

Table 13. Reference points from the ARIMA model for each survey and the probability (P) that the terminal year's fitted index (i_f) is below the reference point. The 1998 reference is i_{1998} and the lower quartile reference is Q_{25}. Reference points are based on ln transformed index values. Relative trends since the last benchmark assessment (trend since 2017) and last stock assessment update (trend since 2012) are indicated.

ARIMA Models – Southeast

Survey	i_f	i_{1998}	$P(i_f<i_{1998})$	Q_{25}	$P(i_f<Q_{25})$	Trend since 2017	Trend since 2012
Southeast Region							
NC Gill Net - Spring Combined Sexes	0.00			-1.23	16%	No Trend	No Trend
SC CRMS - Spring Combined Sexes	0.24	-0.44	7%	-0.43	10%	No Trend	↑
SC SEAMAP - Fall Combined Sexes ★	-0.69			-0.34	21%	No Trend	↓
SC Trammel Net - Spring Combined Sexes ★	-1.05	-0.99	22%	-0.73	41%	↓	↓
GA Trawl - Spring Combined Sexes	0.90			1.12	45%	↓	↓
GA-FL SEAMAP - Fall Combined Sexes ★	-1.72			-1.14	38%	No Trend	↓

Table 13. Reference points from the ARIMA model for each survey and the probability (P) that the terminal year's fitted index (i_f) is below the reference point. The 1998 reference is i_{1998} and the lower quartile reference is Q_{25}. Reference points are based on ln transformed index values. Relative trends since the last benchmark assessment (trend since 2017) and last stock assessment update (trend since 2012) are indicated.

★ Trends should be interpreted with caution due to reduced sampling 2020-2022

Stock Status

- Based on the percentage of surveys within a region (or coastwide) having a >50% probability of their terminal year fitted value being less than the 1998 index-based reference point from ARIMA model fits.

- Included: Combined-sex indices and extend back to at least 1998 and 2022 terminal year

- “Poor”: >66% of surveys meeting the >50% criterion

- “Good”: <33% of surveys

- “Neutral”: 34 – 65% of surveys

Stock Status

Region	2009 Benchmark	2013 Update	2019 Benchmark	2024 update	2024 Stock Status
Northeast	2 out of 3	5 out of 6	1 out of 2	1 out of 2	Neutral
New York	1 out of 5	3 out of 5	4 out of 4	3 out of 4	Poor
Delaware Bay	5 out of 11	4 out of 11	2 out of 5	0 out of 5	Good
Southeast	0 out of 5	0 out of 2	0 out of 2	0 out of 2	Good
Coastwide	7 out of 24	12 out of 24	7 out of 13	4 out of 13	Good

Research Recommendations

- Recommendations from the benchmark that have been addressed or initiated:
- Collect more info on ecology and movement
  - Juvenile habitat use: Cheng et al. 2021, Colon et al. 2021
  - Use of salt marshes for spawning: Kendrick et al. 2021, Sasson et al. (*in press*)
  - NY diet study: Bopp et al. 2023
  - Movement and survival: Bopp et al. 2019
- Work regarding biomedical industry
  - Tagging studies: Owings et al. 2019, Smith et al. 2020, Watson et al. 2022
  - Aquaculture and biomedical: Tinker-Kulberg et al. 2020
  - Effects of temperature, stressors: Owings et al. 2020, Litzenberg 2023

Research Recommendations

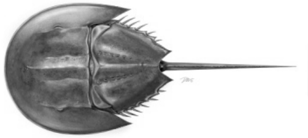
- Use of the CMSA in the ARM Framework
  - ASMFC 2022 (ARM Revision), Anstead et al. 2023
- Additional recommendations from the update:
  - Address reduced sampling in southern surveys
  - Maintain pre-pandemic levels of tagging effort
  - Evaluate the use of *Z* instead of *M* in the CMSA
  - Re-examine stock structure with more years of genetic and tagging data

Questions?

Horseshoe Crab Bait Use

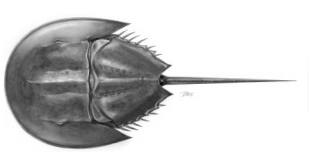
Horseshoe Crab Management Board

April 30, 2024



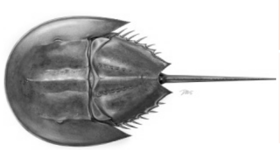
Survey of States

- What Commercial pot/trap fisheries (e.g. eel pot, whelk pot) use horseshoe crabs as bait?
- Has a survey been conducted about baits used and alternatives?
- Are data collected that could reveal trends in effort?
- For states with heavy HSC harvest restrictions, have commensurate restrictions on the use of bait by your pot fishermen been considered?
- Does your state collect any data on quantity and origin of HSC imported from other states?



What fisheries use HSC bait?

State	Eel	Whelk
MA	No	Yes
RI	Minimal	Yes
CT	Yes	Yes
NY	Yes	Yes
NJ	Yes	Possibly
MD	Yes	Yes
DE	Yes	Yes
VA	Yes	Yes
NC	Negligible	Negligible
SC	No	??
GA	No	??
FL	Yes	??



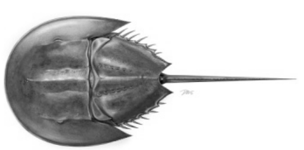
Has your state conducted a survey?

- No state has conducted an independent survey of pot fishermen on bait use and alternatives
- ASMFC conducted a survey of eel fishermen in 2017

Table 5. Bait types typically used by American eel fishermen in 2016 shown in numbers and percentages of responses to eel bait surveys. Fishermen may typically use multiple bait types, so percentages do not sum to 100%. (Q9-10)

Bait Type	**Eel (N=90)**	
	Responses	Use Percentage
Blue crabs	54	40.60%
Fish racks or whole	36	27.07%
Horseshoe crab	30	22.56%
Shellfish	27	20.30%
Other**	9	6.77%
Razor Clams	7	5.26%
Green crabs	1	0.75%
Manufactured bait	1	0.75%
Rock crabs	1	0.75%
Jonah crabs	1	0.75%
Sharks/Skates/Dogfish	0	0.00%

**No individual bait type included in Other had a use percentage greater than 5% for the American eel trap/pot fishery.



Data that could show trends in effort?

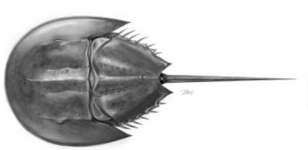
State	Eel	Whelk
MA	NA	Yes. Pot hauls, permits, landings.
RI	Yes. Landings	Yes. Landings, permits. Maybe traps fished.
CT	Trip level effort	Trip level effort
NY	Number of fishers reporting landings.	Permits
NJ	Yes. Participants and landings.	Yes. Participants and landings.
MD	Landings and participants	Landings and participants
DE	Yes. Participants, #pots, soak days, harvest/pot soak days	Yes. Harvest/pot soak days.
VA	Yes. # trips, gear amount, hours fished	Yes. # trips, gear amount, hours fished
NC	Possibly	Possibly
SC	NA	??
GA	NA	??
FL	Yes	??

Describe trends in effort

State	Eel	Whelk
MA	NA	Declining effort and landings
RI	Has not been analyzed	Has not been analyzed
CT	Steady low effort.	Data since 2016. Decline from mid-2000s to min 2010s. Has stabilized at a lower level.
NY	No significant trends in landings, trips, or fishers reporting landings.	Whelk pot landings, trips, and fishers reporting landings all increased since 2014. Permits increased from 2000 to 2023 by 24.4%. Has been declining since 2009.
NJ	Overall increase from 2021-2023	Increasing since 2021
MD	Since 2012, decrease in eel potters and landings.	Since 2012, decrease in whelk potters and increase in landings.
DE	Significant decrease since female harvest ban	Participants have decreased but soak days and landings have increased
VA	Declining effort	Effort increased then decreased
NC	NA	NA

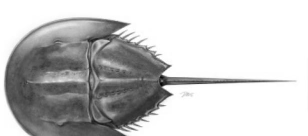
Measures to limit bait use

State	Eel
MA	No. Standard restrictions on HSC.
RI	No. Standard restrictions on HSC.
CT	Hand harvest banned in 2023. No formal regulations on restricting bait use.
NY	No. Standard restrictions on HSC.
NJ	Commercial moratorium on HSC. No restrictions on bait use.



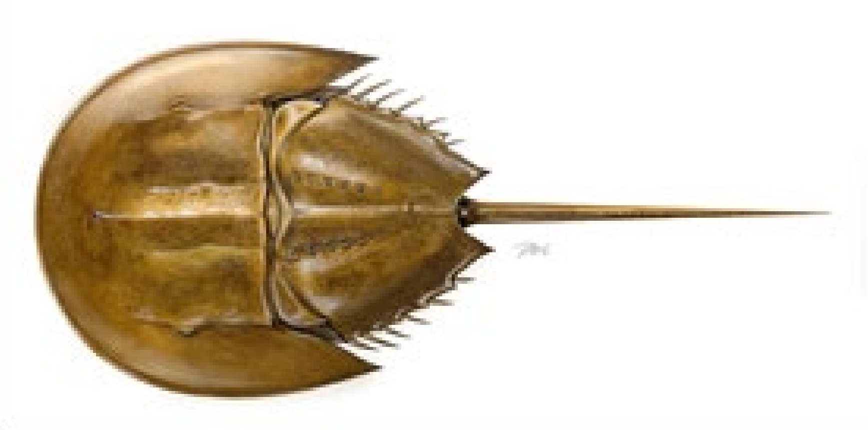
Does your state collect any data that would show quantity and origin of horseshoe crabs imported from other states?

- All states indicated they do not collect any such data



Questions?

Technical Response to External Review of 2022 ARM Framework



Horseshoe Crab Management Board Meeting

April 30, 2024

Introduction

- Original Adaptive Resource Management (ARM) Framework was adopted for management use in 2012, setting harvest levels for 2013
- From 2013 – 2022: 500K males and 0 females
- ARM Revision had many changes to the modeling and was adopted for management use in 2022
- Potential for female harvest created controversy resulting in extensive public comments prior to October 2022 and October 2023 Board meetings
- Board decided to still set female harvest at 0 after both meetings

Introduction

- Earthjustice contracted outside experts to review the ARM Revision Report
- Earthjustice's September 2022 public comments contained reviews by Dr. Kevin Shoemaker (Univ. Nevada, Reno) and Dr. Romauld Lipcius (VIMS)
- Earthjustice's September 2023 public comments contained additional review and analysis by Dr. Shoemaker
- During the October 2023 meeting, the Board tasked the ARM Subcommittee with responding to the 2023 review by Dr. Shoemaker

Introduction

- Responses to 6 major criticisms by Dr. Shoemaker from his 2023 review of the ARM Framework
- Brief responses to additional items contained in the 2022 reviews by Dr. Shoemaker and Dr. Lipcius
- Greater detail is supplied in the ARM Subcommittee’s report

Criticism 1

Estimates of red knot survival used in the ARM appear to be artificially inflated, resulting in falsely optimistic estimates of population resilience.

- High survival and long lifespans are common for red knots and other shorebirds of similar size and life histories.
- Survival rates used in the ARM are calculated from the tagging data for red knots in the Delaware Bay region and are comparable with other published survival values.
- The tagging data were critically analyzed by the ARM subcommittee to represent the best available data and caveats to the survival estimates were provided in the 2022 ARM Report. The analysis of the tagging data and its use in the modeling was commended by the peer review panel.

Criticism 1

- Claim that survival estimates are biased by individual misidentification or flag misreads
  - DE Bay misread error is between 0.38% (712 impossible observations/187,587) and 4.5% (8,448 single observations)
  - Tucker et al. (2019) showed this level of error would have minimal impacts on survival estimates

Criticism 2

Trawl-based indices of horseshoe crab abundance are inadequate for modeling the biotic interaction between red knots and horseshoe crabs.

- The inclusion of trawl surveys as indices of horseshoe crab abundance may be imperfect but it is the best available science and its use has been approved by several independent peer reviews.
- Most of the criticisms and caveats relevant to trawl surveys would also apply to egg density and red knot abundance estimates.
- There is consensus among the trawl surveys for an increasing trend in horseshoe crab abundance since 2010.
- Trawl surveys are the standard for bottom dwelling organisms and are the standard to evaluate the abundance of many species.

Criticism 2

- Criticism for not using a GLM or GAM in calculating indices of abundance
  - The DE Trawl does use a GLM approach
  - VA Tech Trawl follows a stratified sampling design
- Criticism for a lack of correlation between trawl surveys
  - Each trawl still shows an increasing trend
  - It is the consensus among trends that is important
  - More on this in Criticism 3

Criticism 3

Red knot survival is strongly sensitive to horseshoe crab egg density, indicating that persistent degradation of the horseshoe crab egg resource could have dire consequences for the red knot population.

- Egg density data were requested, but not provided to the modeling team. Therefore, it could not be considered as data input to the models.

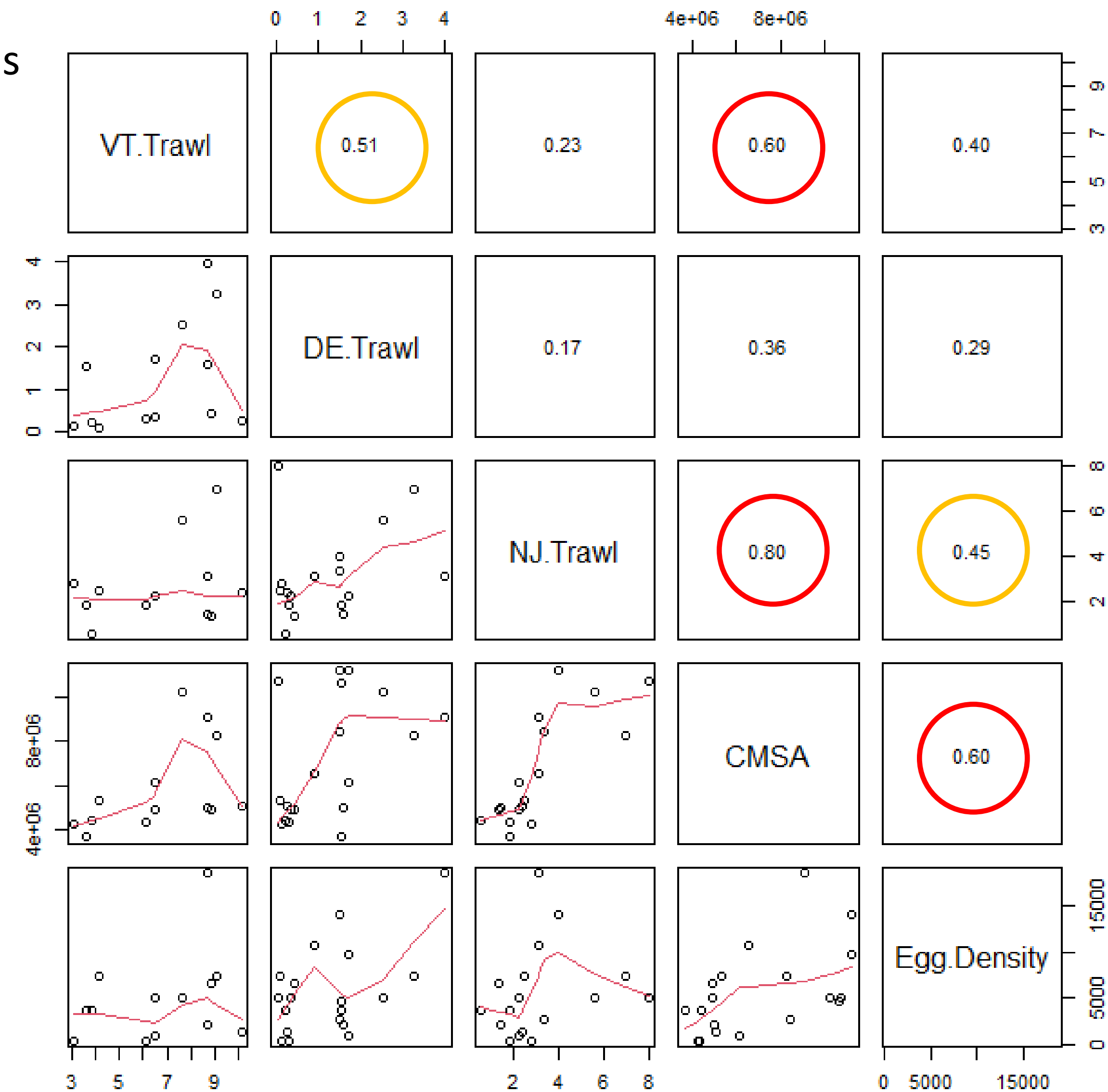
- Trends in egg density (extracted from Smith et al. 2022) are correlated with other data inputs for the years included in the ARM models and thus the inclusion of egg density data is unlikely to result in any meaningful difference from the current ARM Framework in terms of harvest recommendations.

- Smith et al. (2022) showed a general increasing trend in horseshoe crab egg density in recent years similar to that of horseshoe crab abundance, consistent with findings from the ARM Revision.

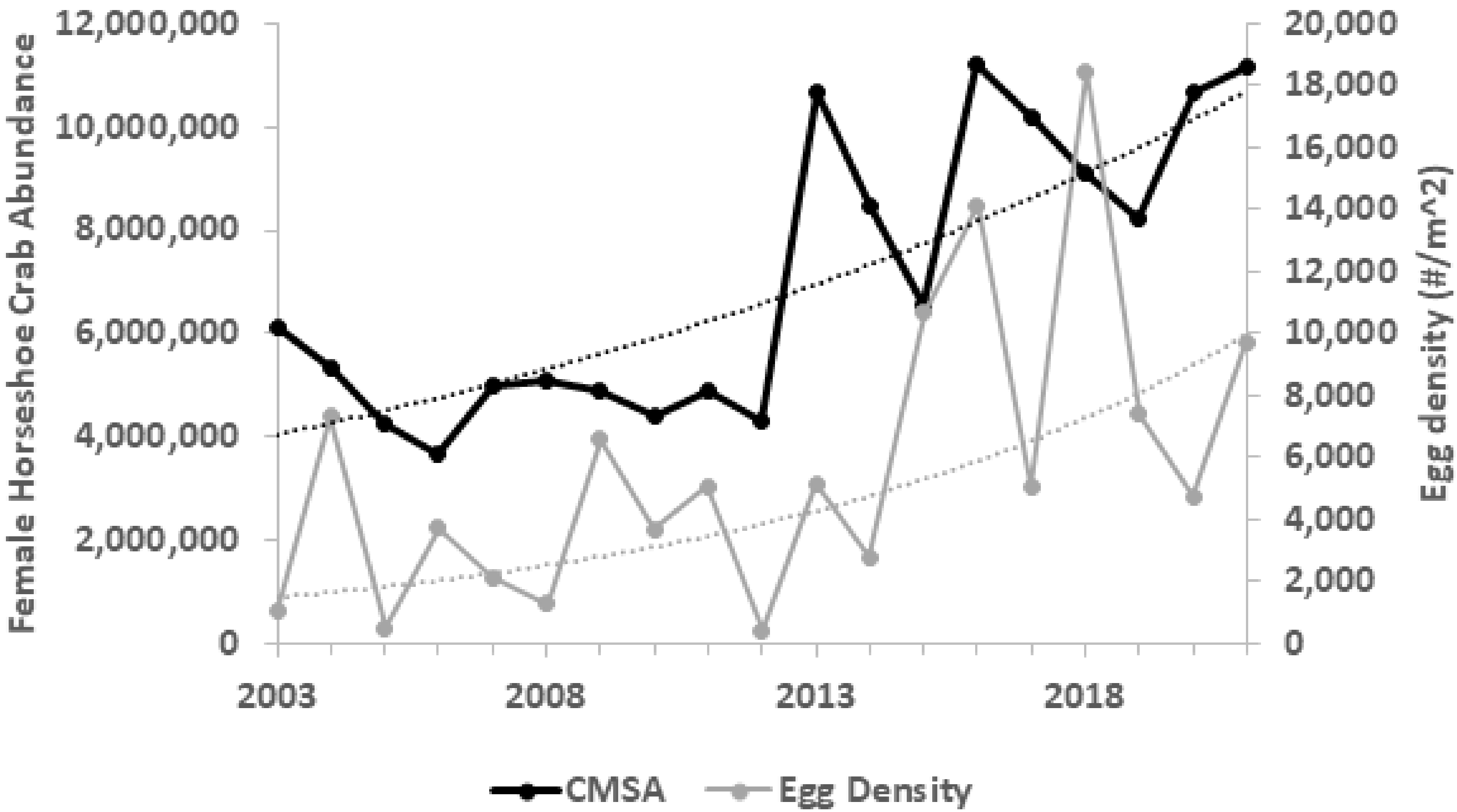
Criticism 3

Spearman Rank correlations from 2003 – 2022

O significant at $P \leq 0.05$
O significant at $P \leq 0.10$



Criticism 3



Egg density data were digitized from Figure 2 in Smith et al. (2022)

Criticism 3

- Dr. Shoemaker also reanalyzed the Smith et al. (2022) egg density data to account for differences in survey methodology through time.
  - Contrary to Smith et al. (2022), he found no trend
- Dr. Shoemaker conducted an analysis to determine the effect of egg density on red knot survival
  - Survival was positively correlated with egg density
  - Methods were not documented in great detail
  - Only included NJ side of the bay

Criticism 3

- If Dr. Shoemaker's analyses are correct, we have…
  - Positive relationship between egg density and red knot survival
  - No trend in egg density
  - But an increasing trend in female abundance as shown by the ARM Subcommittee and SAS
- How do we then link harvest → crab abundance → egg density → red knot survival?
- Dr. Shoemaker does not propose a parameterized model to do so.

Criticism 4

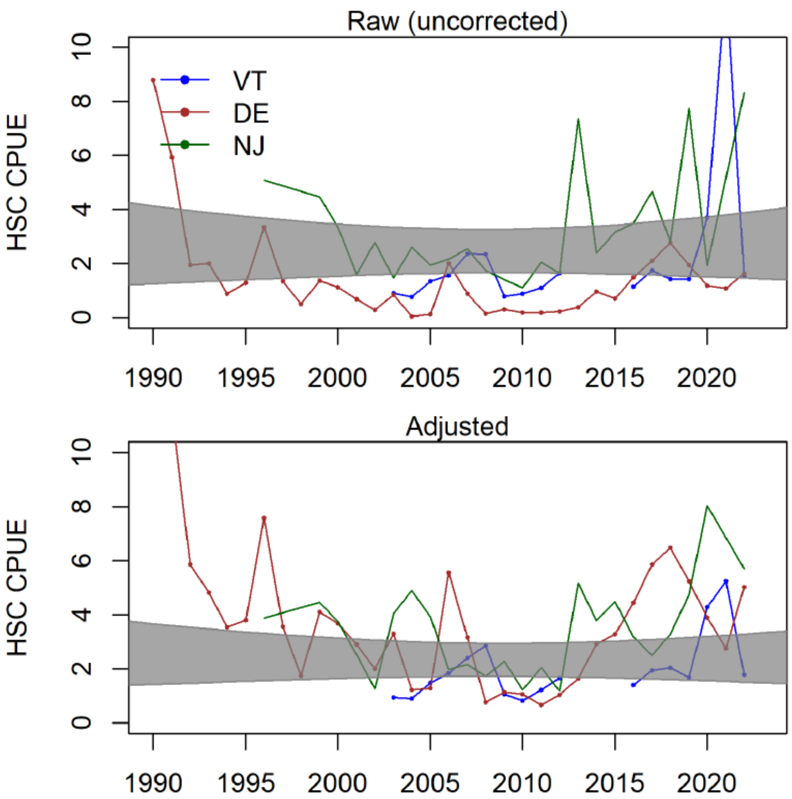
The ARM exaggerates the evidence for an increasing trend in the number of female horseshoe crabs in the Delaware Bay

- The analysis provided in Dr. Shoemaker’s report has some errors, including the use of incorrect data subsetting for the indices and application of an analysis that was inappropriate for the data.
- The trawl-based indices were thoroughly considered by the ARM modelers and represent the best available data for tracking horseshoe crab abundance.
- The goal of the ARM modelers was not to find an increasing trend, but to develop the data in the most statistically sound way possible regardless of the answer.

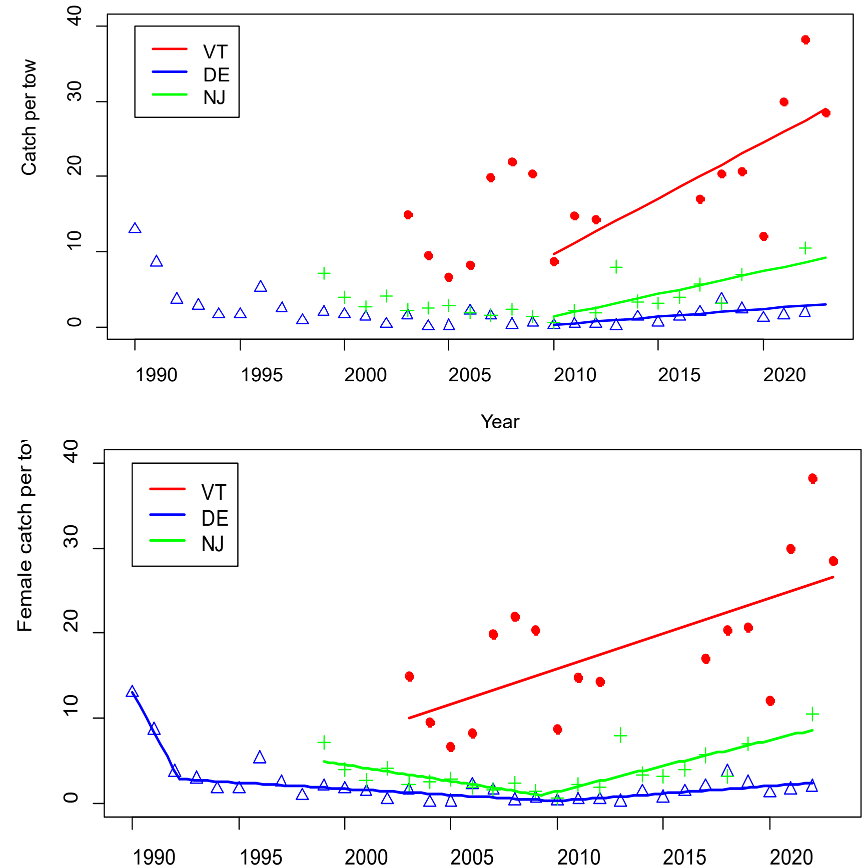
Criticism 4

- When provided the data, Dr. Shoemaker reanalyzed the NJ Ocean Trawl data using a GLM approach
  - The ARM Subcommittee has no issue with using a GLM approach, but it didn’t improve the index when attempted during the 2019 stock assessment
  - However, Dr. Shoemaker subset the data in an inappropriate manner
- Dr. Shoemaker made a questionable analytical choice when conducting a trend analysis

Criticism 4



Dr. Shoemaker's linear model approach



ARM Subcommittee approach

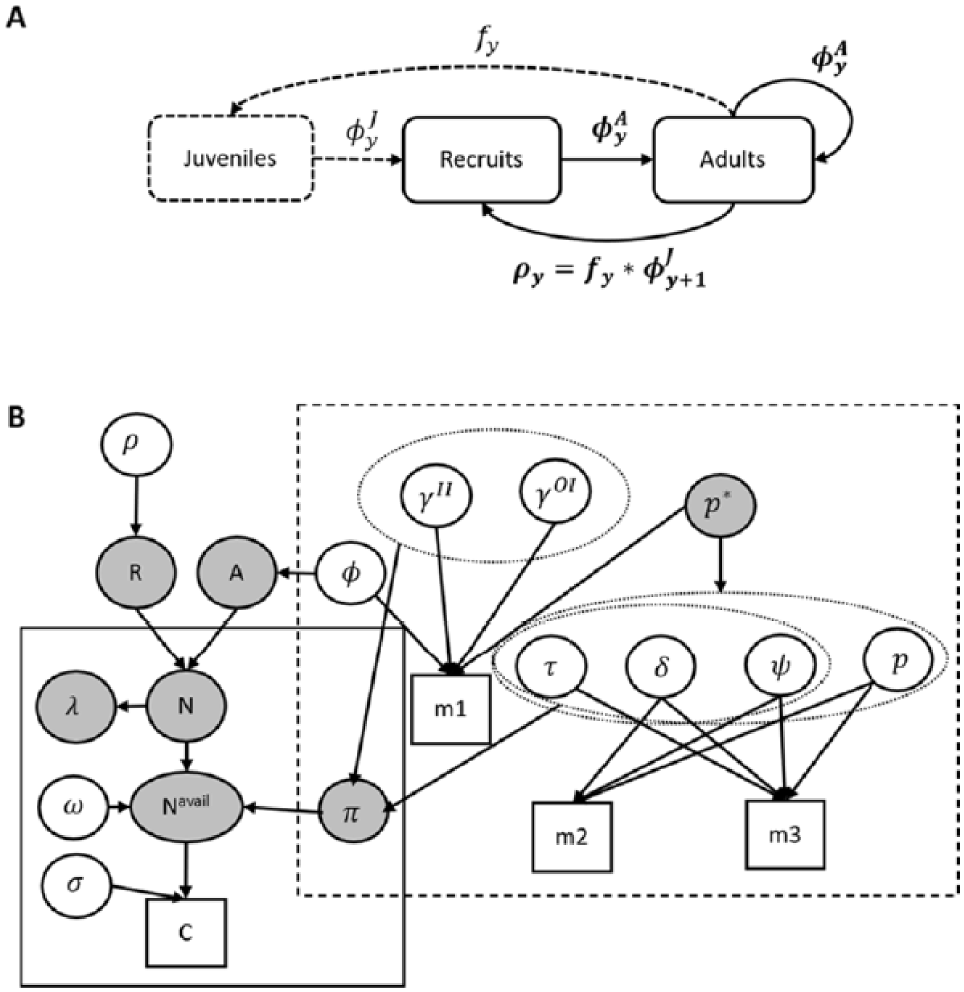
Criticism 5

The integrated population model used for estimating red knot population parameters is overparameterized and likely to yield spurious results

- Dr. Shoemaker’s criticism of the red knot model is unsubstantiated and misrepresents the models used in the ARM Framework.
- Much like the trawl surveys, the red knot data are imperfect but represent the best available data.
- Dr. Shoemaker assumes that too many parameters will produce incorrect results, when the relationship between overparameterization and biased models is more nuanced.

Criticism 5

Integrated population model (IPM)



Life cycle model

Open robust model to estimate survival

State space model for red knot count data

Criticism 5

- Dr. Shoemaker failed to recognize the structural linkages between sub-models in the IPM
- His claims of overparameterization are valid for traditional applications of singular models, but more nuanced for an IPM
- Overparameterization does not necessarily bias results. Under-parameterization can too.

Criticism 6

The integrated population model exhibits poor fit to the available data

- Dr. Shoemaker provides conflicting arguments for the use of the goodness of fit test for the red knot model.
- Goodness of fit tests applied to the red knot model indicated poor fit in one model component, but the portion of the model including the survival probability of red knots did not fail the test.

Criticisms 7 - 11

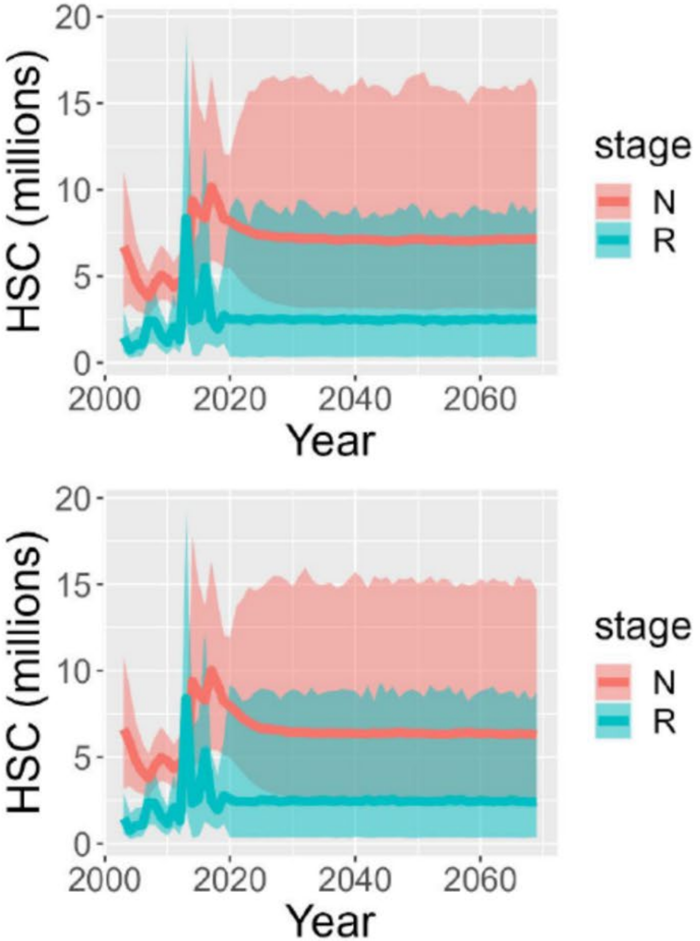
- From the 2022 reviews by Dr. Shoemaker and Dr. Lipcius
- From the supplemental section of Dr. Shoemaker's 2023 review

Criticism 7

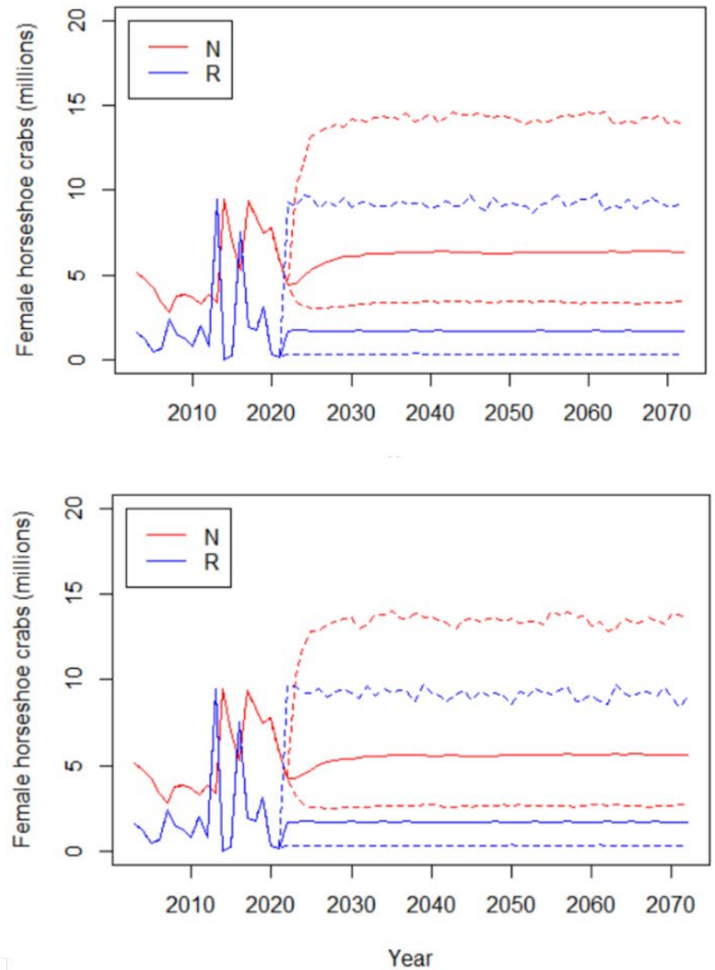
The estimate of mean horseshoe crab recruitment and propagation of error within the horseshoe crab population dynamics model is inappropriate

- The estimate of mean horseshoe crab recruitment used by the ARM Workgroup is the most biologically realistic. If mean recruitment were lower, as Dr. Shoemaker suggests, the current population estimate of horseshoe crabs would be well above a predicted "carrying capacity" of the Delaware Bay region.
- Dr. Shoemaker's proposed method of error propagation is worth considering in a future revision of the ARM model, but comparison of his population projections to those by the ARM Subcommittee are nearly identical.

Criticism 7



Dr. Shoemaker – 2022 Review



ARM Subcommittee

No Female Harvest

210,000 Female Harvest

Criticism 8

The ARM model would not predict a decline in red knots under a total collapse of the horseshoe crab population is evidence that the model is fatally flawed

- Dr. Shoemaker is incorrect that the ARM model would not predict a decline in red knots if the horseshoe crab population collapsed. His assertion that red knots would continue to increase in the absence of horseshoe crabs is mathematically impossible in the model.

Criticism 8

- Red Knot survival ~ log(Female Crab Abundance)
- Survival declines to 0 as crab abundance decreases
- A complete collapse of the HSC population is a sensationalized and extreme scenario – nobody would argue in favor of continued female harvest if abundance dips to levels lower than, and outside the range of data used to develop the ARM models

Criticism 9

Demographic data indicate a declining horseshoe crab population

- Declining individual size of horseshoe crabs began after harvest was greatly curtailed in the Delaware Bay region and is not indicative of overfishing.
- Assuming natural mortality has not changed, abundance of horseshoe crabs could not have increased if egg deposition and hatch had also not increased.
- Recent low estimates of female newly mature crabs do not necessarily represent recruitment failure. Male newly mature crabs did not decrease over the same time period.

Criticism 10

There is an incorrect specification of "pi" parameter in the red knot IPM

- π_{jt} is the probability of being present in DE Bay in occasion *t* of year *j*
- This is a criticism that does warrant further consideration by the ARM Workgroup

Criticism 11

There is an over-representation of Mispillion Harbor in red knot resighting data

- Use of data from Mispillion Harbor does not result in biased inferences

Criticism 11

Year	Resighted in Mispillion Harbor only	Resighted at non-Mispillion sites only	Resighted at both Mispillion and other sites
2005	0.26	0.45	0.30
2006	0.28	0.40	0.32
2007	0.48	0.17	0.35
2008	0.48	0.30	0.23
2009	0.46	0.28	0.26
2010	0.12	0.69	0.20
2011	0.46	0.30	0.25
2012	0.30	0.46	0.24
2013	0.29	0.53	0.18
2014	0.36	0.43	0.20
2015	0.54	0.24	0.22
2016	0.25	0.62	0.14
2017	0.53	0.27	0.21
2018	0.48	0.29	0.23

Conclusions

- Continued scientific review is welcomed
- The ARM Revision represented some great advancements in our understanding of population dynamics of both species AND methods to optimize harvest.
- Why was the original ARM not criticized nearly as much? Is the real problem with the final answer and not the data, methods, or process?

Conclusions

- The benefit of the ARM Framework is the ability to make decisions with imperfect knowledge
- The ARM Subcommittee strived to design a modeling framework in which routine monitoring would allow for rapid learning – A critical feature not addressed by Dr. Shoemaker in his reviews

Conclusions

- Many criticisms stem from the belief that there must be a "strong" relationship between HSC, egg density, & RK survival.
- Dr. Shoemaker postulated that the collection of additional data may show the relationship between HSC abundance and RK survival could disappear or become negative.
- "This outcome would pose an existential problem for the ARM Framework, decoupling the two-species Framework and rendering the RK model unusable in the context of management."
- ARM Subcommittee Question: Would we not expect the relationship between HSC abundance and RK survival to disappear if HSC abundance were high enough such that it did not limit red knot survival?

Conclusions

- There is no question Dr. Shoemaker is a very knowledgeable quantitative ecologist
- However, his criticisms focus on specific model components and why each may be wrong
  - He doesn’t provide recommendations for how to assemble all the pieces into a unifying decision making framework
  - Fails to recognize how uncertainty is handled in the optimization (approximate dynamic programming)

Conclusions

- There will always be room for improvement and the ARM Framework is designed to do that through the double-loop learning process.
- The critiques by Dr. Shoemaker (and Earthjustice) fail to make any real recommendations for improvement
- The ARM Subcommittee stands firm in our belief that our work currently provides the best approach to addressing the problem statement.

Manage harvest of horseshoe crabs in the Delaware Bay to maximize harvest but also to maintain ecosystem integrity, provide adequate stopover habitat for migrating shorebirds, and ensure that the abundance of horseshoe crabs is not limiting the red knot stopover population or slowing recovery.

Questions?