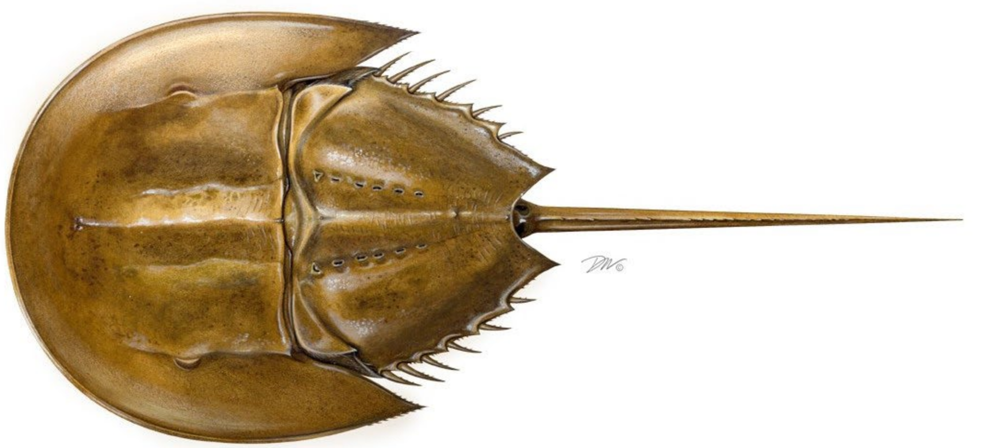
Atlantic States Marine Fisheries Commission

2024 Horseshoe Crab Stock Assessment Update



Accepted for Management Use by the Horseshoe Crab Management Board
April 30, 2024

Sustainable and Cooperative Management of Atlantic Coastal Fisheries

Atlantic States Marine Fisheries Commission

Horseshoe Crab Stock Assessment Update

Prepared by the
ASMFC Horseshoe Crab Stock Assessment Subcommittee

Katherine Rodrigue (Chair), Rhode Island Department of Environmental Management
Kristen Anstead, Atlantic States Marine Fisheries Commission
Linda Barry, New Jersey Division of Fish and Wildlife
Margaret Conroy, Delaware Division of Fish and Wildlife
Jeffrey Dobbs, North Carolina Division of Marine Fisheries
Derek Perry, Massachusetts Division of Marine Fisheries
Daniel Sasson, South Carolina Department of Natural Resources
Caitlin Starks, Atlantic States Marine Fisheries Commission
John Sweka, U.S. Fish and Wildlife Service

With Additional Support From

Josh Newhard, US Fish and Wildlife Service

And the ASMFC Horseshoe Crab Technical Committee

Kristen Anstead, Atlantic States Marine Fisheries Commission
Ingrid Braun, Potomac River Fisheries Commission
Jeff Brunson, South Carolina Department of Natural Resources
Joanna Burger, Rutgers University
Claire Crowley, Florida Fish and Wildlife Research Institute
Jeffrey Dobbs, North Carolina Department of Environmental Quality
Steve Doctor, Maryland Department of Natural Resources
Jennifer Lander, New York Department of Environmental Conservation
Eddie Leonard, Georgia Department of Natural Resources
Samantha MacQuesten, New Jersey Division of Fish and Wildlife
Kelli Mosca, Connecticut Department of Energy and Environmental Protection
Derek Perry, Massachusetts Division of Marine Fisheries
Katherine Rodrigue, Rhode Island Department of Environmental Management
Ethan Simpson, Virginia Marine Resource Commission
Caitlin Starks, Atlantic States Marine Fisheries Commission
Chris Wright, NOAA Fisheries
Jordan Zimmerman, Delaware Division of Fish and Wildlife

A publication of the Atlantic States Marine Fisheries Commission pursuant to National Oceanic and Atmospheric Administration Award No. NA20NMF4740012.

ACKNOWLEDGEMENTS

The Atlantic States Marine Fisheries Commission (ASMFC) thanks all of the individuals who contributed to the development of the horseshoe crab stock assessment update. The Commission specifically thanks the ASMFC Horseshoe Crab Technical Committee (TC) and Stock Assessment Subcommittee (SAS) members who provided data and developed the stock assessment update report. Thank you to Atlantic Coastal Cooperative Statistics Program staff Heather Power for validating landings. Additionally, the SAS thanks Josh Newhard (USFWS) for providing the tagging analysis for this assessment despite taking another position within the USFWS during its development.

EXECUTIVE SUMMARY

The purpose of this assessment is to update the 2019 Horseshoe Crab Benchmark Stock Assessment (ASMFC 2019) with recent data from 2018-2022 and evaluate the current status of horseshoe crabs along the US Atlantic coast. This coastwide assessment is different from the Adaptive Resource Management (ARM) Framework, which evaluates the population in the Delaware Bay and recommends harvest with consideration for migratory shorebirds.

Commercial Fisheries

All quantifiable sources of horseshoe crab removals were updated as part of this stock assessment. Horseshoe crabs are harvested commercially as bait and landings have remained well below the coastwide quota since it was implemented in 2000. Generally, the majority of horseshoe crab harvest comes from the Delaware Bay, followed by the New York, the Northeast, and the Southeast regions, although in 2021 and 2022 the landings from the Northeast were greater than those from the New York region. Coastwide, horseshoe crab landings for 1998-2022 peaked in 1999 at 2.6 million horseshoe crabs and have decreased since the late 1990s. Landings have remained under 1 million horseshoe crabs since 2003 and were 573,633 horseshoe crabs in 2022.

Horseshoe crabs are also collected by the biomedical industry to support the production of Limulus amebocyte lysate (LAL), a clotting agent that aids in the detection of endotoxins in patients, drugs, and intravenous devices. Biomedical use has increased since 2004, when reporting began, and the estimated total mortality due to the biomedical industry in 2022 was 145,920 horseshoe crabs coastwide, the highest value in the time series.

Horseshoe crabs are caught as bycatch in several other commercial fisheries. Commercial discards were estimated for the Delaware Bay region as part of this assessment with data from the Northeast Fisheries Observer Program. Estimates indicate a variable amount of horseshoe crabs are captured and discarded in other fisheries, although a large amount of uncertainty is associated with the estimates.

Indices of Relative Abundance

All fishery-independent surveys along the Atlantic coast that were used to develop abundance indices in the 2019 benchmark stock assessment were updated for this report, although several had missing data points or reduced sampling during the COVID years which impacts the uncertainty of recent trends. The indices are used in the trend analysis both regionally and coastwide to determine stock status.

Assessment Methods

A tagging model was used in the 2019 benchmark stock assessment to estimate survival rates regionally. Tagging effort was greatly reduced in 2020-2022 due to COVID and reduced effort impacted the survival estimates. The substantial reduction of tagged horseshoe crabs in 2020, coupled with reductions in recapture reports in 2020 and 2021, likely caused the tagging model to underestimate survival rates. A substantial reduction in reporting rate will cause tagging models to account for “missing” tag recaptures as mortalities or emigrants and subsequently reduce survival estimates. And, in fact, all regions saw a decline in survival and an increase in

the uncertainty of the estimates since the benchmark with the exception of coastal New York-New Jersey, which did not see a substantial reduction in its tagging effort during COVID. The survival estimates should be interpreted with caution and this analysis should be updated in the next assessment when tagging effort has resumed to normal levels in all regions.

The catch multiple survey analysis (CMSA) was developed in the 2019 benchmark stock assessment and further developed for the 2022 ARM Revision. The CMSA is not used for management in this coastwide stock assessment, although the results are included in this report. Based on the CMSA, there were approximately 40 million mature male and 16 million mature female horseshoe crabs in the Delaware Bay region in 2022. Mature female horseshoe crabs have been steadily increasing in the region since the implementation of the initial ARM Framework in 2012.

The coastwide horseshoe crab population is primarily evaluated using autoregressive integrated moving average models (ARIMA). ARIMA is a simple trend analysis on the current suite of fishery-independent indices developed for horseshoe crab. The results are used to determine stock status.

Stock Status

To date, no overfishing or overfished definitions have been adopted by the Management Board. Stock status is determined using the results of the ARIMA. The reference point from the ARIMA is the 1998 index-based reference point because this reference point represents the point in time when horseshoe crabs became actively managed by the ASMFC and status relative to this reference point gives an indication of the effects of management on populations. Stock status is determined by the ARIMA analysis and how many surveys are currently below where they were in 1998.

The current stock status indicates that the Northeast region is in a neutral state and the New York region continues to be in a poor state, with three out of four surveys being below 1998 reference points. Based on the ARIMA results, the Delaware Bay, Southeast, and coastwide populations are in good condition, an improvement since the 2019 benchmark.

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

Summary

- Data gaps due to reduced sampling during COVID impacts the trends in fishery-independent indices and the tagging model, making some results uncertain.
- Stock status has improved in the Delaware Bay and at the coastwide level.
- Stock status remains good in the Southeast, although some abundance indices may be trending down.
- Stock status remains neutral in the Northeast.
- Stock status in the New York region continues to be poor.

TABLE OF CONTENTS

INTRODUCTION 1
TOR 1. Fishery-Dependent Data 1
TOR 2. Fishery-Independent Data 2
TOR 3. Life History Information and Model Parameterization 4
TOR 4. Updated CMSA and ARIMA 6
TOR 5. Stock Status 8
TOR 6. Projections 9
TOR 7. Research Recommendations 10
REFERENCES 12
TABLES 15
FIGURES 37
APPENDICES 68

LIST OF TABLES

Table 1. Coastwide horseshoe crab commercial bait landings in numbers, 1998-2022, as validated by ACCSP. ... 15

Table 2. Numbers of horseshoe crabs collected and bled, by sex, and estimated mortality for the biomedical industry as reported in annual Fishery Management Plan Reviews. ... 16

Table 3. Estimated number of dead horseshoe crabs caught and discarded from other commercial fisheries ... 17

Table 4. Fishery-independent surveys used for developing indices of relative horseshoe crab abundance ... 18

Table 5. Results of the power analysis by survey ... 20

Table 6. Data and results for the Mann-Kendall test of temporal trends in sex ratios ... 23

Table 7. Sex ratio and proportion female information, with associated confidence limits, for the New Jersey Ocean Trawl. ... 24

Table 8. Sex ratio and proportion female information, with associated confidence limits, for the Delaware Adult Trawl. ... 25

Table 9. Recapture rate relative to total recaptures for each region of release ... 26

Table 10. Regional apparent annual survival rates ... 27

Table 11. Number of tag releases (top) and recaptures (bottom) from 2009-2022 ... 28

Table 12. ARIMA summary statistics for horseshoe crab surveys. ... 29

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. ... 32

Table 14. Stock status determination for the coastwide and regional stocks based on the 1998 index-based reference points from ARIMA models. ... 35

Table 15. Details of surveys used in determining regional stock status of horseshoe crabs. ... 36

LIST OF FIGURES

Figure 1. Coastwide horseshoe crab bait landings, 1998-2022, by sex where available. Coastwide ASMFC quota indicated in orange. Source: ACCSP......... 37

Figure 2. Map of the Atlantic coast showing the regions for horseshoe crab assessment......... 38

Figure 3. Horseshoe crab bait harvest by region, 1998-2022. 39

Figure 4. Horseshoe crab bait landings of Delaware Bay-Origin, 2003-2022, by sex...... 39

Figure 5. Coastwide number of horseshoe crabs (HSC) collected and bled by the biomedical industry and the total resulting mortality 40

Figure 6. Estimated number of dead horseshoe crabs discarded in the Delaware Bay region from commercial fisheries......... 41

Figure 7. Indices of relative abundance of horseshoe crabs developed from the Massachusetts Trawl Survey for north and south of Cape Cod (CC)......... 42

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......... 43

Figure 9. Indices of relative abundance of horseshoe crabs developed from the Northeast Area Monitoring and Assessment Program (NEAMAP) and Maryland Coastal Bays Surveys 44

Figure 10. Indices of relative abundance of horseshoe crabs developed from the New Jersey Ocean Trawl (NJ OT) Survey......... 45

Figure 11. Indices of relative abundance of horseshoe crabs developed from the Delaware 30' Adult Trawl Survey......... 46

Figure 12. Indices of relative abundance of horseshoe crabs developed from the Virginia Tech Trawl Survey......... 47

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......... 48

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 49

Figure 15. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the Northeast region 50

Figure 16. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the New York region 51

Figure 17. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the Delaware Bay region......... 52

Figure 18. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the Delaware Bay region used in the ARM Framework 53
Figure 19. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the Southeast region 54
Figure 20. Number of tag releases by region, 2009-2022. 55
Figure 21. Number of tag recaptures by region, 2009-2022. 56
Figure 22. Comparison between the benchmark stock assessment (2019) and update (2024) estimates for survival rate (%) with 95% confidence intervals by region 57
Figure 23. Population estimates from the CMSA for mature female horseshoe crabs 58
Figure 24. Population estimates from the CMSA for male horseshoe crabs 59
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. 60
Figure 26. ARIMA model fits to horseshoe crab indices Massachusetts and Rhode Island Trawl Surveys in the Northeast Region. 61
Figure 27. ARIMA model fits to horseshoe crab indices in the New York Region. 62
Figure 28. ARIMA model fits to horseshoe crab indices from the Delaware Trawl Survey in the Delaware Bay Region. 63
Figure 29. ARIMA model fits to horseshoe crab indices from the New Jersey Ocean Trawl Survey in the Delaware Bay Region. 64
Figure 30. ARIMA model fits to horseshoe crab indices from Delaware Bay NEAMAP and Maryland Coast Bays Surveys in the Delaware Bay Region. 65
Figure 31. ARIMA model fits to horseshoe crab indices from the Virginia Tech Trawl Survey in the Delaware Bay Region. 66
Figure 32. ARIMA model fits to horseshoe crab indices from the surveys in the Southeast Region. 67

INTRODUCTION

This Terms of Reference (TOR) Report describes the update to the most recent benchmark stock assessment for horseshoe crab (ASMFC 2019). This assessment extends the fishery-independent and –dependent data for horseshoe crab through 2022, reruns the tagging model, sex-ratio analysis, catch multiple survey analysis (CMSA), and determines stock status using the autoregressive integrated moving average (ARIMA) reference points defined in ASMFC 2019 and accepted for management use in 2019.

TOR 1. Fishery-Dependent Data

Update fishery-dependent data (landings, discards, catch-at-age, etc.) that were used in the previous peer-reviewed and accepted benchmark stock assessment.

There are three sources of fishery-dependent data used in the horseshoe crab stock assessment: bait landings, biomedical harvest and mortality, and commercial discards from other fisheries.

Since 1998, states have been required to report annual bait landings of horseshoe crab through the compliance reporting process and to the Atlantic Coastal Cooperative Statistics Program (ACCSP) Data Warehouse. Landings used in this assessment for 1998-2022 were validated by state agencies through ACCSP. Since the 2019 benchmark, coastwide landings decreased in 2020 due to the COVID-19 pandemic and then increased in 2021 and 2022 to levels similar to the recent years preceding 2020 (Table 1; Figure 1). Landings have remained well-below the coastwide quota since its implementation in 2000. Stock status is determined by four regions: Northeast, New York, Delaware Bay, and Southeast (Figure 2). Regionally, the majority of bait landings are harvested from the Delaware Bay region (Figure 3) and are predominately males due to harvest restrictions from the ARM Framework (Figure 4).

Since 2004, ASMFC has required states to monitor the biomedical use of horseshoe crabs to determine the source of crabs, track total harvest, and characterize pre- and post-bleeding mortality. In recent years, sex data is also provided. The bleeding mortality rate of 15% from the meta-analysis of bleeding studies during the benchmark was applied to the numbers of bled crabs to estimate bleeding mortality. This was added to the number of crabs observed dead during the biomedical process to estimate the total mortality attributable to biomedical use (Table 2; Figure 5). These values represent the number of horseshoe crabs estimated to have died coastwide as a result of the biomedical industry. The number of horseshoe crabs collected and bled has increased over time. The estimated mortality from the biomedical industry in 2022 was 145,920 horseshoe crabs, the highest in the time series.

Discard information from observed commercial fishing trips was obtained from NOAA Northeast Fisheries Science Center's (NEFSC) Northeast Fisheries Observer Program (NEFOP). The NEFOP program collects data on harvested and discarded catch, gear, effort, and species' lengths and weights using trained fishery observers from Maine to North Carolina. Data on horseshoe crabs have been collected since 2004 and discard estimates for the Delaware Bay were completed using the methods described in ASMFC 2019 and updated for ASMFC 2022. The estimated number of dead horseshoe crab discards in the Delaware Bay region has been variable through time, with the highest values in 2016 and 2021 and the lowest value in 2022 (Table 3; Figure 6). The variability can be attributed to influential observed trips, such as a dredge trip in 2016 that discarded numerous horseshoe crabs. Since dredge landings for other species (e.g., surf clam, sea scallop) in the Delaware Bay are larger than landings from gill nets and trawls, when the discard estimates are scaled up to the landings in the region these influential trips result in large discard estimates.

TOR 2. Fishery-Independent Data

Update fishery-independent data (abundance indices, age-length data, etc.) that were used in the previous peer-reviewed and accepted benchmark stock assessment.

For the last assessment (ASMFC 2019), the SAS explored using nominal and generalized linear model (GLM) standardization for developing abundance indices from fishery-independent surveys but encountered issues with these methods due to the high proportion of zero catch in many of the sampling events. Therefore, all indices in ASMFC 2019 were developed using the delta distribution for the mean and variance to take into account the number of zero catches (Pennington 1983). During the peer review for the Revision to the Adaptive Resource Management Framework (ARM Revision, ASMFC 2022) for horseshoe crab in the Delaware Bay, the panel noted that the delta mean should not be used for fixed stations surveys (e.g., the Delaware Bay Adult Trawl). In this stock assessment update, all fixed station surveys were standardized using a GLM instead of the delta mean (Table 4; Figure 7- Figure 14; Table A1). Since ASMFC 2019, the name of the South Carolina Crustacean Research and Monitoring Survey has been changed to the Estuarine Trawl Survey. The previous name was maintained in this report for consistency with the benchmark but the name change is acknowledged throughout the tables and figures.

Correlation between indices for horseshoe crabs was evaluated by region using the methods in ASMFC 2019. Of the three comparisons in the Northeast Region, none were significantly correlated (Figure 15). Of the 10 comparisons in the New York Regions, 4 were significant and positively correlated (Figure 16). For the Delaware Bay, 28 out of the 91 comparisons were significant and positively correlated (Figure 17). The Delaware Bay indices were subset to those used in the ARM Revision and of the 28 comparisons, 12 were significant and positively correlated (Figure 18). Of the 15 comparisons in the Southeast Region, 3 were significant and positively correlated and 1 was significant and negatively correlated (Figure 19).

a. Sampling Issues

Several surveys collected no data in 2020-2021 due to restricted sampling during the pandemic years. Additionally, the South Carolina Trammel Net and Southeast Area Monitoring and Assessment (SEAMAP) surveys had reduced sampling in 2020-2022. For the Trammel Net Survey, strata used in the index (ACE Basin/St. Helena Sound, Charleston Harbor, Muddy and Bulls Bays, and Romain Harbor) were sampled monthly through 2019. Beginning in 2020, strata were sampled two of three months per quarter or one or two times quarterly depending on the strata. The 2020 data were dropped because there was incomplete sampling in the months used in the survey (March-May) in addition to the decreased sampling events. For SEAMAP, some strata were not sampled due to storms or boat issues in recent years. Additionally, the seasons used in SEAMAP have changed from three (April-May, July-August, and September-November) to two that straddle the previous seasons (mid-April-June and mid-August-October). With the reduced sampling in 2020-2022, the decline in the abundance index for those years could be due to a real decline in abundance or an artifact of the change in sampling. Similarly, 1995-1997 for the Trammel Net Survey and 2019 for SEAMAP (GA-FL index) should also be interpreted cautiously. Index standardization can mitigate the effects of some missing data, but in this case, whole strata were unsampled for multiple years. Typically, the SAS would stop updating an index when a survey changes sampling design, as was done for the New Jersey Surf Clam Dredge Survey for horseshoe crab (ASMFC 2019), and the SAS should consider this in the next benchmark.

For additional supporting information about the sampling issues, see Appendix Table A2 - Table A3.

b. Power Analysis

Power analysis was used to calculate the probability of detecting trends in the abundance indices developed from fishery-independent data using the methods of Gerrodette 1987. As was done in ASMFC 2019, all fishery-independent surveys that were developed into abundance indices were tested in the power analysis. Briefly, variability in abundance as a function of both linear and exponential change was tested using a one-tailed test. Power was calculated for a change of ±50% over a 20-year time period for both a linear and exponential trend. It should be noted that this is not a retrospective power analysis (e.g., one done after a statistical test for a trend is conducted). It is an indication of the probability of detecting a trend if it should actually occur. A fishery-independent survey could have high power, but still not show any increasing or decreasing trend if it does not occur. Likewise, a survey with low power could show a statistically significant trend if that trend is large enough in magnitude or the time series is long enough. This power analysis is a means to qualify the data from a given survey.

Median coefficients of variation (CVs) for horseshoe crab surveys ranged from 0.13 – 0.78 and as the CV increased, the power to detect a linear or exponential trend decreased. Overall, only 8 out of 42 surveys had estimated power to detect a ±50% change over a 20-year period exceeding 0.80. These included the Connecticut Long Island Trawl, New York Peconic Bay Trawl, Delaware Adult Trawl (fall and spring indices for combined sexes), New Jersey Ocean Trawl (spring index for females), Virginia Tech Trawl (all crabs combined), Georgia Trawl, and the North Carolina Gill Net Surveys (Table 5).

TOR 3. Life History Information and Model Parameterization

Tabulate or list the life history information used in the assessment and/or model parameterization (M, age plus group, start year, maturity, sex ratio, etc.) and note any differences (e.g., new selectivity block, revised M value) from benchmark.

c. Sex ratio

Updated temporal trends in sex ratios of males to female horseshoe crabs from the New Jersey Ocean Trawl and Delaware Adult Trawl Survey are shown in Table 6. As in the 2019 benchmark, a Mann-Kendall analysis was used to test for trends in the sex ratio data over time. All surveys except for the New Jersey Ocean Trawl spring indices show significantly increasing male biased sex ratios. In the 2019 benchmark, only the spring Delaware Bay Adult Trawl Survey had a significant positive trend in the sex ratio. The sex ratio from the New Jersey Ocean Trawl did not significantly differ between the spring and the fall (paired t-test, $P = 0.26$). However, like in the 2019 benchmark, the sex ratio in the Delaware Adult Trawl Survey was higher in the fall than in the spring (paired t-test, $P < 0.001$).

The year-by-year proportion female and sex ratio data for each trawl survey, along with their lower and upper confidence limits, can be found in Table 7 - Table 8. There are occasional minor differences in these results from the 2019 benchmark due to slight differences in the data provided by the states. Additionally, the New Jersey Ocean Trawl Survey was not conducted in 2020 or 2021.

d. Survival Rates and Natural Mortality

Tagging data from the US Fish and Wildlife Service (USFWS) horseshoe crab database were analyzed by region to estimate apparent survival rates using the same methods as ASMFC 2019. The regions used in this analysis are slightly different from the four management regions used elsewhere in the assessment and include the Northeast, coastal New York-New Jersey, Delaware Bay, coastal Delaware-Virginia, and the Southeast. Northeast, coastal New York-New Jersey, Delaware Bay, and the Southeast showed high rates (>90%) of within-region recaptures (Table 9).

Survival analysis was conducted using program MARK (White and Burnham 1999) which showed regional variation in annual survival rate (Table 10). As in ASMFC 2019, releases were sufficient to support survival analysis for the Northeast, coastal New York-New Jersey, Delaware Bay, coastal Delaware-Virginia, and the Southeast. The highest survival rates were in Delaware Bay. The lowest were in the Southeast. All regions saw a decline in survival since the benchmark with the exception of coastal New York-New Jersey.

The observed declines in survival rate may be due to reduced tagging and resight efforts in recent years due to the COVID pandemic. While there was enough data to complete the analysis, all regions had significant reductions in tagging effort in 2020 and, in some regions, those reductions were also seen in 2021-2022 (Table 11; Figure 20 - Figure 21). The reductions ranged between -23% and -99% of the average number of releases from the pre-pandemic years, 2009-2019. While not to the same degree, reductions in recapture reports also occurred, ranging between -2% to -79% of the average number of recaptures reported between 2009-2019. The decline in effort varied between the regions. The Northeast and Southeast region had declines in both releases and recaptures for 2020-2022, and the Delaware Bay had declines in recaptures for 2020-2022 and declines in releases for 2020-2021. The comparison of tags released in 2020-2022 to the 2009-2019 average in the Northeast is somewhat skewed since there was a larger tagging effort in that region in the early part of the time series, but the effort was low during the COVID years nonetheless. Conversely, some regions maintained their tagging effort after the decline in 2020, such as in coastal New York-New Jersey. That region was the only one that did not see a significant decrease in survival and had the most consistent survival estimates from ASMFC 2019 to this stock assessment update (Table 10).

Additionally, apparent survival rates do not distinguish between mortality and emigration, so any horseshoe crab missing from the analysis leads to a reduction in survival. The significant reduction of tagged horseshoe crabs in 2020, coupled with reductions in recapture reports in 2020 and 2021 would likely cause the tagging model to underestimate survival rates (Table A4). Tagging models rely on consistent reporting rates (number of recaptures/number of releases) to produce reliable estimates. Reporting rates can change with changes in tagging effort and/or changes in recapture effort. Any significant reduction in reporting rate will cause tagging models to account for “missing” tag recaptures as mortalities or emigrants and subsequently reduce survival estimates. While tagging effort varies from year-to-year, significant changes in effort can impact the results by having increased error and wider confidence intervals (Figure 22), making it challenging to detangle real changes in survival from data issues. Therefore, due to the lower sampling effort during the COVID years, the revised survival rates should be interpreted with caution and the data should be re-analyzed once tagging efforts resume to pre-pandemic levels. Yet, even with those caveats, the benchmark estimates for all regions except the Southeast fall within the stock assessment update confidence intervals (Figure 22).

Using the methods from ASMFC 2019 and the updated tagging data through 2022, an instantaneous natural mortality rate (M) for the Delaware Bay was estimated for use in the catch multiple survey analysis (CMSA). In Delaware Bay, the estimate was M=0.4 (from the estimated survival of 67%), which is higher than the M=0.274 used in ASMFC 2019 or M=0.3 used in ASMFC 2022 based on the same analysis. Because the natural mortality rate is derived from the survival rate in the Delaware Bay region, it should also be used with caution due to the reduced sampling effort during the pandemic. The SAS decided to use the M=0.3 for the CMSA base run since it did not use the recent years with reduced sampling in the region. A sensitivity run of the CMSA was done and a research recommendation for estimating M was developed. During the development of this assessment, the SAS also noted that the calculation from survival rate (S) to mortality ($S=e^{-Z}$) results in an estimate of total mortality (Z; $Z=M+F$ where F is fishing mortality), not solely M, and the assessment team should consider this in the next assessment.

TOR 4. Updated CMSA and ARIMA

Update accepted model(s) or trend analyses and estimate uncertainty. Include sensitivity runs and retrospective analysis if possible and compare with the benchmark assessment results. Include bridge runs to sequentially document each change from the previously accepted model to the updated model.

a. Catch Multiple Survey Analysis

The catch multiple survey analysis (CMSA) for horseshoe crab was developed for ASMFC 2019 and updated in ASMFC 2022. The CMSA is updated annually as part of the ARM Framework to support harvest specification setting in the Delaware Bay region. The CMSA uses quantifiable sources of mortality (i.e., bait harvest in Delaware Bay states, coastwide biomedical mortality, and commercial dead discards; Figure 4 - Figure 6) to estimate male and female horseshoe crab populations. Population estimates for horseshoe crabs were made using the coastwide biomedical data or no biomedical data, which provide upper and lower bounds for the public since Delaware Bay-specific data is confidential. The Virginia Tech Trawl Survey estimates are used in the CMSA along with the spring portion of the New Jersey Ocean Trawl and the Delaware Adult Trawl Surveys (Figure 10 - Figure 12).

The CMSA was updated in 2023 with a terminal year of 2022. In 2021, the number of newly mature female horseshoe crabs estimated in the Virginia Tech Trawl survey was zero (Figure 12). This data point is lagged forward to represent 2022, the terminal year of the current model, and poses an issue for the CMSA. The CMSA is a simple, stage-based model that essentially sums the newly mature and mature crabs, subtracts harvest and accounts for natural mortality, and predicts the next year's population. The model will not run with an estimate of zero newly mature horseshoe crabs and has struggled to reconcile the high mature female horseshoe crab population estimates in the Virginia Tech Trawl Survey with the low newly mature population estimates for the last few years. The ARM Subcommittee and Delaware Bay Ecosystem Technical Committee (DBETC) previously discussed three hypotheses for the low newly mature horseshoe crabs in the Virginia Tech Trawl Survey: 1) a catchability issue where newly mature crabs are not in the same location as mature crabs, 2) a multi-year recruitment failure beginning in 2010 that began to show up 9 years later (the length of time to maturity) in 2019, the first year of low newly mature crabs, or 3) an identification issue where the onboard technicians since 2019 have been misclassifying newly mature horseshoe crabs as mature or immature. Recruitment failure seems like the least likely hypothesis because multiparous females continued to increase and there was not a concurrent decrease in primiparous males.

To gap-fill the newly mature female horseshoe crab time series so there are no zeros, the ARM Subcommittee and DBETC used an average ratio of newly mature to mature females from previous years based on stage data from the Virginia Tech Trawl and Delaware Adult Trawl Surveys (Figure A6). Using the average of 19.9%, the years of 2019-2022 in the Virginia Tech Trawl were adjusted such that the observed newly mature and mature female horseshoe crabs were added together and then 19.9% of the total were attributed to the newly mature stage. This method did not increase the number of total female horseshoe crabs in the model, but rather re-proportioned them between the two stages of newly mature and mature. This approach is supported by the biology of horseshoe crabs since it is not possible to have an increase in mature females with no newly mature females in the previous year. This approach also resulted in CMSA estimates of total females that were closer to swept area estimates from the Virginia Tech Trawl Survey. If the trend of low newly mature female horseshoe crabs continues in the future, the ARM and DBETC will re-evaluate gap-filling methods as needed. No adjustments had to be made for the male horseshoe crab model.

Using the CMSA model, there were approximately 40.3 million mature male and 16.1-16.2 million mature female horseshoe crabs in the Delaware Bay region in 2022, depending on the use of coastwide or no biomedical data (Figure 23 - Figure 24). The swept area estimates from the Virginia Tech Trawl were 44.9 million male and 15.5 million female mature horseshoe crabs for comparison (Figure 12).

While the CMSA used the natural mortality estimate (M=0.3) from ASMFC 2022 due to the data caveats from the reduced sampling effort in the tagging model, a sensitivity run was done using the revised M=0.4 for both sexes. The population estimates from the sensitivity runs varied minimally from the base runs but resulted in higher terminal year population estimates using coastwide biomedical data: 16.8 million mature female and 40.9 million mature male horseshoe crabs (Figure 25).

For additional supporting information about the CMSA, see Appendix Table A5 and Figure A1 - Figure A8.

b. ARIMA

The autoregressive integrated moving average models (ARIMA, Box and Jenkins 1976) were applied to the fishery-independent indices using the same methods as ASMFC 2019. Like ASMFC 2019, two index-based reference points were considered: 1) the bootstrapped lower quartile of the fitted abundance index (Q_{25}) as proposed by Helser and Hayes (1995); and 2) the bootstrapped fitted abundance index from 1998 (i_{1998}) representing the time of the initiation of the Horseshoe Crab Fishery Management Plan. Neither reference point should be viewed as a biological reference point for determining overfished status. The ARIMA reference points allow qualitative evaluation of status with respect to historic levels and when a change in management occurred. Trends since the terminal years in the last benchmark stock assessment (2017) and last stock assessment update (2012) are also provided and were determined via Mann-Kendall tests for monotonic trends.

The residuals of ARIMA model fits were tested for normality using a Shapiro-Wilk test and if residuals were found to be non-normal, caution should be used interpreting the probability of the terminal year being greater than an index-based reference point.

ARIMA model fit results were summarized within a region with respect to the Q_{25} and 1998 reference points (Table 12). The fraction of surveys whose $P(i_f<Q_{25})$ and $P(i_f<i_{1998})$ values were greater than 0.50 was enumerated for each region. If an abundance index time series did not extend back to 1998, it was not included in the regional summary.

The Northeast region showed mixed ARIMA model results. Massachusetts Trawl Surveys showed increasing or stable trends with low probabilities of being less than the Q_{25} or 1998 reference points (Figure 26; Table 13). Contrary to the surveys in Massachusetts, the ARIMA fit to the Rhode Island Trawl Survey has continued to decrease since 2003 with the terminal year of 2022 having a high probability of being less than both the Q_{25} and 1998 reference points (Figure 26; Table 13).

The New York region generally continued to show declining trends, as has been evident since the 2009 benchmark stock assessment. The Jamaica Bay, Littleneck and Manhasset Bay, and Peconic Bay Surveys all had high probabilities of their terminal year ARIMA indices being lower than their 1998 reference points (Figure 27; Table 13). The Connecticut Long Island Sound has an increasing trend since 2012 and Northeast Area Monitoring and Assessment Program (NEAMAP) and the New York Peconic Trawl Surveys increased over the last five years.

ARIMA model fits to the Delaware Bay surveys generally all showed increasing trends and low probabilities of being less than Q_{25} and 1998 reference points by the terminal year (Figure 28 - Figure 31; Table 13). One exception is the Virginia Tech Trawl Survey for primiparous females which has shown low abundance since 2019. As discussed in TOR 4a, three possible hypotheses for this observation have been discussed among SAS and TC members: 1) recruitment failure in recent years; 2) a change in the spatial distribution of primiparous females resulting in lower catchability; or 3) misclassification of primiparous individuals as multiparous individuals. Recruitment failure seems like the least likely hypothesis because multiparous females continued to increase and there was not a concurrent decrease in primiparous males.

Previous benchmark assessments and stock assessment updates for the Southeast Region generally showed increasing or stable trends in horseshoe crab abundance. This update indicates that there may now be some decline in abundance. The South Carolina Trammel Net, Georgia Trawl, and the Georgia-Florida portion of the Southeast Area Monitoring and Assessment Program (SEAMAP) Surveys showed declining trends in recent years, although probabilities of being less than Q_{25} and 1998 reference points were still rather low (i.e., <50%; Figure 32; Table 13). As discussed in TOR 2a, the South Carolina Trammel Net and Southeast Area Monitoring and Assessment (SEAMAP) Surveys had reduced sampling in 2020-2022. Because it is unknown if their recent trends are due to abundance or reduced sampling, those recent trends should be interpreted with caution.

TOR 5. Stock Status

Update the biological reference points or trend-based indicators/metrics for the stock. Determine stock status.

As in ASMFC 2019, stock status was 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. This reference point represents the point in time when horseshoe crabs became actively managed by ASMFC and status relative to this reference point gives an indication of the effects of management on populations. ARIMA results from surveys used to determine stock status included those surveys with combined-sex indices, time series extended back to at least 1998, and 2022 as the terminal year. Within a region, “Poor” status was considered >66% of surveys meeting the >50% criterion, “Good” status was <33% of surveys, and “Neutral” status was 34 – 65% of surveys.

The stock status of the Northeast region was “Neutral”; New York region was “Poor”; Delaware Bay region was “Good”; and Southeast region was “Good” (Table 14). These regional stock status determinations remained the same as was found in the 2019 benchmark assessment except that the Delaware Bay region improved from a “Neutral” status to a “Good” status. When taken as a whole, the coastwide stock status also moved from a “Neutral” status in the 2019 benchmark assessment to a “Good” stock status in 2024. A more detailed description of the surveys used to determine stock status is provided in Table 15. Trends since the terminal years in the last benchmark stock assessment (2017) and last stock assessment update (2012) are also provided and were determined via Mann-Kendall tests for monotonic trends. All surveys used for stock status in the Delaware Bay region showed increasing trends since the last stock assessment update (2012 terminal year). Other regions showed mixed recent trends. Stock status in the New York region remained “Poor” since the 2019 benchmark stock assessment. Two surveys (Jamaica Bay and Littleneck and Manhasset Bays) continued to decrease since 2012, but the Connecticut Long Island Sound Trawl Survey increased since 2012. The two hypotheses for the status of the New York region put forth in the 2019 benchmark assessment remain possible: 1) bait harvest remains at a level that is not sustainable in the New York region; or 2) the habitat has changed and cannot support the number of horseshoe crabs it once did.

Although the stock status of the Southeast region was determined to be “Good” according to the methods and surveys included in the 2019 stock status determination, this stock status should be viewed with caution. Stock status in the Southeast region is based on only two surveys that extend back to 1998, one of which showed recent declining trends (South Carolina Trammel Net). Also, other surveys in the Southeast that were not used to make the stock status determination for that region have shown decreasing trends (Georgia Trawl and Georgia-Florida portion of SEAMAP) or no trend (South Carolina portion of SEAMAP) since 2012. Regardless, none of these surveys showed a high probability of being less than their Q_{25} reference points, so they are certainly not near their lowest recorded levels, but recent possible declines may be noteworthy to managers. As discussed in TOR 2a, the South Carolina Trammel Net and Southeast Area Monitoring and Assessment (SEAMAP) Surveys had reduced sampling in 2020-2022. Because it is unknown if their recent trends are due to abundance or reduced sampling, those recent trends should be interpreted with caution.

TOR 6. Projections

Conduct short term projections when appropriate. Discuss assumptions if different from the benchmark and describe alternate runs.

There are no projections associated with any model in this stock assessment.

TOR 7. Research Recommendations

Comment on research recommendations from the benchmark stock assessment and note which have been addressed or initiated. Indicate which improvements should be made before the stock undergoes a benchmark assessment.

Several studies published since the 2019 benchmark have addressed the research recommendation to collect more information on horseshoe crab ecology and movement. Two studies focused on juvenile habitat use. Cheng et al. (2021) used SCUBA-diving methods to survey juveniles in Great Bay, New Hampshire, which found that horseshoe crabs were generally occupying sub- and inter-tidal mudflats within 2.5 km of known spawning beaches. Colon et al. (2021) found that salt marsh tidal creeks and restored intertidal flats may be important habitat for juveniles in Plumb Beach, New York, and that the presence of juveniles in these habitats fluctuated both seasonally and annually. Increasing evidence also suggests that adults may use salt marsh habitat for spawning. Kendrick et al. (2021) found developing eggs in the salt marshes of South Carolina, and Sasson et al. (2024) found that horseshoe crab spawning densities in salt marshes are similar to those on beaches in New Hampshire, Connecticut, and South Carolina. Bopp et al. (2023) used stable isotopes to investigate ontogenetic shifts and regional differences in the diets of juveniles and adults in Long Island, New York; while confirming that horseshoe crabs at all stages are dietary generalists, resource use differed by location and sex. A mark-recapture study in that same region also found spatial and sex differences in the movement patterns and survival of adult horseshoe crabs (Bopp et al. 2019).

Numerous studies focusing on the biomedical industry have also been published since ASMFC 2019. Several papers focused on horseshoe crab aquaculture for use by the biomedical industry (Tinker-Kulberg et al. 2020a, 2020b, 2020c). A large-scale mark-recapture analysis of crabs tagged in the Delaware Bay and coastal Delaware and Virginia found higher survival for bled male crabs than unbled males; results were more mixed for females (Smith et al. 2020). The authors suggest this may, in part, be due to a selection bias for healthier or younger crabs in the biomedical industry. Bleeding also led to a reduced post-release capture probability, potentially indicating decreased spawning activity, which was a pattern also seen in a study that attached acoustic transmitters to bled and unbled crabs (Owings et al. 2019). Further acoustic telemetry research by Watson et al. (2022) showed that bled females were less likely to spawn than unbled females. Owings et al. (2020) also found that while bleeding alone resulted in low (6%) mortality, adding multiple stressors such as exposure to direct sunlight or heat greatly increased mortality rates. Finally, Litzenberg (2023) found that the age of male horseshoe crabs or the temperature of the water in which they were kept did not correlate with amoebocyte and hemocyanin concentration. However, water temperature affected metabolic rates, and both age and water temperature correlated with metabolomic signatures of stress.

ASMFC 2019 recommended that the ARM Subcommittee consider using the CMSA model, discard estimates, and biomedical data in the ARM Framework and that change was made and peer reviewed in the ARM Revision (ASMFC 2022). Additionally, the CMSA was peer reviewed and published in Anstead et al. 2023. The CMSA depends on the Virginia Tech Trawl Survey and a research recommendation in ASMFC 2019 was to fund and operate that survey annually, which has been done through 2023. The CMSA also depends on staged data from the Virginia Tech Trawl Survey, although collecting more stage-based data was a research recommendation, and that work has begun in New Jersey, Delaware, and South Carolina in various fishery-independent surveys.

All research recommendations from ASMFC 2019 remain important to the continued assessment of horseshoe crabs, including those updated in this section. The complete list of research recommendations can be found in Appendix c. In addition, the SAS would like to add the following research recommendations:

- Consider abbreviating the time series for the South Carolina Trammel Net and SEAMAP surveys for years with reduced sampling in the strata/stations used for the relative abundance indices.

- Maintain pre-pandemic levels of tagging effort along the Atlantic coast and revise the natural mortality estimate in the Delaware Bay region once tagging efforts resume to pre-pandemic levels.

- Evaluate the use of Z instead of M calculated from the survival estimates that are used in the CMSA for the Delaware Bay.

- Reexamine stock structure, especially in the northeast region, given more recent genetic analysis and tagging data analysis.

REFERENCES

Anstead, K.A., J.A. Sweka, L. Barry, E.M. Hallerman, D.R. Smith, N. Ameral, M. Schmidtke, and R.A. Wong. 2023. Application of a catch multiple survey analysis for Atlantic horseshoe crab *Limulus polyphemus* in the Delaware Bay. Marine and Coastal Fisheries 15(5): e10250.

Atlantic States Marine Fisheries Commission (ASMFC). 2019. Horseshoe Crab Benchmark Stock Assessment and Peer Review Report. Arlington, VA.

Atlantic States Marine Fisheries Commission (ASMFC). 2022. Revision to the Adaptive Resource Management Framework and Peer Review Report. Arlington, VA.

Bopp, J., J.A. Olin, M. Sclafani, B. Peterson, M.G. Frisk, and R.M. Cerrato. 2023. Contrasting trophic niche and resource use dynamics across multiple American horseshoe crab (*Limulus polyphemus*) populations and age groups. Estuaries and Coasts 46(1): 227-245.

Bopp, J., M. Sclafani, D.R. Smith, K. McKown, R. Sysak, and R.M. Cerrato. 2019. Geographic-specific capture–recapture models reveal contrasting migration and survival rates of adult horseshoe crabs (*Limulus polyphemus*). Estuaries and Coasts 42: 1570-1585.

Box, G. E. and G. M. Jenkins. 1976. Time series analysis: forecasting and control, revised ed. Holden-Day, Oakland, CA.

Cheng, H., C.C. Chabot, and W.H. Watson III. 2021. Distribution of juvenile American horseshoe crabs *Limulus polyphemus* in the Great Bay Estuary, New Hampshire, USA. Marine Ecology Progress Series 662: 199-203.

Cheng, H., V. Vaattovaara, M. Conelly, B. Looney, C. Chabot, and W. Watson. 2022. Temperature and Salinity Preferences of Adult American Horseshoe Crabs (*Limulus polyphemus)* in the Great Bay Estuary, New Hampshire USA. Eds. Tanacredi, J.T, Botton, M.L., Shin, P.K.S., Iwasaki, Y., Cheung, S.G., Kwan, K. Y., Mattei, J.H. International Horseshoe Crab Conservation and Research Efforts: 2007-2020: Conservation of Horseshoe Crabs Species Globally. Cham: Springer International Publishing, 2022. 581-598.

Colon, C.P., M.L. Botton, P. Funch, E. Hoffgaard, K. Mandeep, and K. Mansfield. 2022. Ecology of Juvenile American Horseshoe Crabs (*Limulus polyphemus*) at Plumb Beach, Jamaica Bay, New York. In International Horseshoe Crab Conservation and Research Efforts: 2007-2020: Conservation of Horseshoe Crabs Species Globally (pp. 669-690). Cham: Springer International Publishing.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology, 68(5): 1364-1372.

Helser, T. E. and D. B. Hayes. 1995. Providing quantitative management advice from stock abundance indices based on research surveys. Fishery Bulletin 93: 290 – 298.

Kendrick, M.R., J.F. Brunson, D.A. Sasson, K.L. Hamilton, E.L. Gooding, S.L. Pound, and P.R. Kingsley-Smith. 2021. Assessing the viability of American horseshoe crab (*Limulus polyphemus*) embryos in salt marsh and sandy beach habitats. The Biological Bulletin 240(3): 145-156.

Litzenberg, K.L. 2023. The Physiological Effects of Age and Temperature on Blood Chemistry, Metabolism, and Mortality of Harvested Horseshoe Crabs *(Limulus polyphemus)* (Doctoral dissertation, College of Charleston).

Owings, M., C. Chabot, and W. Watson III. 2019. Effects of the biomedical bleeding process on the behavior of the American horseshoe crab, *Limulus polyphemus*, in its natural habitat. The Biological Bulletin 236(3): 207-223.

Owings, M., C. Chabot, and W. Watson III. 2020. Effects of the biomedical bleeding process on the behavior and hemocyanin levels of the American horseshoe crab (*Limulus polyphemus*). Fishery Bulletin 118.3.

Pennington, M. 1983. Efficient estimators of abundance, for fish and plankton surveys. Biometrics: 281-286.

Sasson, D.A., C.C. Chabot, J.H. Mattei, J.F. Brunson, F.K. Hall, J.H. Huber, J.E. Kasinak, C. McShane, P.T. Puckette, G. Sundin, P.R. Kingsley-Smith, and M.R. Kendrick. 2024. The American horseshoe crab, *Limulus polyphemus*, spawns regularly in salt marshes. Frontiers in Ecology and the Environment: e2738.

Smith, D.R., J.J. Newhard, C.P. McGowan, and C.A. Butler. 2020. The long-term effect of bleeding for limulus amebocyte lysate on annual survival and recapture of tagged horseshoe crabs. Frontiers in Marine Science 7: 607668.

Tinker-Kulberg, R., A. Dellinger, T.E. Brady, L. Robertson, M.K. Goddard, J. Bowzer, S.K. Abood, C. Kepley, and K. Dellinger. 2020a. Effects of diet on the biochemical properties of Limulus amebocyte lysate from horseshoe crabs in an aquaculture setting. Frontiers in Marine Science 7: 541604.

Tinker-Kulberg, R., K. Dellinger, T. E. Brady, L., Robertson, J.H. Levy, S.K. Abood, F.M. LaDuca, C.L. Kepley, and A.L. Dellinger. 2020b. Horseshoe crab aquaculture as a sustainable endotoxin testing source. Frontiers in Marine Science 7: 153.

Tinker-Kulberg, R., A.L. Dellinger, L.C. Gentit, B.A. Fluech, C.A. Wilder, I.L. Spratling, C.L. Kepley, L. Robertson, M.K. Goddard, and K. Dellinger. 2020c. Evaluation of indoor and outdoor aquaculture systems as alternatives to harvesting hemolymph from random wild capture of horseshoe crabs. Frontiers in Marine Science 7: 568628.

Watson III, W.H., A.G. Lemmon, and C.C. Chabot. 2022. Impacts of biomedical bleeding on locomotion and mating behavior in the horseshoe crab *Limulus polyphemus*. Marine Ecology Progress Series 699: 65-74.

TABLES

Table 1. Coastwide horseshoe crab commercial bait landings in numbers, 1998-2022, as validated by ACCSP.

Year	Female Horseshoe Crabs (#s)	Male Horseshoe Crabs (#s)	Unclassified Sex (#s)	Total Horseshoe Crabs (#s)
1998	382,199	413,698	732,119	1,916,450
1999	388,280	466,540	1,219,625	2,605,280
2000	189,653	392,123	822,207	1,676,913
2001	155,561	280,626	215,077	785,407
2002	299,296	558,704	270,181	1,266,794
2003	233,583	415,456	273,697	1,048,100
2004	146,399	201,252	239,363	656,441
2005	142,303	258,774	253,614	710,534
2006	201,063	212,478	241,602	796,697
2007	141,705	186,625	363,462	785,855
2008	89,817	229,265	246,361	661,209
2009	115,590	339,447	208,119	757,550
2010	97,546	269,118	176,384	599,562
2011	79,827	315,679	212,768	697,656
2012	135,266	287,991	248,962	796,867
2013	83,161	477,844	241,640	951,362
2014	38,314	423,265	196,028	787,398
2015	33,398	247,593	198,044	596,646
2016	42,636	402,770	235,166	790,971
2017	151,157	659,947	166,061	977,165
2018	128,379	375,093	173,620	677,092
2019	127,963	465,461	219,107	812,531
2020	34,956	222,084	182,997	440,037
2021	91,191	483,785	181,207	756,183
2022	80,958	348,128	144,547	573,633

Table 2. Numbers of horseshoe crabs collected and bled, by sex, and estimated mortality for the biomedical industry as reported in annual Fishery Management Plan Reviews.

Year	Horseshoe Crabs Collected	Males Bled	Females Bled	Unsexed Bled	Total Horseshoe Crabs Bled	Total Mortality
2004	284,215	488	20,276	80,256	101,020	25,298
2005	248,475	52,308	25,171	112,883	190,362	31,584
2006	237,822	41,751	15,053	120,795	177,599	29,090
2007	416,824	61,656	18,209	272,780	352,645	57,560
2008	422,958	79,976	25,664	292,169	397,809	66,147
2009	414,959	88,678	35,712	261,728	386,118	64,236
2010	480,914	108,941	42,118	261,722	412,781	68,746
2011	545,164	122,999	82,002	281,849	486,850	97,166
2012	541,956	134,807	103,025	260,124	497,956	82,063
2013	464,657	114,459	84,914	241,029	440,402	71,507
2014	467,897	124,965	83,135	224,240	432,340	70,509
2015	494,123	139,135	92,289	233,082	464,506	75,038
2016	344,495	31,214	46,320	240,989	318,523	48,782
2017	483,245	262,133	141,903	40,079	444,115	72,674
2018	510,407	279,013	156,450	43,679	479,142	77,459
2019	637,029	353,609	235,752	0	589,361	101,193
2020	697,025	393,919	255,627	0	649,546	106,339
2021	718,809	388,220	279,731	0	667,951	112,104
2022	911,826	358,602	284,066	185,513	828,181	145,920

Table 3. Estimated number of dead horseshoe crabs caught and discarded from other commercial fisheries with upper and lower 95% confidence intervals (LCI, UCI) by sex for use in the catch multiple survey model.

Year	Males			Females		
	Dead Discards	LCI	UCI	Dead Discards	LCI	UCI
2003	9,117	2,545	16,623	6,567	1,722	11,455
2004	13,265	3,882	22,649	9,554	2,796	16,313
2005	4,209	1,709	7,009	3,031	1,231	5,048
2006	12,028	1,066	22,992	8,664	768	16,560
2007	9,024	2,716	15,333	6,500	1,956	11,043
2008	7,059	2,580	11,537	5,084	1,859	8,309
2009	11,767	3,317	20,218	8,475	2,389	14,562
2010	16,004	7,403	24,623	11,527	5,332	17,735
2011	20,468	8,627	32,310	14,742	6,213	23,271
2012	6,488	1,684	11,336	4,673	1,213	8,165
2013	15,179	3,391	26,966	10,933	2,443	19,423
2014	21,919	578	53,372	15,787	417	38,441
2015	16,096	7,944	24,247	11,593	5,722	17,464
2016	70,904	31,211	110,597	51,069	22,480	79,658
2017	43,451	4,527	82,374	31,295	3,261	59,330
2018	12,752	1,263	24,240	9,184	910	17,459
2019	50,177	20,042	80,312	36,140	14,435	57,845
2020	32,057	7,485	56,630	23,089	5,391	40,788
2021	76,078	70	173,196	54,795	50	124,745
2022	3,040	554	5,526	2,190	399	3,980

Table 4. Fishery-independent surveys used for developing indices of relative horseshoe crab abundance. Additional information on season, horseshoe crab sex, model used, and time series for each index provided. Information on covariates used in the generalized linear model (GLM) standardization can be found in Table A1. Table continues on next page. Surveys with an * indicate there was reduced sampling in the strata used in the index in 2020-2022 and therefore those trends should be interpreted cautiously.

Survey	Region	Season	Sex	Model	Time Series
Massachusetts Trawl - North of Cape Cod	Northeast	Fall	All	Delta	1982-2019, 2021-2022
Massachusetts Trawl - South of Cape Cod	Northeast	Fall	All	Delta	1982-2019, 2021-2022
Rhode Island Monthly Trawl	Northeast	Fall	All	Negative binomial (NB) GLM	1998-2022
Connecticut Long Island Sound Trawl Survey (LISTS)	New York	Fall	All	Delta	1997-2009, 2011-2019, 2021-2022
New York Peconic Trawl	New York	Fall	All	Delta	1987-2022
New York Western Long Island Sound (WLIS) Beach Seine - Jamaica Bay	New York	Spring	All	NB GLM	1987-2019, 2021-2022
New York WLIS Beach Seine - Little Neck and Manhasset Bays	New York	Spring	All	NB GLM	1987-2019, 2021-2022
NEAMAP - New York	New York	Fall	All	Delta	2007-2022
NEAMAP - Delaware Bay	Delaware Bay	Fall	All	Delta	2007-2022
New Jersey Ocean Trawl (NJ OT)	Delaware Bay	Spring	All	Delta	1999-2019, 2022
NJ OT	Delaware Bay	Spring	Females	Delta	1999-2019, 2022
NJ OT	Delaware Bay	Spring	Males	Delta	1999-2019, 2022
New Jersey Ocean Trawl (NJ OT)	Delaware Bay	Spring	All	Delta	1999-2019, 2022
NJ OT	Delaware Bay	Spring	Females	Delta	1999-2019, 2022
NJ OT	Delaware Bay	Spring	Males	Delta	1999-2019, 2022
NJ OT	Delaware Bay	Fall	All	Delta	1999-2019, 2022
NJ OT	Delaware Bay	Fall	Females	Delta	1999-2019, 2022
NJ OT	Delaware Bay	Fall	Males	Delta	1999-2019, 2022

Table 4 continued from previous page. Surveys with an * indicate there was reduced sampling in the strata used in the index in 2020-2022 and therefore those trends should be interpreted cautiously. ** Since ASMFC 2019, the South Carolina Crustacean Research and Monitoring Survey has been renamed as the Estuarine Trawl Survey but this update uses the older name for consistency with the benchmark.

Survey	Region	Season	Sex	Model	Time Series
Delaware Adult 30' Trawl	Delaware Bay	Spring	All	NB GLM	1990-2022
Delaware Adult 30' Trawl	Delaware Bay	Spring	Females	NB GLM	1990-2022
Delaware Adult 30' Trawl	Delaware Bay	Spring	Males	NB GLM	1990-2022
Delaware Adult 30' Trawl	Delaware Bay	Fall	All	NB GLM	1990-2022
Delaware Adult 30' Trawl	Delaware Bay	Fall	Females	NB GLM	1990-2022
Delaware Adult 30' Trawl	Delaware Bay	Fall	Males	NB GLM	1990-2022
Maryland Coastal Bays	Delaware Bay	Spring	All	NB GLM	1990-2022
Virginia Tech Trawl	Delaware Bay	Fall	Females	Delta	2002-2011, 2016-2022
Virginia Tech Trawl	Delaware Bay	Fall	Females	Delta	2002-2011, 2016-2022
North Carolina Gill Net	Southeast	Spring	All	Delta	2001-2016, 2018-2019, 2022
* SEAMAP - South Carolina	Southeast	Fall	All	Delta	2001-2019, 2021-2022
* SEAMAP - Georgia and Florida	Southeast	Fall	All	Delta	2001-2019, 2021-2022
**South Carolina Crustacean Research Monitoring Survey (CRMS)	Southeast	Spring	All	NB GLM	1995-2019, 2021-2022
* South Carolina Trammel Net	Southeast	Spring	All	NB GLM	1995-2019, 2021-2022
Georgia Ecological Monitoring Survey	Southeast	Spring	All	NB GLM	1999-2023

Table 5. Results of the power analysis by survey for linear and exponential trends in horseshoe crab abundance indices over a twenty-year period. Power was calculated as the probability of detecting a 50% change following the methods of Gerrodette (1987). Table continues on next two pages.

Survey	Median CV	Exponential		Linear	
		50%	-50%	50%	-50%
Northeast Region					
MA Trawl North of Cape Cod - Fall Combined Sexes	0.78	0.13	0.20	0.11	0.16
MA Trawl South of Cape Cod - Fall Combined Sexes	0.55	0.20	0.32	0.18	0.27
RI Monthly Trawl - Fall Combined Sexes	0.45	0.27	0.43	0.25	0.38
New York Region					
CT Long Island Sound Trawl - Fall Combined Sexes	0.23	0.70	0.90	0.69	0.89
NY Jamaica Bay Beach Seine - Spring Combined Sexes	0.46	0.26	0.41	0.24	0.37
NY Little Neck and Manhasset Bay Beach Seine - Spring Combined Sexes	0.29	0.51	0.73	0.50	0.71
NY NEAMAP - Fall Combined Sexes	0.38	0.34	0.53	0.32	0.49
NY Peconic Bay Trawl - Fall Combined Sexes	0.13	0.99	1.00	0.99	1.00
Delaware Bay Region					
DE Adult Trawl - Fall Combined Sexes	0.15	0.96	1.00	0.96	1.00
DE Adult Trawl - Fall Female	0.62	0.17	0.27	0.15	0.22
DE Adult Trawl - Fall Male	0.27	0.57	0.80	0.56	0.78
DE Adult Trawl - Spring Combined Sexes	0.13	1.00	1.00	0.99	1.00
DE Adult Trawl - Spring Female	0.36	0.38	0.58	0.36	0.55
DE Adult Trawl - Spring Male	0.29	0.53	0.76	0.51	0.73

Table 5 Continued.

Survey	Median CV	Exponential		Linear	
		50%	-50%	50%	-50%
Delaware Bay Region (continued)					
Delaware Bay NEAMAP - Fall Combined Sexes	0.31	0.47	0.69	0.46	0.66
MD Coastal Bays - Spring Combined Sexes	0.42	0.30	0.47	0.28	0.43
NJ Ocean Trawl - Fall Adults Combined Sexes	0.33	0.42	0.64	0.41	0.61
NJ Ocean Trawl - Fall All Crabs Combined Sexes	0.32	0.44	0.66	0.43	0.63
NJ Ocean Trawl - Fall Female	0.31	0.48	0.70	0.47	0.68
NJ Ocean Trawl - Fall Male	0.37	0.36	0.55	0.34	0.51
NJ Ocean Trawl - Spring Adults Combined Sexes	0.29	0.52	0.75	0.51	0.72
NJ Ocean Trawl - Spring All Crabs Combined Sexes	0.29	0.53	0.76	0.52	0.74
NJ Ocean Trawl - Spring Female	0.25	0.64	0.85	0.63	0.84
NJ Ocean Trawl - Spring Male	0.30	0.50	0.73	0.49	0.70
VA Tech Trawl - All Crabs	0.16	0.94	1.00	0.94	1.00
VA Tech Trawl - Immature Female	0.31	0.47	0.69	0.46	0.67
VA Tech Trawl - Immature Male	0.33	0.42	0.64	0.41	0.60
VA Tech Trawl - Multiparous Female	0.28	0.56	0.78	0.54	0.76
VA Tech Trawl - Multiparous Male	0.28	0.54	0.77	0.53	0.75
VA Tech Trawl - Primiparous Female	0.31	0.48	0.71	0.47	0.68
VA Tech Trawl - Primiparous Male	0.34	0.40	0.61	0.39	0.58

Table 5 Continued. * Since ASMFC 2019, the South Carolina Crustacean Research and Monitoring Survey (CRMS) has been renamed as the Estuarine Trawl Survey but this update uses the older name for consistency with the benchmark.

Survey	Median CV	Exponential		Linear	
		50%	-50%	50%	-50%
Southeast Region					
GA Trawl - Spring Combined Sexes	0.23	0.72	0.91	0.72	0.90
GA-FL SEAMAP - Fall Combined Sexes	0.39	0.33	0.52	0.32	0.48
NC Gill Net - Spring Combined Sexes	0.15	0.96	1.00	0.96	1.00
* SC CRMS - Spring Combined Sexes	0.55	0.20	0.32	0.18	0.27
SC SEAMAP - Fall Combined Sexes	0.50	0.22	0.36	0.21	0.32
SC Trammel Net - Spring Combined Sexes	0.35	0.39	0.59	0.37	0.56

Table 6. Data and results for the Mann-Kendall test of temporal trends in sex ratios, defined as the ratio of males to females. Significant *P*-values are in bold. The New Jersey Ocean trawl did not operate in 2020-2021 due to COVID.

Survey	Season	Sex Ratio	tau	*P*-value	Years included in analysis
DE Adult Trawl	Spring	1.21	0.44	**0.00**	1990 - 2022
DE Adult Trawl	Fall	2.10	0.30	**0.02**	1990 - 2022
NJ Ocean Trawl	Spring	1.18	0.16	0.32	1999 - 2022
NJ Ocean Trawl	Fall	1.36	0.35	**0.02**	1999 - 2022

Table 7. Sex ratio and proportion female information, with associated confidence limits, for the New Jersey Ocean Trawl. There was no sampling in 2020-2021 due to COVID.

Season	Year	Proportion Female	LCL	UCL	Sex Ratio	LCL	UCL
Spring	1996	60%	52%	68%	0.67	0.44	0.91
Spring	1999	44%	36%	52%	1.26	0.86	1.67
Spring	2000	49%	43%	54%	1.05	0.82	1.28
Spring	2001	45%	38%	53%	1.20	0.85	1.56
Spring	2002	63%	51%	74%	0.60	0.30	0.90
Spring	2003	48%	41%	55%	1.08	0.77	1.40
Spring	2004	51%	45%	57%	0.97	0.75	1.19
Spring	2005	47%	41%	54%	1.11	0.82	1.39
Spring	2006	54%	38%	70%	0.85	0.30	1.41
Spring	2007	53%	40%	65%	0.90	0.45	1.35
Spring	2008	50%	45%	55%	1.00	0.81	1.18
Spring	2009	44%	37%	51%	1.25	0.90	1.61
Spring	2010	42%	38%	45%	1.41	1.19	1.63
Spring	2011	56%	47%	65%	0.79	0.49	1.08
Spring	2012	46%	41%	52%	1.16	0.89	1.43
Spring	2013	53%	44%	61%	0.90	0.59	1.21
Spring	2014	52%	40%	63%	0.94	0.52	1.36
Spring	2015	46%	32%	60%	1.18	0.52	1.83
Spring	2016	49%	43%	54%	1.06	0.81	1.30
Spring	2017	43%	29%	57%	1.31	0.57	2.06
Spring	2018	41%	34%	48%	1.43	1.03	1.83
Spring	2019	54%	41%	68%	0.84	0.39	1.30
Spring	2022	39%	33%	45%	1.59	1.18	2.00

Season	Year	Proportion Female	LCL	UCL	Sex Ratio	LCL	UCL
Fall	1996	44%	39%	48%	1.30	1.04	1.56
Fall	1999	52%	46%	58%	0.93	0.71	1.14
Fall	2000	51%	41%	60%	0.98	0.61	1.35
Fall	2001	52%	44%	60%	0.94	0.63	1.24
Fall	2002	50%	42%	58%	1.00	0.69	1.31
Fall	2003	46%	38%	54%	1.19	0.81	1.58
Fall	2004	51%	47%	56%	0.96	0.78	1.13
Fall	2005	38%	32%	44%	1.63	1.19	2.07
Fall	2006	44%	37%	51%	1.28	0.90	1.66
Fall	2007	44%	39%	49%	1.28	1.01	1.54
Fall	2008	59%	49%	68%	0.70	0.42	0.98
Fall	2009	50%	36%	64%	1.02	0.45	1.59
Fall	2010	46%	31%	62%	1.16	0.45	1.86
Fall	2011	43%	31%	55%	1.34	0.68	2.01
Fall	2012	45%	31%	60%	1.22	0.51	1.94
Fall	2013	65%	42%	88%	0.54	0.00	1.07
Fall	2014	43%	34%	52%	1.32	0.83	1.81
Fall	2015	47%	37%	58%	1.12	0.64	1.60
Fall	2016	40%	28%	52%	1.52	0.75	2.29
Fall	2017	47%	33%	62%	1.12	0.47	1.77
Fall	2018	38%	26%	50%	1.62	0.79	2.44
Fall	2019	32%	25%	39%	2.10	1.43	2.78
Fall	2022	47%	37%	57%	1.14	0.69	1.58

Table 8. Sex ratio and proportion female information, with associated confidence limits, for the Delaware Adult Trawl.

Season	Year	Proportion Female	LCL	UCL	Sex Ratio	LCL	UCL
Spring	1990	54%	45%	63%	0.86	0.55	1.16
Spring	1991	50%	44%	56%	1.00	0.77	1.23
Spring	1992	50%	41%	60%	0.99	0.63	1.35
Spring	1993	45%	35%	55%	1.23	0.71	1.74
Spring	1994	41%	30%	51%	1.45	0.82	2.08
Spring	1995	51%	43%	59%	0.96	0.64	1.28
Spring	1996	65%	56%	75%	0.53	0.31	0.75
Spring	1997	46%	36%	55%	1.20	0.75	1.65
Spring	1998	55%	44%	65%	0.82	0.47	1.17
Spring	1999	48%	38%	57%	1.11	0.70	1.51
Spring	2000	47%	39%	54%	1.14	0.80	1.48
Spring	2001	52%	43%	61%	0.92	0.58	1.25
Spring	2002	65%	30%	100%	0.54	0.00	1.38
Spring	2003	49%	36%	61%	1.06	0.54	1.58
Spring	2004	60%	0%	100%	0.67	0.00	2.40
Spring	2005	67%	28%	100%	0.50	0.00	1.36
Spring	2006	53%	42%	63%	0.90	0.53	1.28
Spring	2007	37%	27%	47%	1.73	1.00	2.46
Spring	2008	44%	23%	65%	1.27	0.21	2.34
Spring	2009	40%	28%	52%	1.50	0.75	2.25
Spring	2010	28%	11%	45%	2.55	0.40	4.69
Spring	2011	29%	18%	41%	2.43	1.09	3.76
Spring	2012	46%	31%	60%	1.20	0.50	1.90
Spring	2013	36%	1%	70%	1.80	0.00	4.50
Spring	2014	38%	30%	47%	1.61	1.02	2.19
Spring	2015	37%	26%	48%	1.71	0.88	2.55
Spring	2016	43%	34%	51%	1.34	0.89	1.80
Spring	2017	34%	26%	41%	1.99	1.34	2.64
Spring	2018	34%	29%	38%	1.98	1.55	2.41
Spring	2019	37%	29%	44%	1.74	1.15	2.32
Spring	2020	42%	25%	59%	1.39	0.44	2.35
Spring	2021	33%	27%	39%	2.04	1.49	2.59
Spring	2022	37%	27%	48%	1.68	0.94	2.42

Season	Year	Proportion Female	LCL	UCL	Sex Ratio	LCL	UCL
Fall	1990	41%	33%	48%	1.47	1.01	1.92
Fall	1991	43%	33%	54%	1.30	0.76	1.85
Fall	1992	26%	17%	36%	2.83	1.45	4.22
Fall	1993	33%	26%	40%	2.04	1.43	2.64
Fall	1994	29%	7%	50%	2.50	0.00	5.14
Fall	1995	47%	37%	57%	1.12	0.68	1.56
Fall	1996	30%	24%	37%	2.32	1.61	3.04
Fall	1997	37%	25%	49%	1.70	0.82	2.58
Fall	1998	33%	20%	45%	2.08	0.88	3.27
Fall	1999	36%	24%	49%	1.76	0.81	2.70
Fall	2000	50%	39%	61%	1.00	0.57	1.43
Fall	2001	44%	0%	96%	1.25	0.00	3.87
Fall	2002	39%	6%	72%	1.57	0.00	3.77
Fall	2003	35%	21%	50%	1.82	0.67	2.98
Fall	2004	50%	0%	100%	1.00	0.00	13.71
Fall	2005	43%	0%	100%	1.33	0.00	4.50
Fall	2006	29%	22%	36%	2.48	1.62	3.33
Fall	2007	30%	14%	45%	2.38	0.65	4.11
Fall	2008	27%	0%	61%	2.67	0.00	7.22
Fall	2009	24%	2%	47%	3.13	0.00	6.95
Fall	2010	32%	0%	63%	2.14	-0.96	5.25
Fall	2011	25%	0%	54%	3.00	0.00	7.58
Fall	2012	23%	0%	48%	3.40	0.00	8.20
Fall	2013	39%	30%	49%	1.55	0.93	2.16
Fall	2014	30%	17%	44%	2.30	0.85	3.74
Fall	2015	42%	32%	52%	1.38	0.81	1.95
Fall	2016	27%	22%	32%	2.67	2.02	3.32
Fall	2017	26%	17%	34%	2.88	1.62	4.13
Fall	2018	37%	30%	44%	1.72	1.19	2.25
Fall	2019	23%	18%	27%	3.41	2.51	4.30
Fall	2020	35%	25%	45%	1.89	1.05	2.74
Fall	2021	24%	15%	32%	3.26	1.70	4.83
Fall	2022	28%	22%	34%	2.56	1.77	3.34

Table 9. Recapture rate relative to total recaptures for each region of release (source: USFWS tagging database).

	Released	Northeast	Coastal NY-NJ	Delaware Bay	Coastal DE-VA	Southeast
Northeast	100,379	93%	7%	0%	0%	0%
Coastal NY-NJ	62,083	6%	92%	1%	0%	0%
Delaware Bay	96,973	0%	3%	92%	4%	0%
Coastal DE-VA	124,835	1%	2%	31%	66%	0%
Southeast	16,458	0%	0%	1%	1%	97%

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

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 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; source: USFWS tagging database).

RELEASES																	
Region	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2009-2019 Average Releases	2020 Difference from Average	2021 Difference from Average	2022 Difference from Average
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																	
Region	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2009-2019 Average Recaps	2020 Difference from Average	2021 Difference from Average	2022 Difference from Average
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 12. ARIMA summary statistics for horseshoe crab surveys. W is the Shapiro-Wilk test statistic for normality of residuals; *P* is the *P*-value of the normality test; n is the number of years in the time series; r1, r2, and r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; and σ^2_c is the variance of the index. Table continued on next few pages.

Survey	Years	n	W	*P*	r1	r2	r3	θ	SE	σ^2_c
Northeast Region										
MA Trawl North of Cape Cod - Fall Combined Sexes	(1982 - 2022)	41	0.85	0.00	-0.31	-0.39	0.26	0.95	0.21	3.11
MA Trawl South of Cape Cod - Fall Combined Sexes	(1982 - 2022)	41	0.93	0.02	-0.33	-0.25	0.18	0.93	0.17	2.42
RI Monthly Trawl - Fall Combined Sexes	(1998 - 2022)	25	0.97	0.62	-0.58	0.18	0.15	0.67	0.17	0.41
New York Region										
CT Long Island Sound Trawl - Fall Combined Sexes	(1997 - 2022)	26	0.93	0.11	-0.51	0.02	-0.03	0.44	0.20	0.18
NY Jamaica Bay Beach Seine - Spring Combined Sexes	(1987 - 2022)	36	0.96	0.16	-0.44	0.10	0.08	0.80	0.10	0.55
NY Little Neck and Manhasset Bay Beach Seine - Spring Combined Sexes	(1987 - 2022)	36	0.95	0.12	-0.30	-0.14	-0.07	0.60	0.13	0.26
NY NEAMAP - Fall Combined Sexes	(2007 - 2022)	16	0.96	0.71	-0.28	-0.12	0.13	0.41	0.35	0.62
NY Peconic Trawl - Fall Combined Sexes	(1987 - 2022)	36	0.66	0.00	-0.48	0.01	0.08	0.65	0.12	0.79

Table 12 Continued.

Survey	Years	n	W	*P*	r1	r2	r3	θ	SE	σ^2_c
Delaware Bay Region										
DE Adult Trawl - Fall Combined Sexes	(1990 - 2022)	33	0.97	0.46	-0.24	-0.54	0.33	0.69	0.13	1.05
DE Adult Trawl - Fall Female	(1990 - 2022)	33	0.95	0.17	-0.26	-0.45	0.31	0.60	0.15	1.11
DE Adult Trawl - Fall Male	(1990 - 2022)	33	0.97	0.47	-0.22	-0.62	0.45	0.65	0.13	1.24
DE Adult Trawl - Spring Combined Sexes	(1990 - 2022)	33	0.96	0.19	-0.33	-0.19	0.15	0.55	0.16	1.06
DE Adult Trawl - Spring Female	(1990 - 2022)	33	0.98	0.72	-0.35	-0.18	0.16	0.55	0.15	1.08
DE Adult Trawl - Spring Male	(1990 - 2022)	33	0.96	0.22	-0.34	-0.25	0.19	0.58	0.15	1.36
Delaware bay NEAMAP - Fall Combined Sexes	(2007 - 2022)	16	0.91	0.11	-0.31	-0.38	0.30	1.00	0.67	0.44
MD Coastal Bays - Spring Combined Sexes	(1990 - 2022)	33	0.96	0.26	-0.52	0.04	0.17	1.00	0.10	0.51
NJ Ocean Trawl - Fall All Crabs Combined Sexes	(1988 - 2022)	35	0.96	0.28	-0.30	0.06	-0.20	0.73	0.16	0.56
NJ Ocean Trawl - Fall Female	(1999 - 2022)	24	0.96	0.48	-0.10	-0.30	-0.03	0.72	0.22	0.42
NJ Ocean Trawl - Fall Male	(1999 - 2022)	24	0.94	0.22	-0.16	-0.11	-0.13	0.67	0.22	0.61
NJ Ocean Trawl - Spring All Crabs Combined Sexes	(1989 - 2022)	34	0.98	0.67	-0.36	-0.11	0.08	0.45	0.17	0.32
NJ Ocean Trawl - Spring Female	(1999 - 2022)	24	0.94	0.23	-0.43	0.10	-0.04	0.46	0.19	0.34
NJ Ocean Trawl - Spring Male	(1999 - 2022)	24	0.94	0.21	-0.18	-0.16	-0.04	0.20	0.27	0.29

Table 12 Continued. * Since ASMFC 2019, the South Carolina Crustacean Research and Monitoring Survey (CRMS) has been renamed as the Estuarine Trawl Survey but this update uses the older name for consistency with the benchmark.

Survey	Years	n	W	*P*	r1	r2	r3	θ	SE	σ^2_c
Delaware Bay Region (continued)										
VA Tech Trawl - All Crabs	(2002 - 2022)	21	0.98	0.98	-0.45	0.03	0.01	0.76	0.20	0.22
VA Tech Trawl - Immature Female	(2002 - 2022)	21	0.95	0.40	-0.66	0.35	-0.10	1.00	0.16	0.35
VA Tech Trawl - Immature Male	(2002 - 2022)	21	0.95	0.54	-0.66	0.37	-0.17	1.00	0.18	0.49
VA Tech Trawl - Multiparous Female	(2002 - 2022)	21	0.92	0.16	-0.10	-0.43	-0.26	0.48	0.31	0.18
VA Tech Trawl - Multiparous Male	(2002 - 2022)	21	0.93	0.25	-0.18	-0.42	-0.21	0.68	0.16	0.29
VA Tech Trawl - Primiparous Female	(2002 - 2022)	21	0.90	0.08	-0.23	0.14	-0.48	0.22	0.26	1.23
VA Tech Trawl - Primiparous Male	(2002 - 2022)	21	0.94	0.38	-0.47	0.10	-0.15	0.56	0.23	0.85
Southeast Region										
NC Gill Net - Spring Combined Sexes	(2001 - 2022)	22	0.93	0.17	-0.05	-0.07	0.12	0.18	0.32	0.15
* SC CRMS - Spring Combined Sexes	(1995 - 2022)	28	0.95	0.20	-0.32	0.05	-0.18	0.53	0.27	0.61
SC SEAMAP - Fall Combined Sexes	(2001 - 2022)	22	0.85	0.00	-0.56	0.36	-0.18	0.61	0.17	5.88
SC Trammel Net - Spring Combined Sexes	(1995 - 2022)	28	0.94	0.09	-0.16	-0.40	0.05	0.49	0.23	0.49
GA Trawl - Spring Combined Sexes	(1999 - 2023)	25	0.87	0.00	-0.48	-0.04	0.04	0.73	0.17	0.35
GA-FL SEAMAP - Fall Combined Sexes	(2001 - 2022)	22	0.93	0.11	-0.19	-0.17	0.15	0.51	0.17	3.82

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. Surveys that began after 1998 do not have a 1998 reference value. Relative trends since the last benchmark assessment (trend since 2017) and last stock assessment update (trend since 2012) are indicated. Table continued on the next few pages.

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%	↓	↓
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

Table 13 Continued.

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	↑

Table 13 Continued. * Since ASMFC 2019, the South Carolina Crustacean Research and Monitoring Survey (CRMS) has been renamed as the Estuarine Trawl Survey but this update uses the older name for consistency with the benchmark.

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%	↑	↑
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 14. Stock status determination for the coastwide and regional stocks based on the 1998 index-based reference points from ARIMA models. Status was 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. "Poor" status (red) was >66% of surveys meeting this criterion, "Good" status (green) was <33% of surveys, and "Neutral" status (yellow) was 34 – 65% of surveys. The same criteria were applied to results from the 2019 benchmark assessment, 2013 stock assessment update, and 2009 benchmark assessment for comparison purposes.

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

Table 15. Details of surveys used in determining regional stock status of horseshoe crabs. P(i_f<Q_{25}) and P(i_f>1998) represent the probability of the terminal year's fitted index value (i_f) being less than the 25th percentile or 1998 index-based reference points. Trends as determined by a Mann-Kendal test for monotonic trends (increasing, decreasing, or no trend) from the last stock assessment update terminal year (2012) and the last benchmark assessment terminal year (2017) are also indicated. * Since ASMFC 2019, the South Carolina Crustacean Research and Monitoring Survey (CRMS) has been renamed as the Estuarine Trawl Survey but this update uses the older name for consistency with the benchmark.

Region	Survey	P(i_f<Q_{25})	P(i_f<1998)	Since 2017	Since 2012
Northeast	MA Trawl South of Cape Cod - Fall Combined Sexes	21%	35%	No Trend	↑
	RI Monthly Trawl - Fall Combined Sexes	67%	96%	↓	↓
New York	CT Long Island Sound Trawl - Fall Combined Sexes	11%	37%	No Trend	↑
	NY Jamaica Bay Beach Seine - Spring Combined Sexes	70%	99%	↓	↓
	NY Little Neck and Manhasset Bay Beach Seine - Spring Combined Sexes	62%	100%	No Trend	↓
	NY Peconic Trawl - Fall Combined Sexes	55%	100%	↑	No Trend
Delaware Bay	DE 30 ft Trawl - Fall Combined Sexes	0%	2%	No Trend	↑
	DE 30 ft Trawl - Spring Combined Sexes	1%	9%	No Trend	↑
	MD Coastal Bays - Spring Combined Sexes	0%	0%	No Trend	↑
	NJ Ocean Trawl - Fall All Crabs Combined Sexes	10%	16%	No Trend	↑
	NJ Ocean Trawl - Spring All Crabs Combined Sexes	5%	8%	No Trend	↑
Southeast	* SC CRMS - Spring Combined Sexes	10%	7%	No Trend	↑
	SC Trammel Net - Spring Combined Sexes	41%	22%	↓	↓

FIGURES

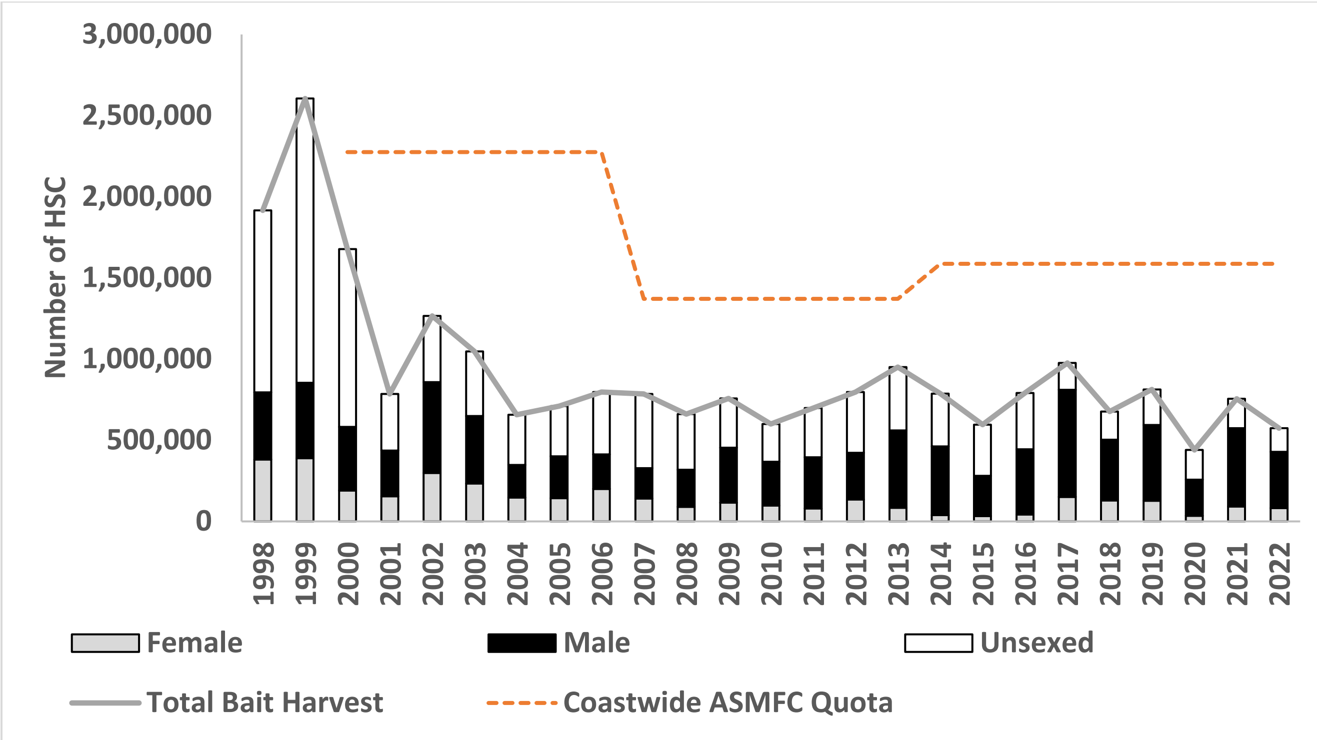


Figure 1. Coastwide horseshoe crab bait landings, 1998-2022, by sex where available. Coastwide ASMFC quota indicated in orange. Source: ACCSP.

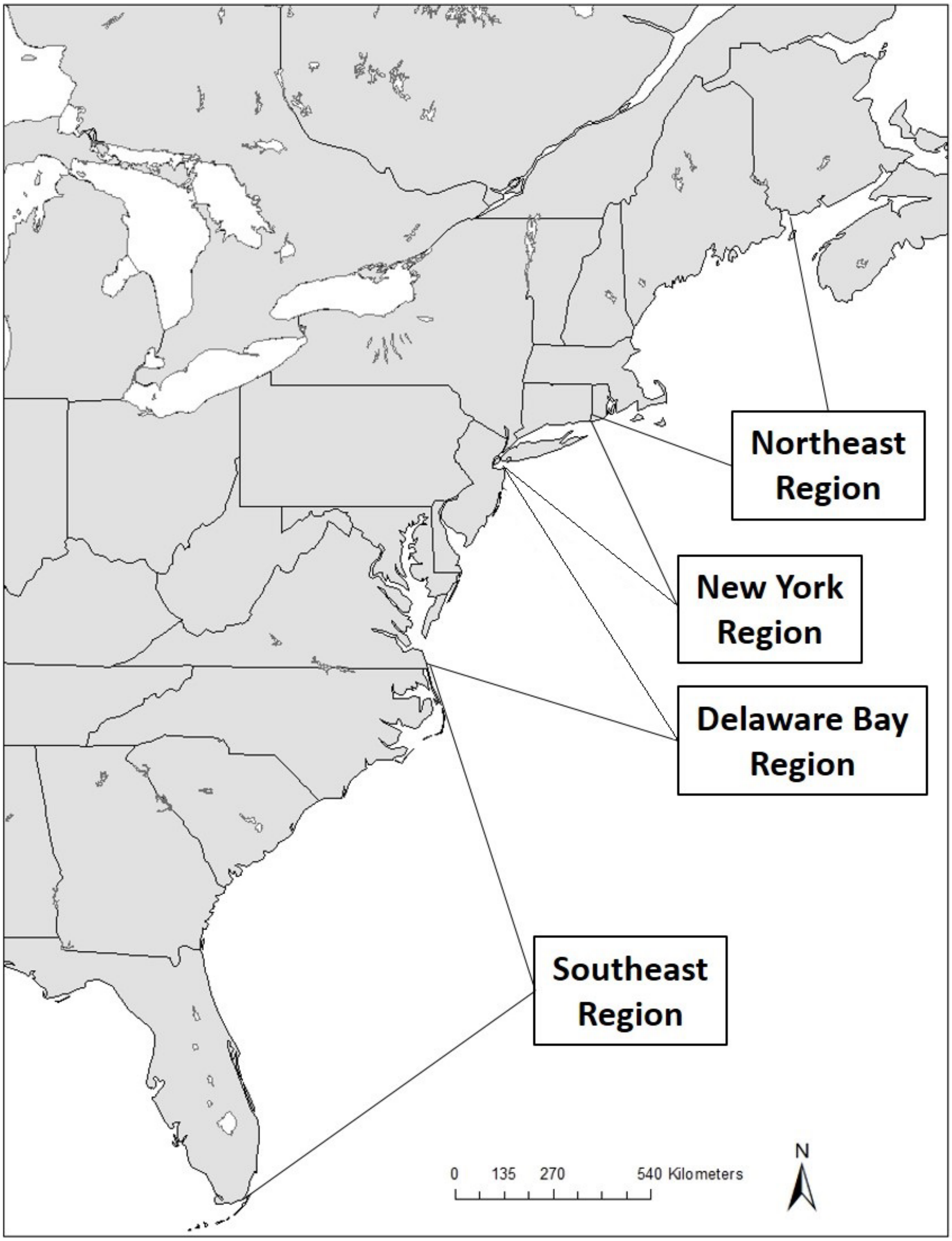


Figure 2. Map of the Atlantic coast showing the regions for horseshoe crab assessment.

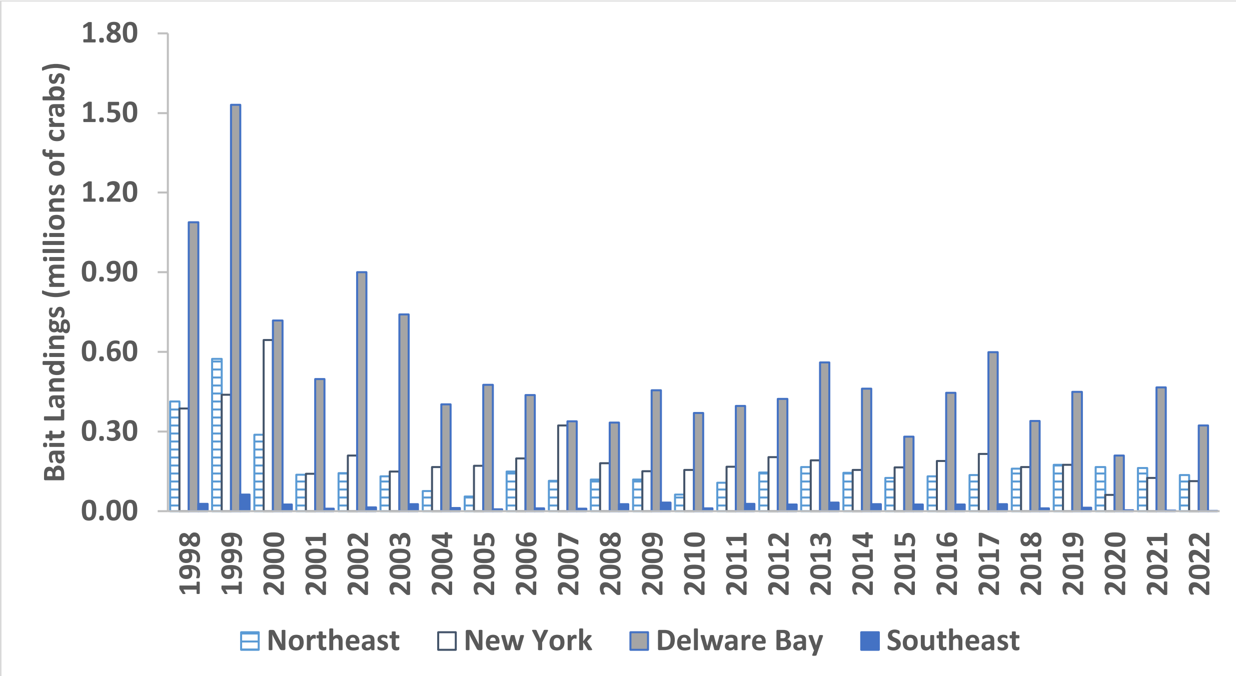


Figure 3. **Horseshoe crab bait harvest by region, 1998-2022. The four regions are the Northeast (Maine-Rhode Island), New York (Connecticut-New York), Delaware Bay (New Jersey-Virginia), and Southeast (North Carolina-Florida).**

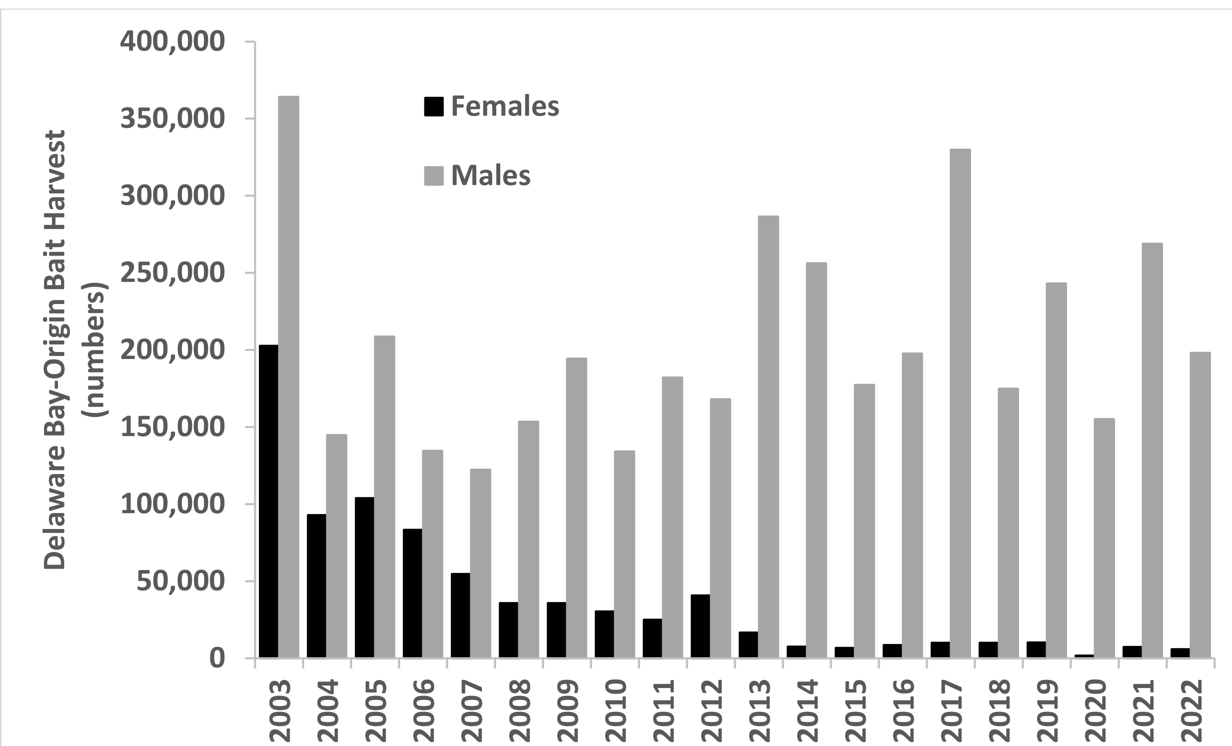


Figure 4. **Horseshoe crab bait landings of Delaware Bay-Origin, 2003-2022, by sex for use in the CMSA. Source: ACCSP.**

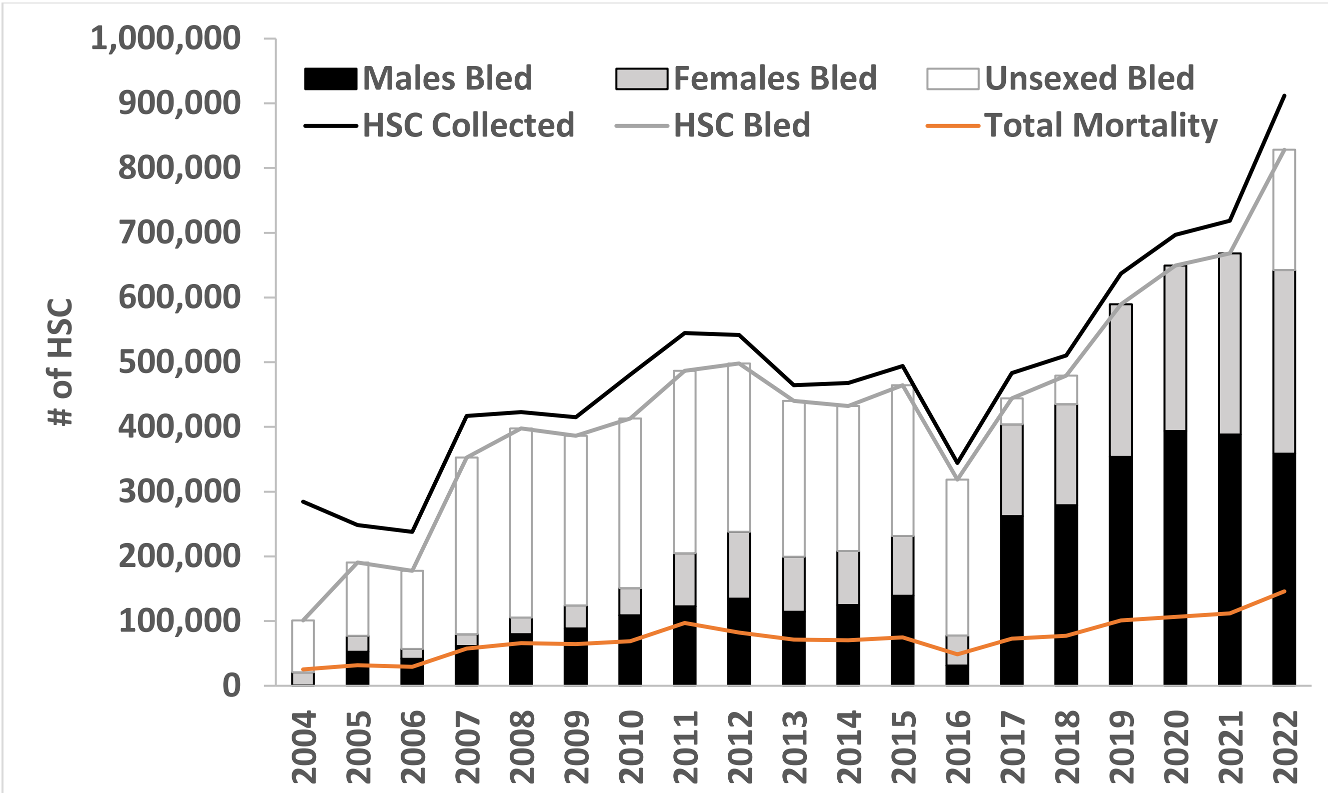


Figure 5. Coastwide number of horseshoe crabs (HSC) collected and bled by the biomedical industry and the total resulting mortality (observed mortality during the bleeding process plus 15% of those bled and released alive).

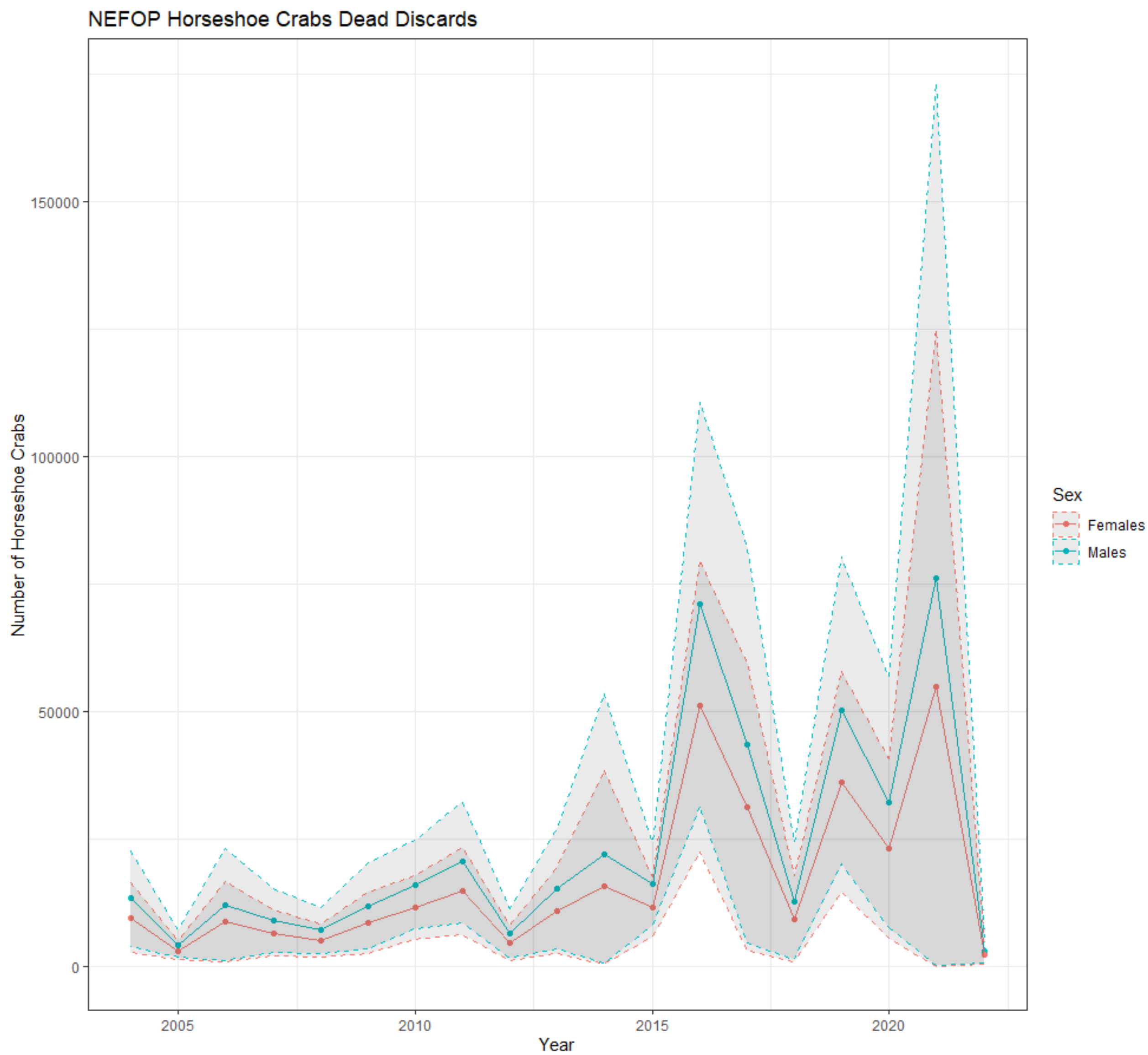


Figure 6. Estimated number of dead horseshoe crabs discarded in the Delaware Bay region from commercial fisheries, 2004-2022, by sex with 95% confidence intervals. Source: NEFOP.

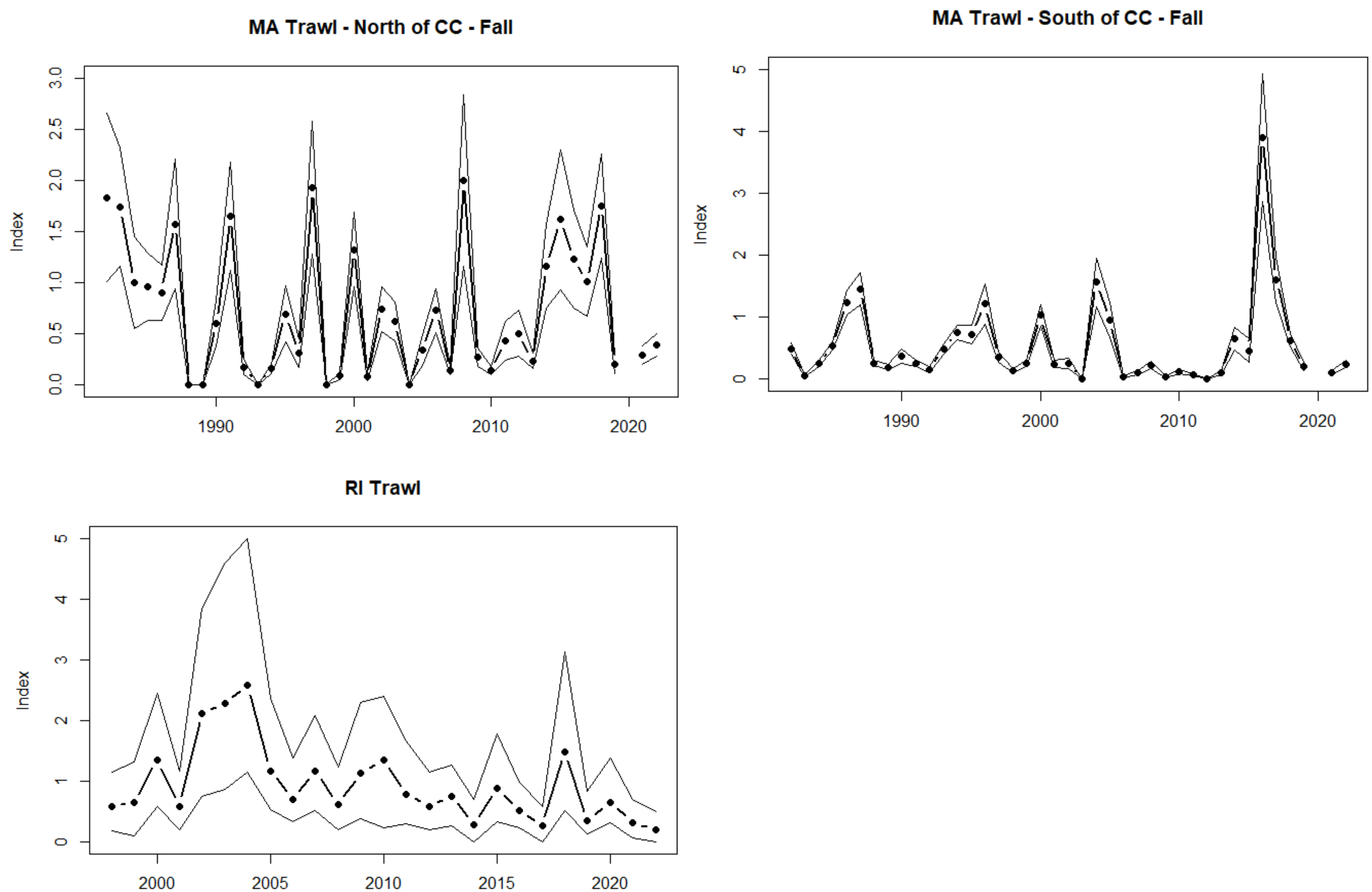


Figure 7. Indices of relative abundance of horseshoe crabs developed from the Massachusetts Trawl Survey for north and south of Cape Cod (CC) in the fall months and the Rhode Island Monthly Trawl Survey with 95% confidence intervals.

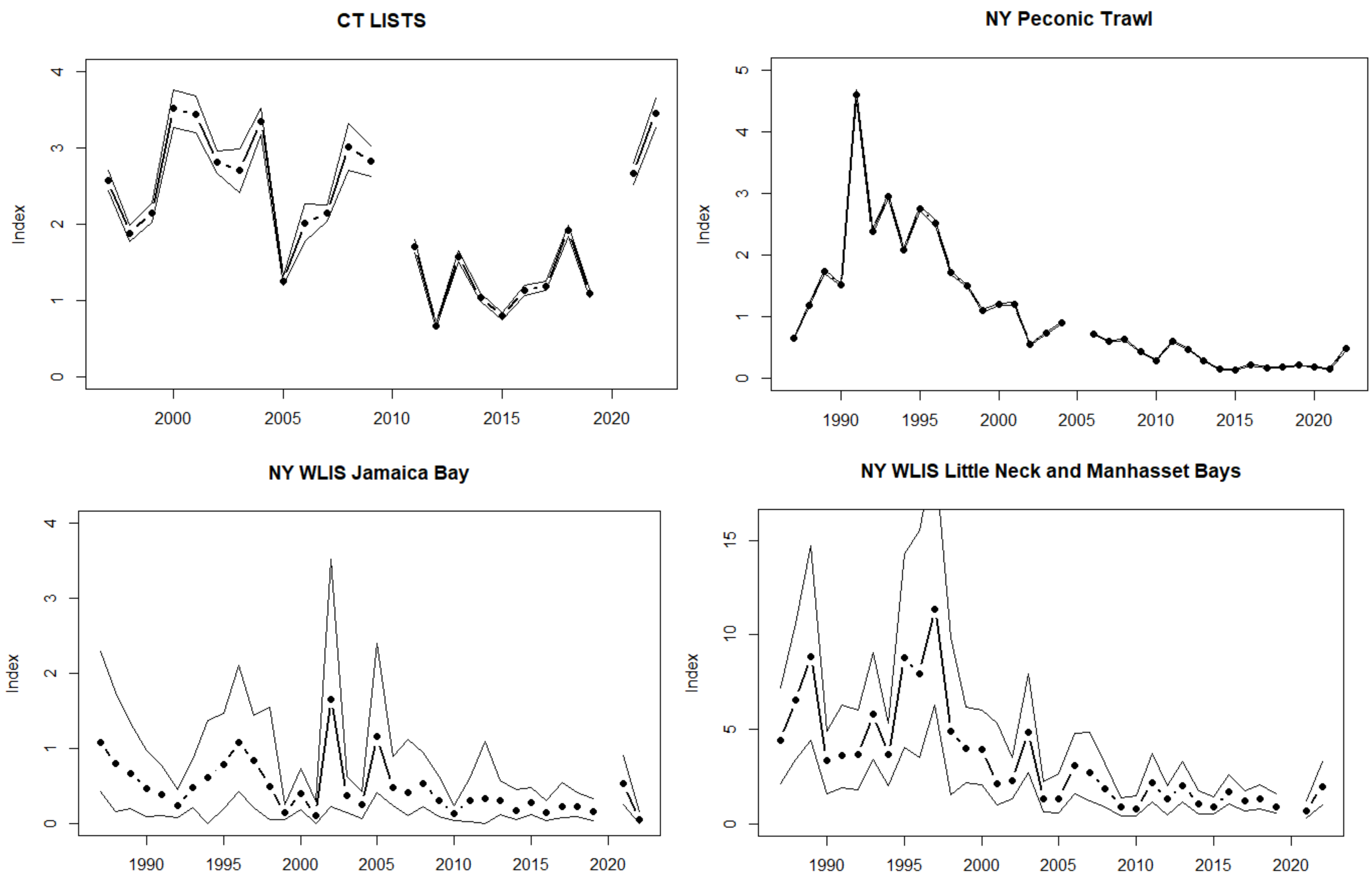


Figure 8. Indices of relative abundance of horseshoe crabs developed from the Connecticut Long Island Sound Trawl (CT LISTS), New York Peconic Bay Trawl, and New York Western Long Island Sound (WLIS) Surveys with 95% confidence intervals.

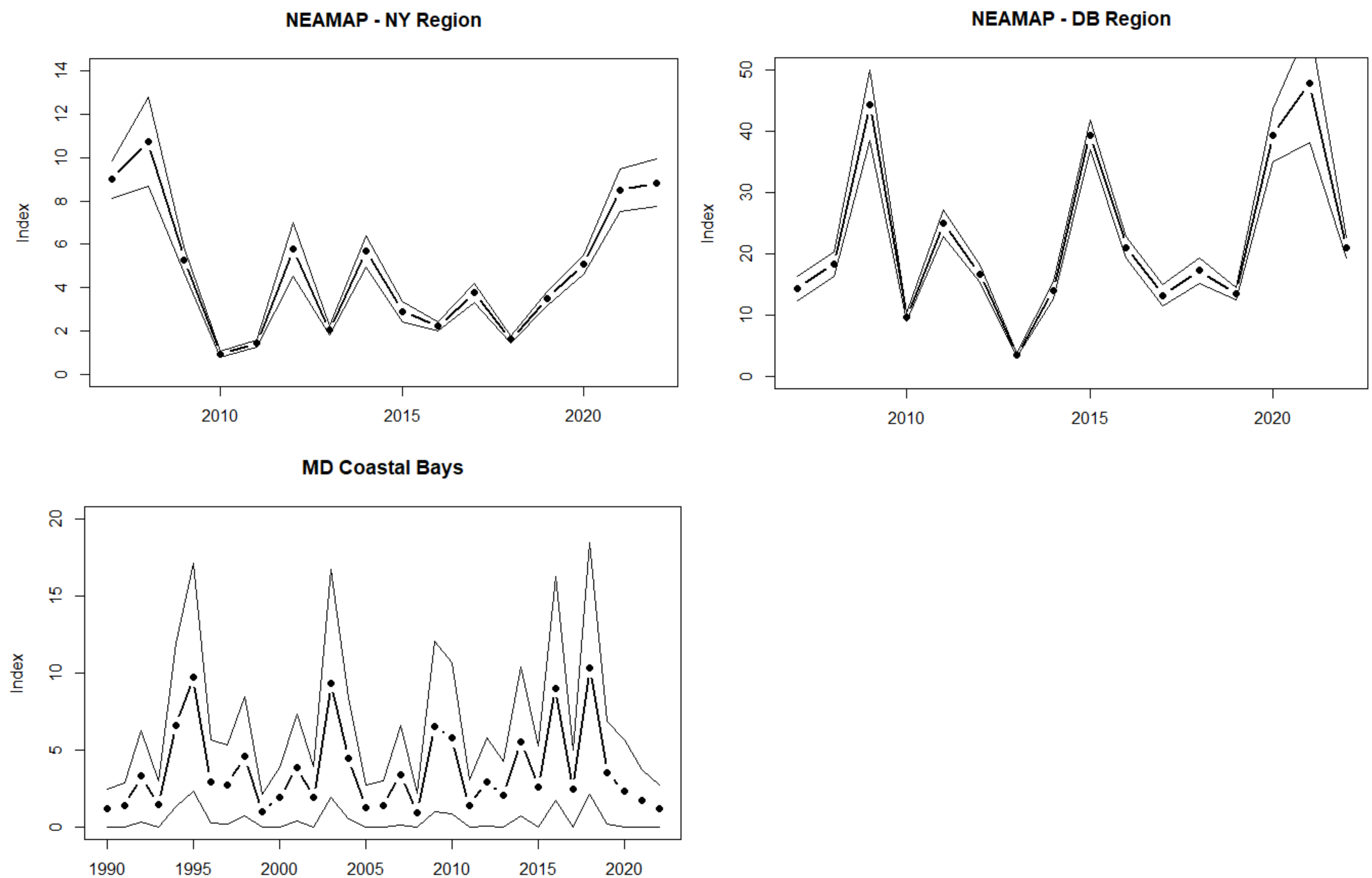


Figure 9. Indices of relative abundance of horseshoe crabs developed from the Northeast Area Monitoring and Assessment Program (NEAMAP) and Maryland Coastal Bays Surveys with 95% confidence intervals.

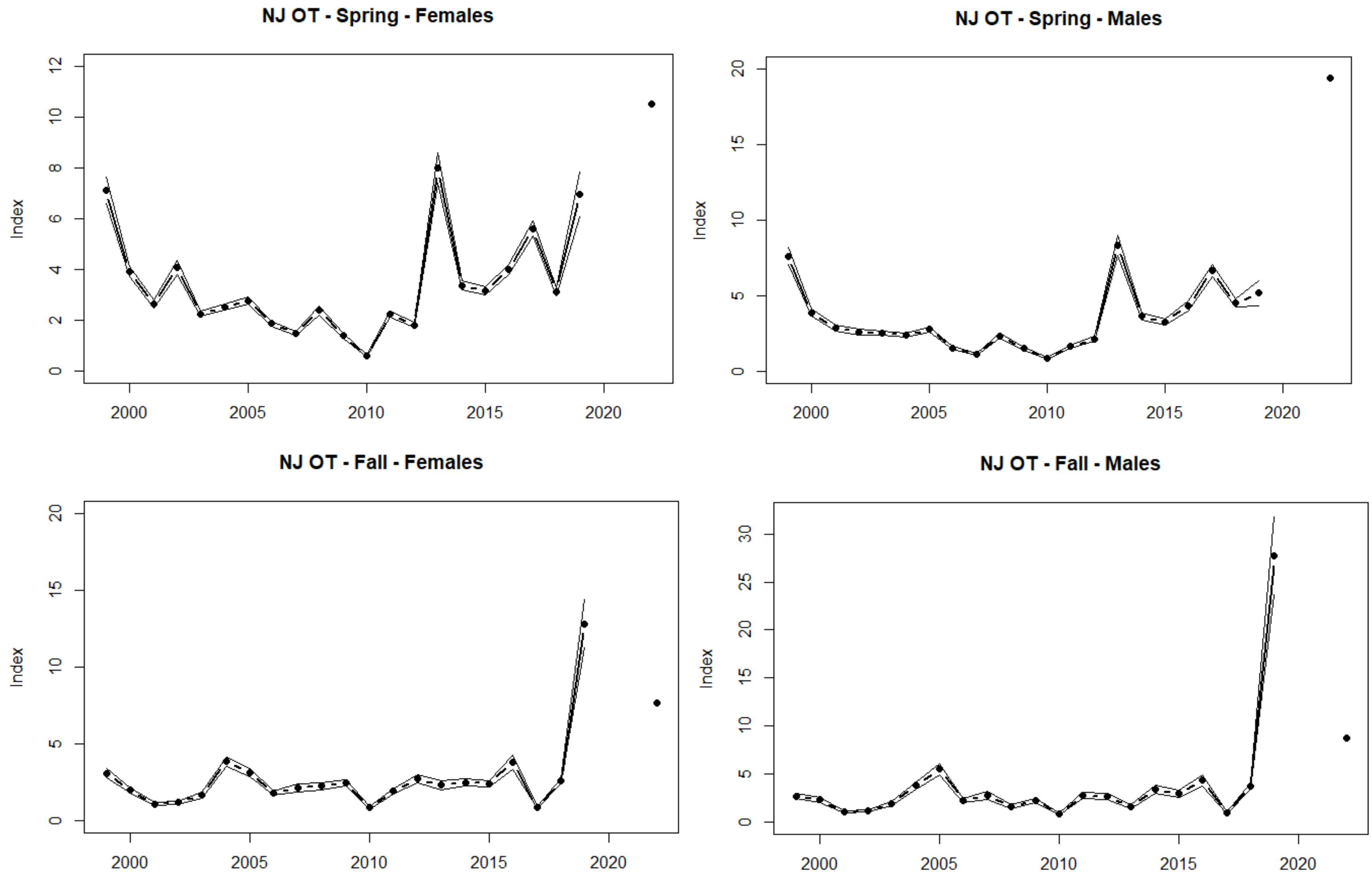


Figure 10. Indices of relative abundance of horseshoe crabs developed from the New Jersey Ocean Trawl (NJ OT) Survey by sex and season with 95% confidence intervals.

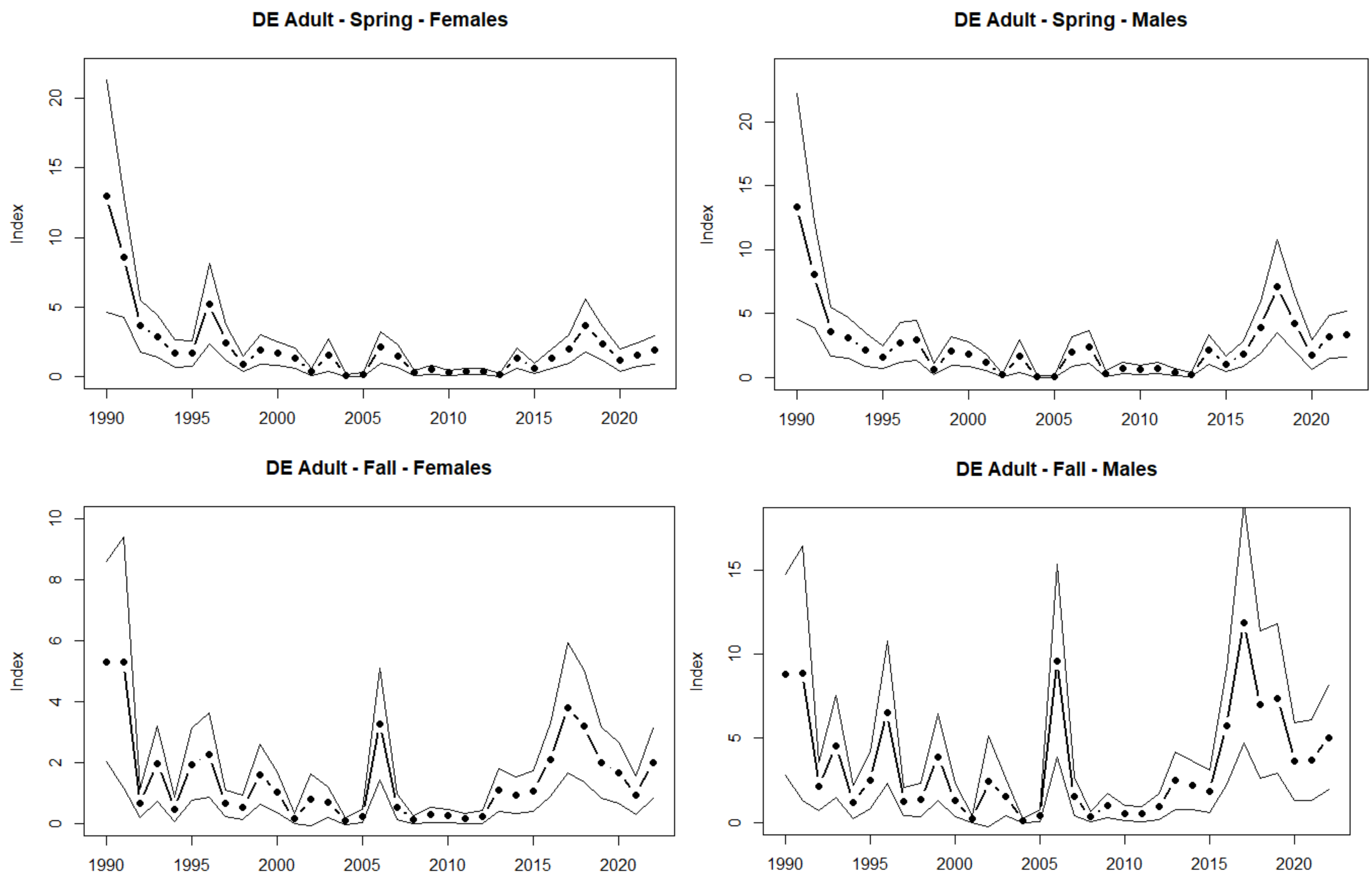


Figure 11. Indices of relative abundance of horseshoe crabs developed from the Delaware 30' Adult Trawl Survey by sex and season with 95% confidence intervals.

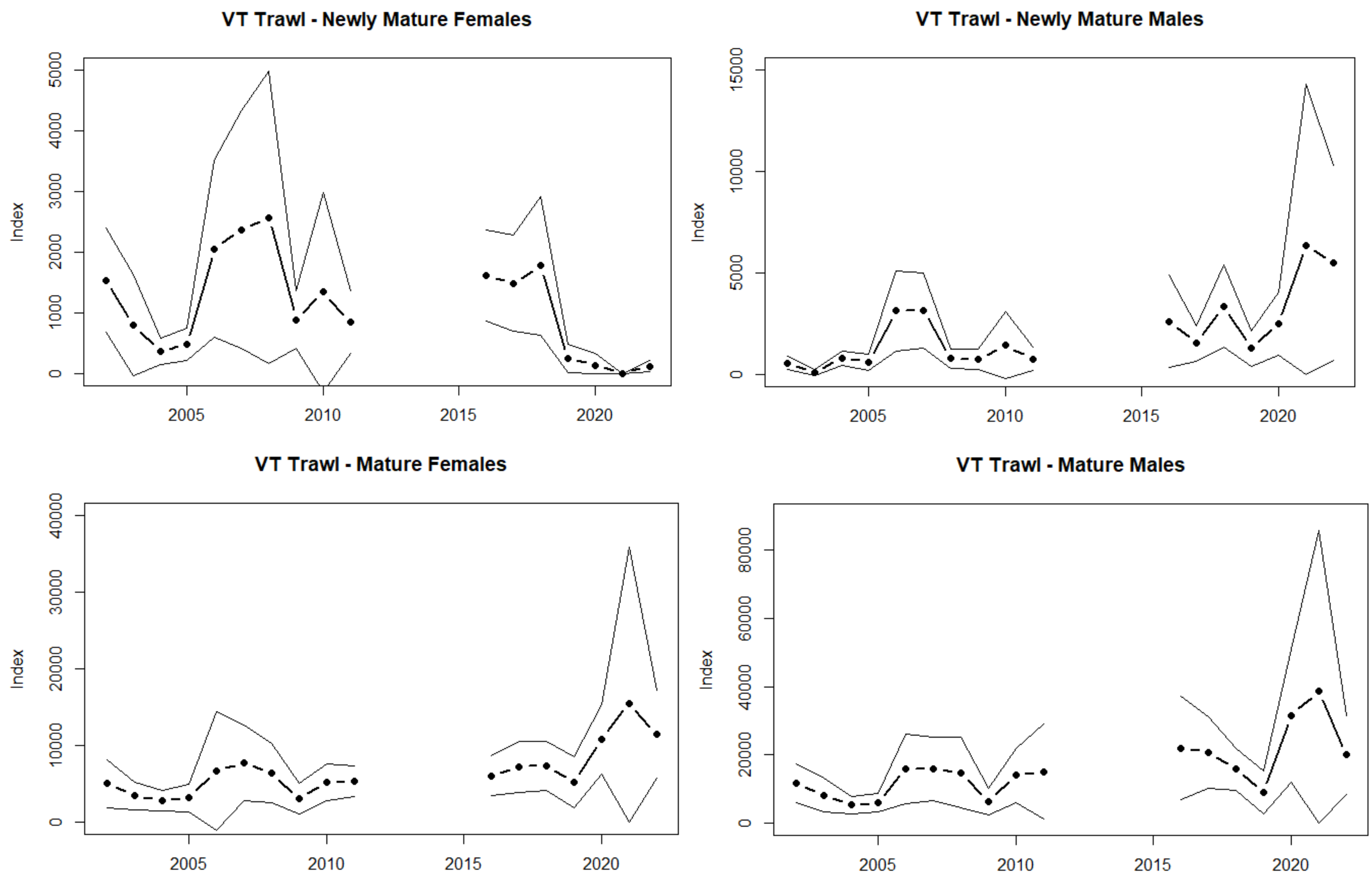


Figure 12. Indices of relative abundance of horseshoe crabs developed from the Virginia Tech Trawl Survey by sex and maturity stage with 95% confidence intervals.

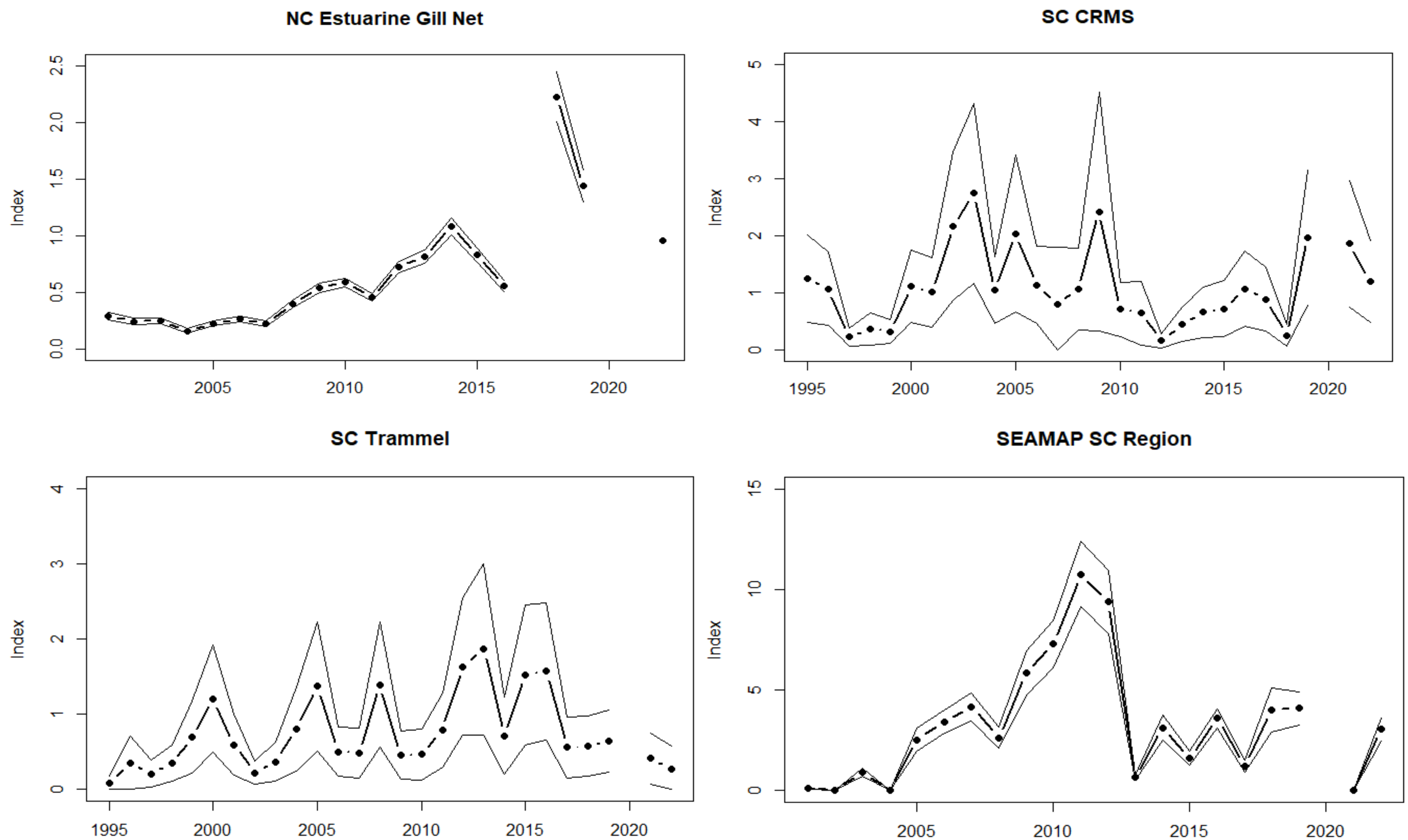


Figure 13. Indices of relative abundance of horseshoe crabs developed from the North Carolina Estuarine Gill Net, South Carolina Crustacean Research and Monitoring (CRMS; recently renamed as Estuarine Trawl Survey), South Carolina Trammel, and Southeast Area Monitoring and Assessment Program (SEAMAP) 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.

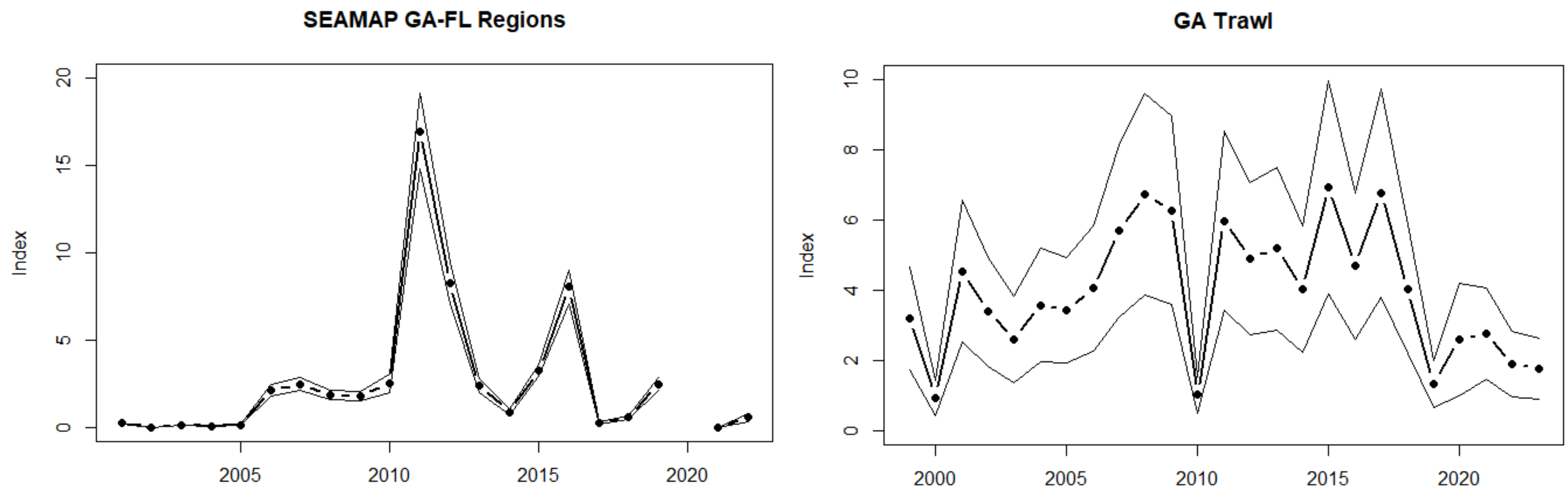


Figure 14. Indices of relative abundance of horseshoe crabs developed from the Southeast Area Monitoring and Assessment Program (SEAMAP) and Georgia Ecological Monitoring Trawl Surveys with 95% confidence intervals. SEAMAP had reduced sampling in the strata used in the index in 2021-2022 and therefore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

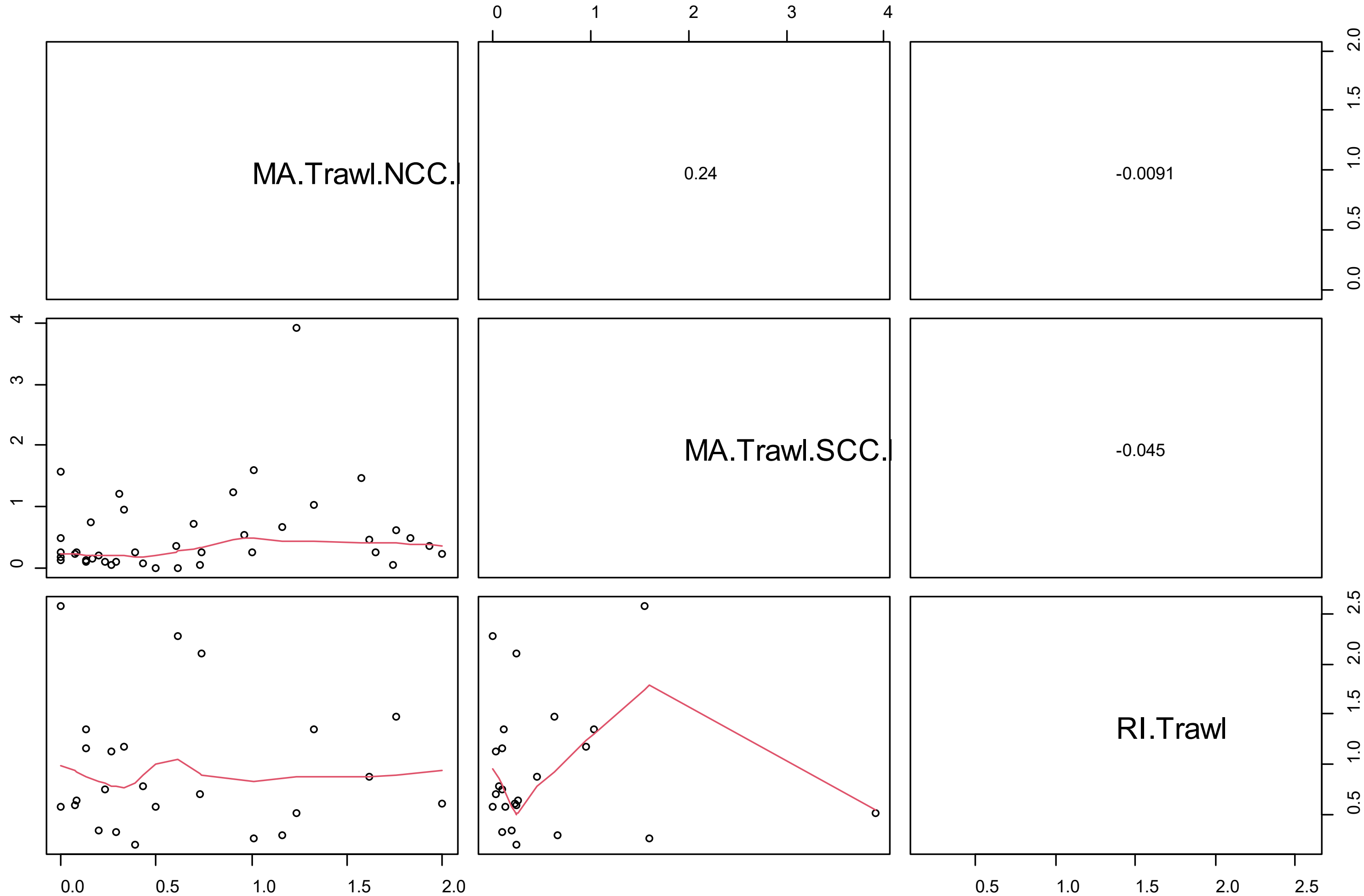


Figure 15. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the Northeast region. None of the correlations were significant (*P*<0.05).

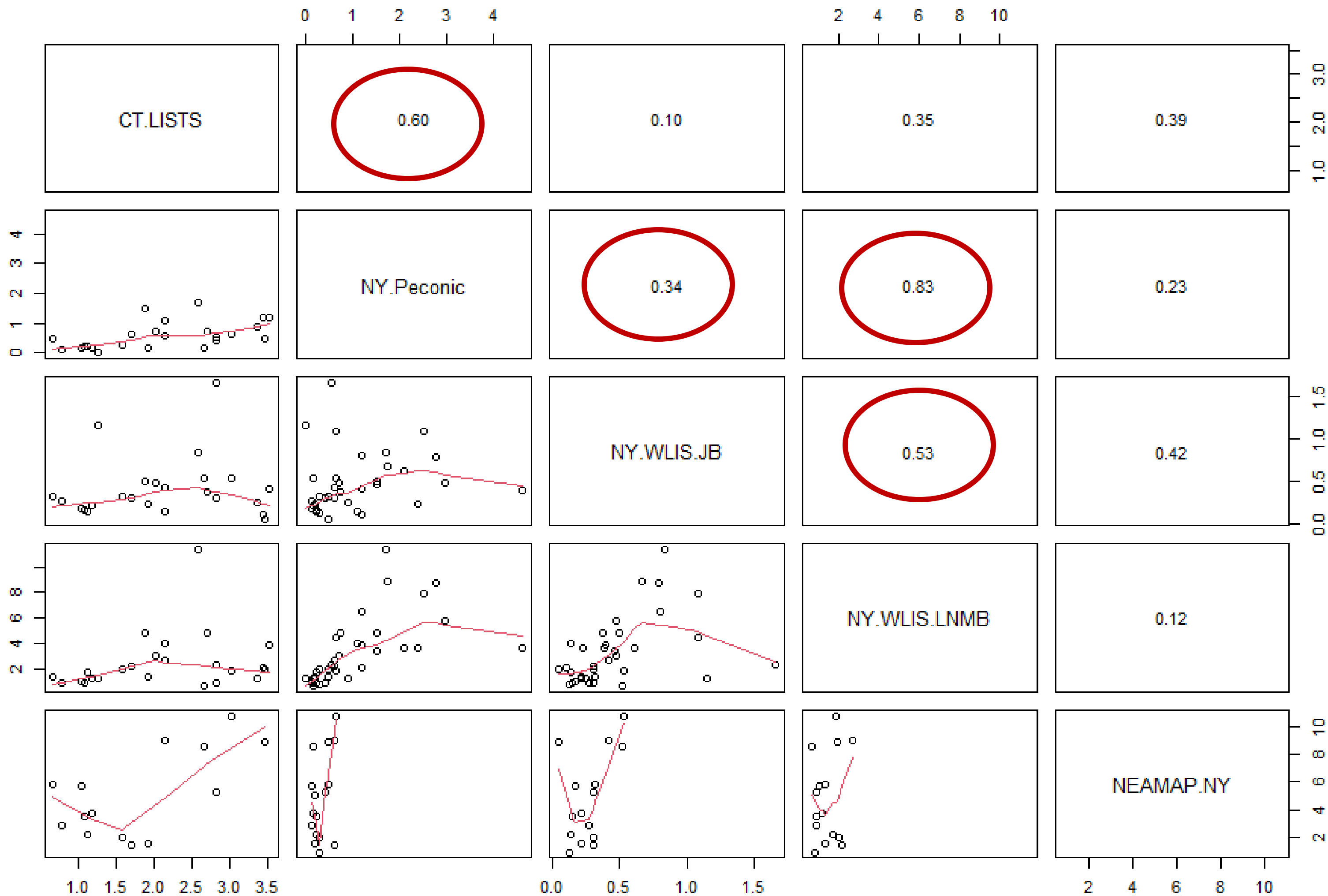


Figure 16. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the New York region. Significant correlations (*P*<0.05) are circled in red.

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.

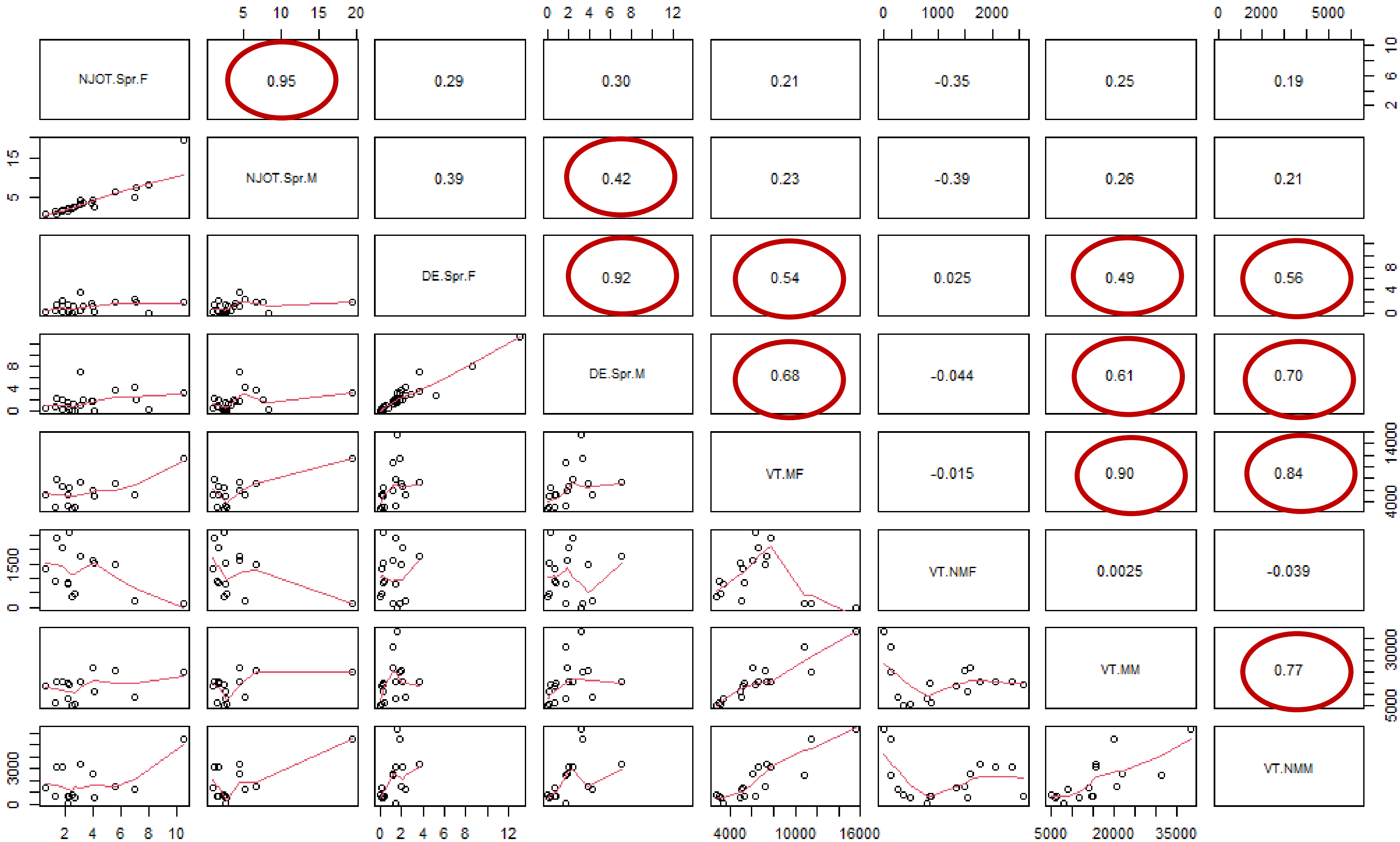


Figure 18. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the Delaware Bay region used in the ARM Framework, 2003-2022, where the Virginia Tech Trawl Survey has been lagged forward one year as it is in the CMSA. Significant correlations (*P*<0.05) are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

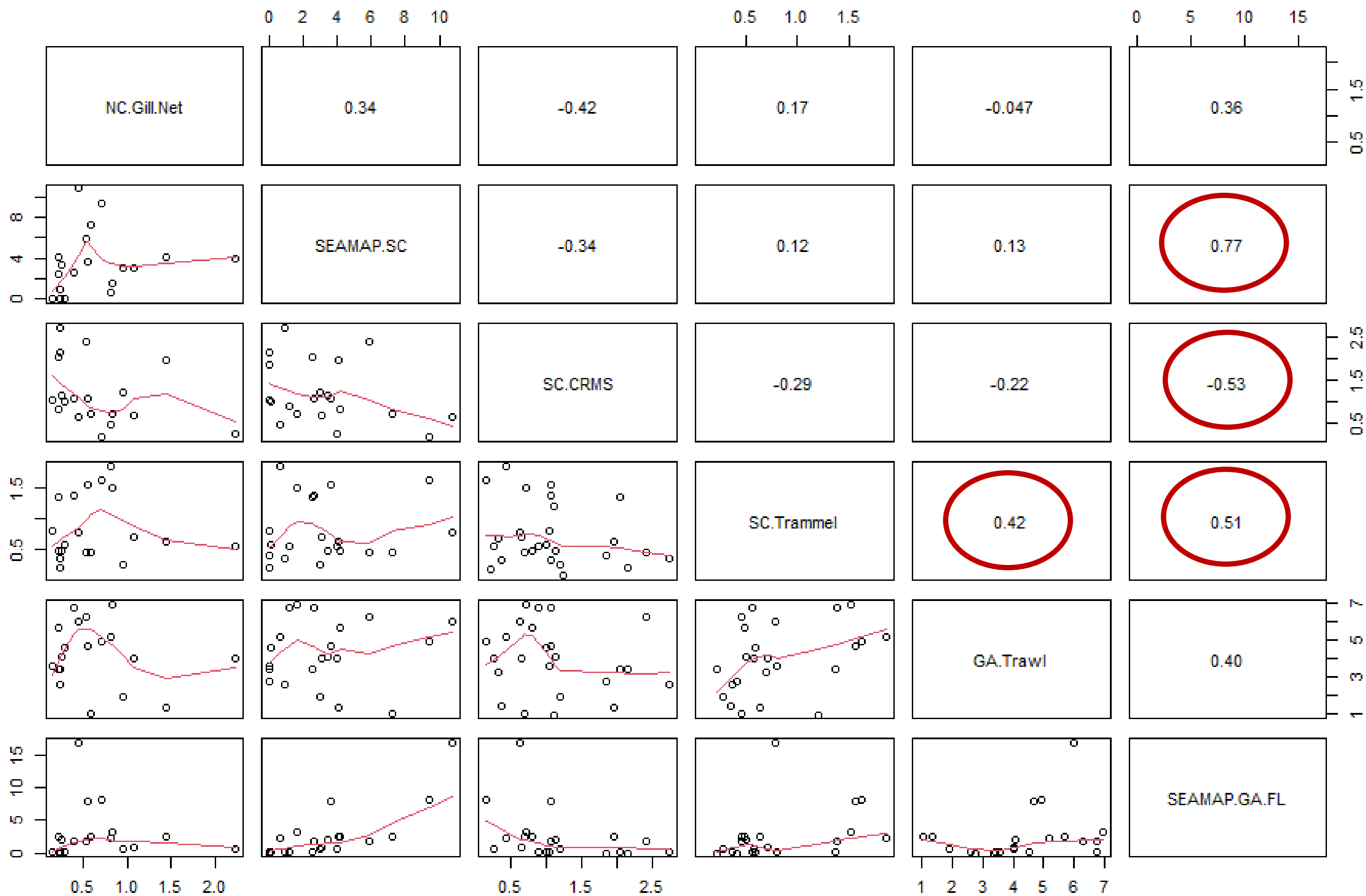


Figure 19. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the Southeast region. Significant correlations (*P*<0.05) are circled in red.

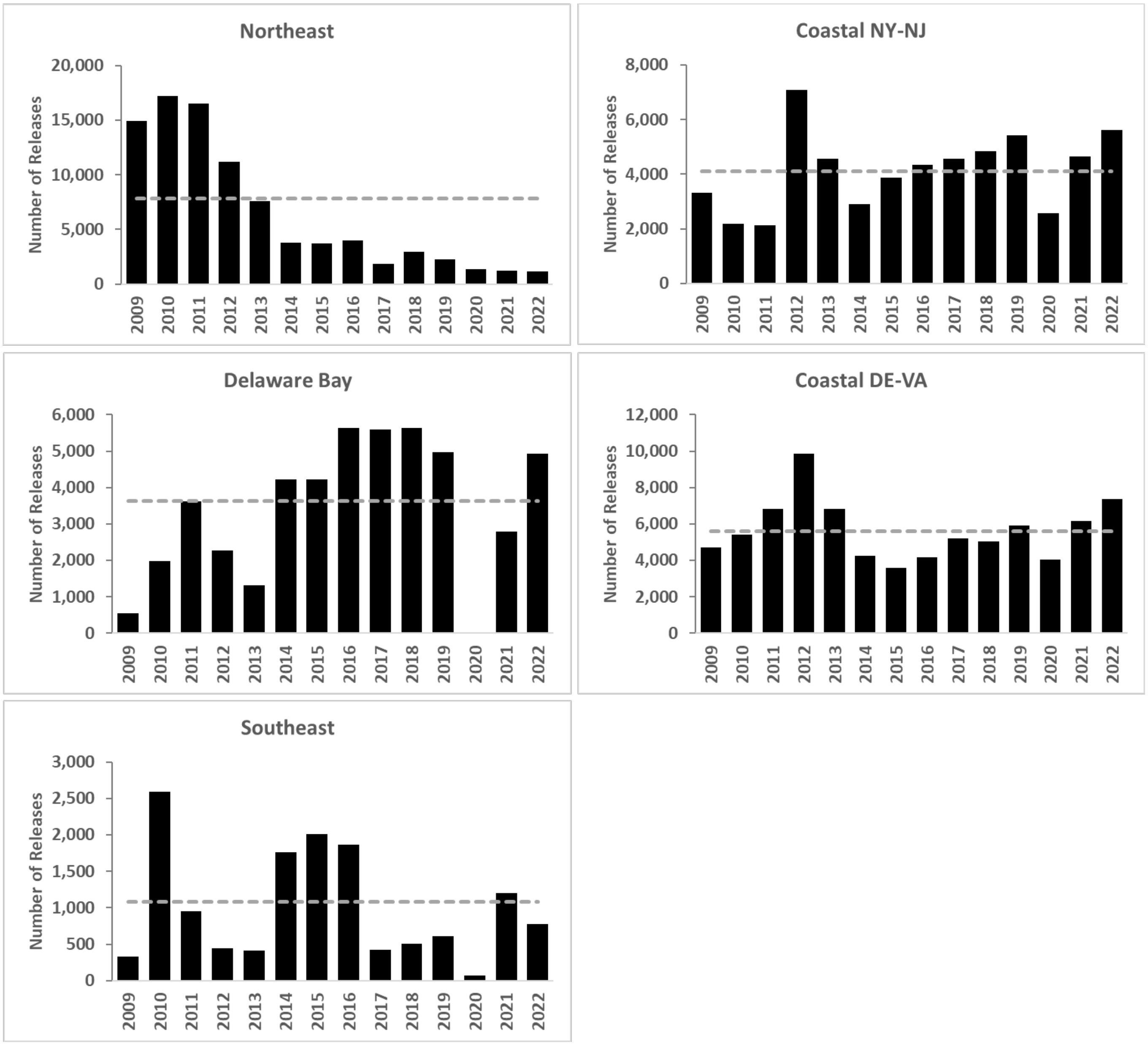


Figure 20. Number of tag releases by region, 2009-2022. Grey dashed line indicates the average number of tag releases from 2009-2019 (the years before COVID) by region (source: USFWS tagging database).

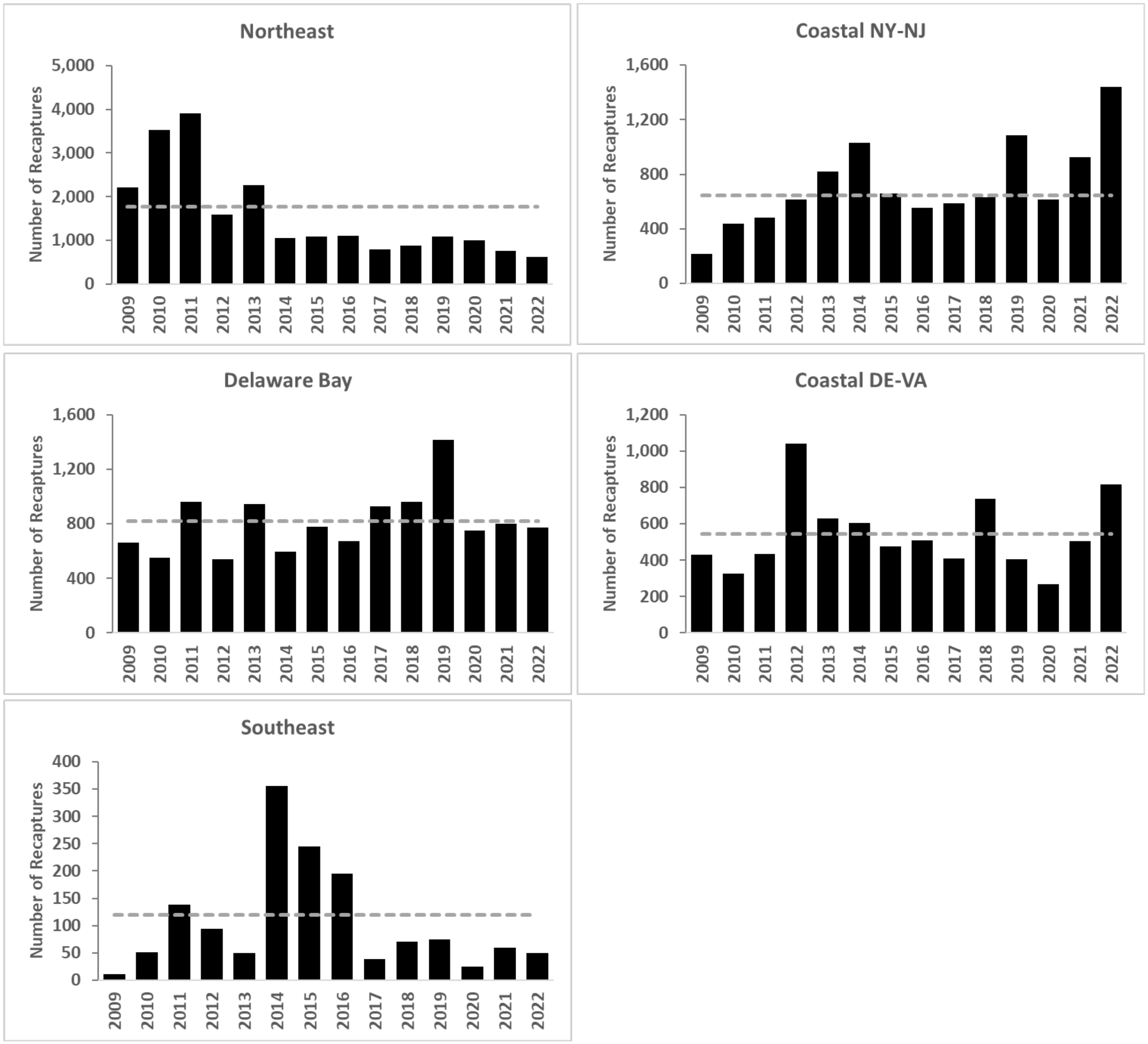


Figure 21. Number of tag recaptures by region, 2009-2022. Grey dashed line indicates the average number of tag releases from 2009-2019 (the years before COVID) by region (source: USFWS tagging database)..

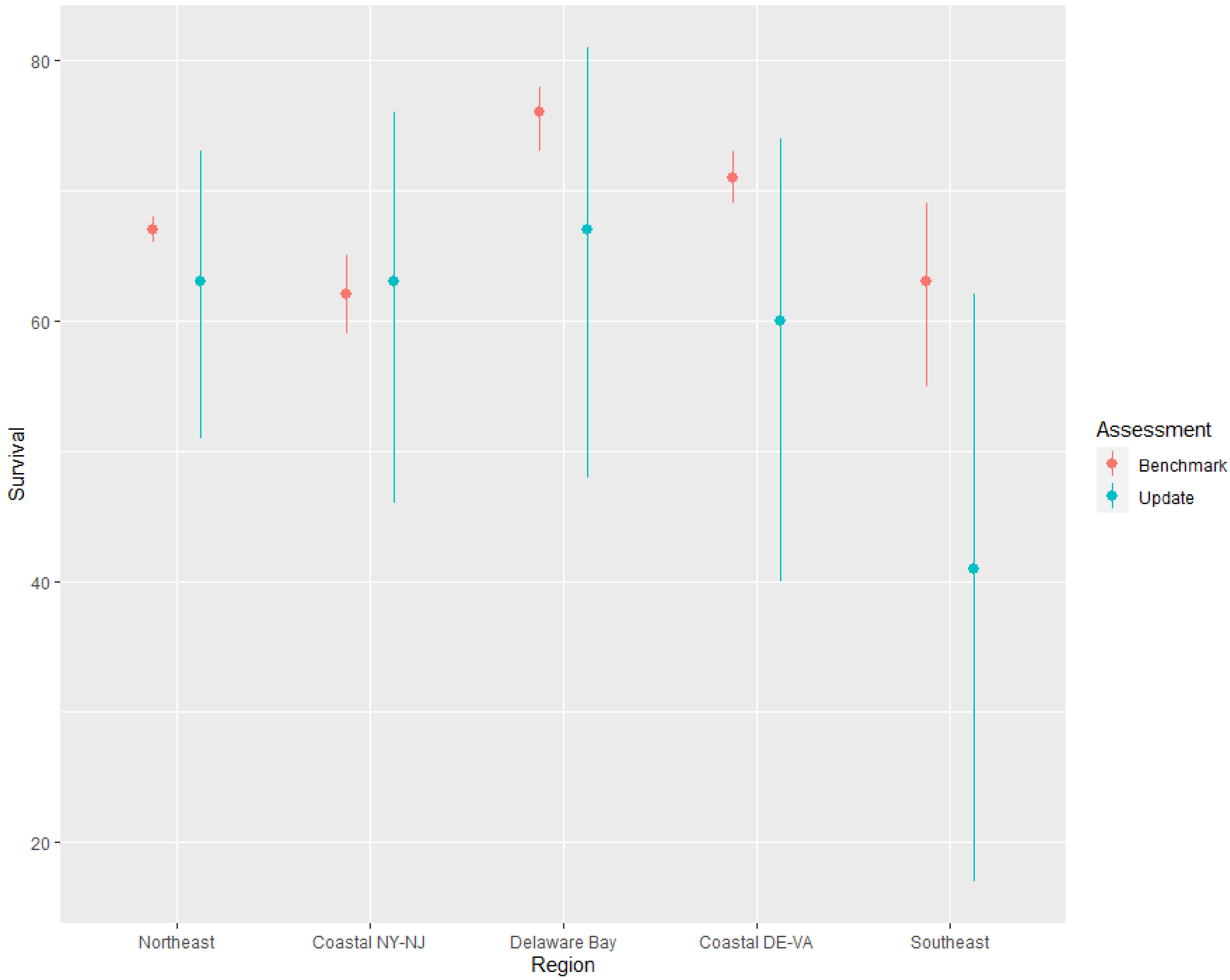


Figure 22. Comparison between the benchmark stock assessment (2019) and update (2024) estimates for survival rate (%) with 95% confidence intervals by region.

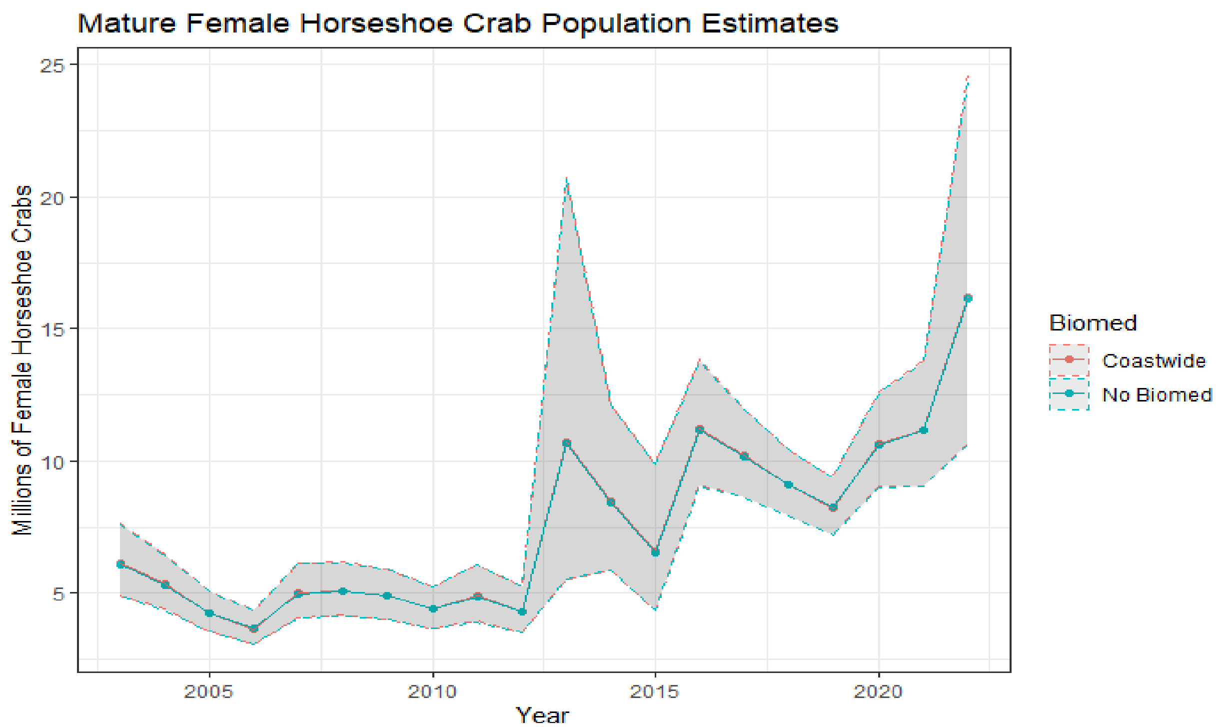


Figure 23. Population estimates from the CMSA for mature female horseshoe crabs with 95% confidence intervals. Delaware Bay biomedical data is confidential so population estimates using coastwide and zero biomedical data provide upper and lower bounds, although there is very little difference between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

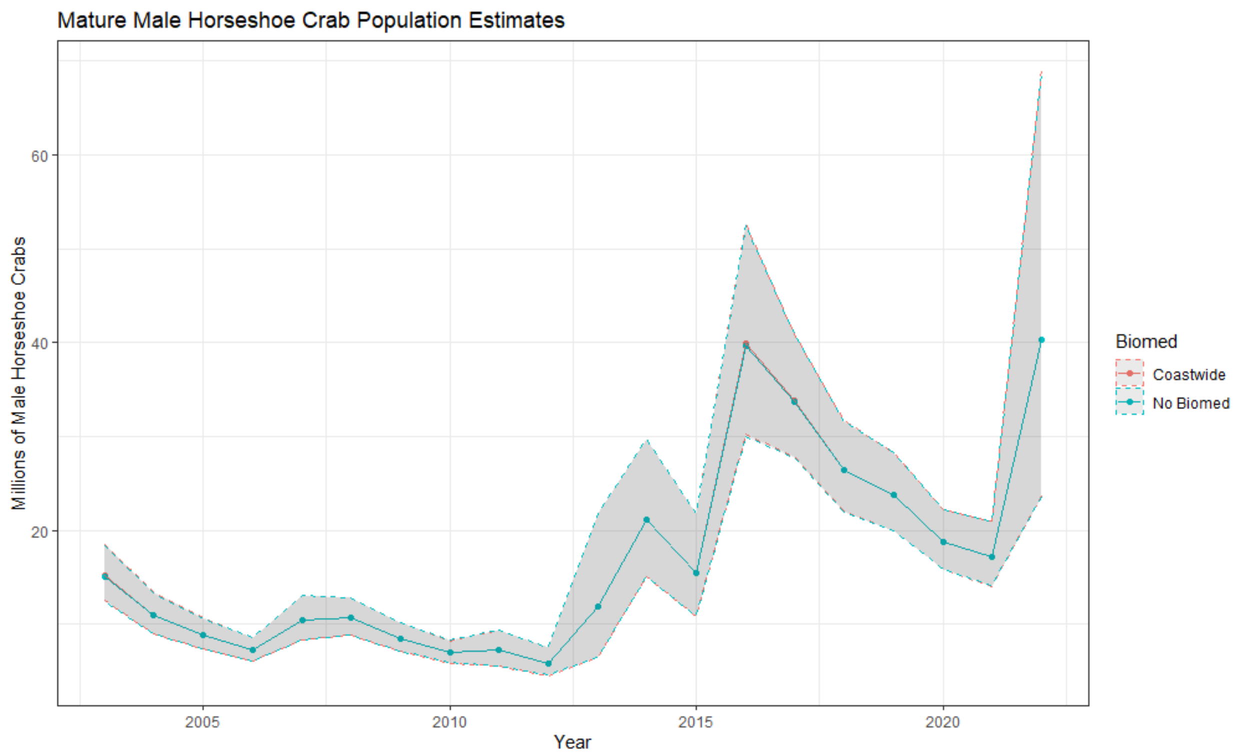
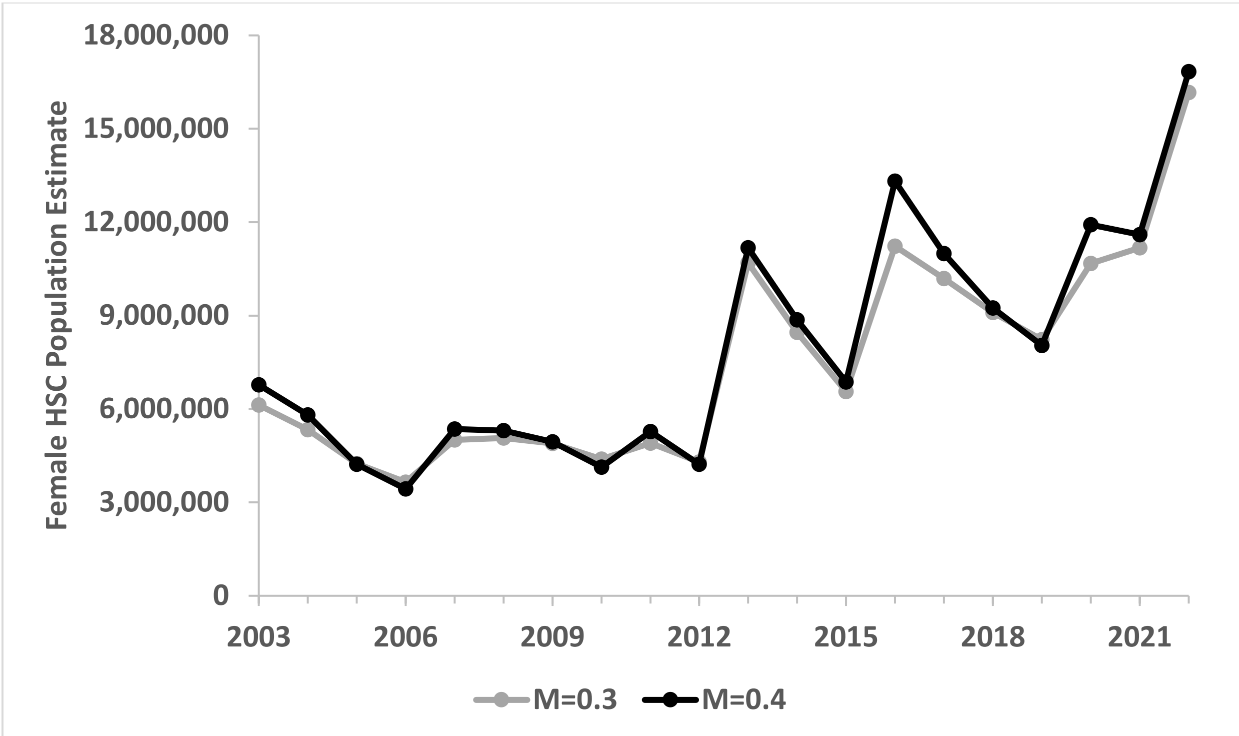


Figure 24. Population estimates from the CMSA for male horseshoe crabs with 95% confidence intervals. Delaware Bay biomedical data is confidential so population estimates using coastwide and zero biomedical data provide upper and lower bounds, although there is very little difference between the two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



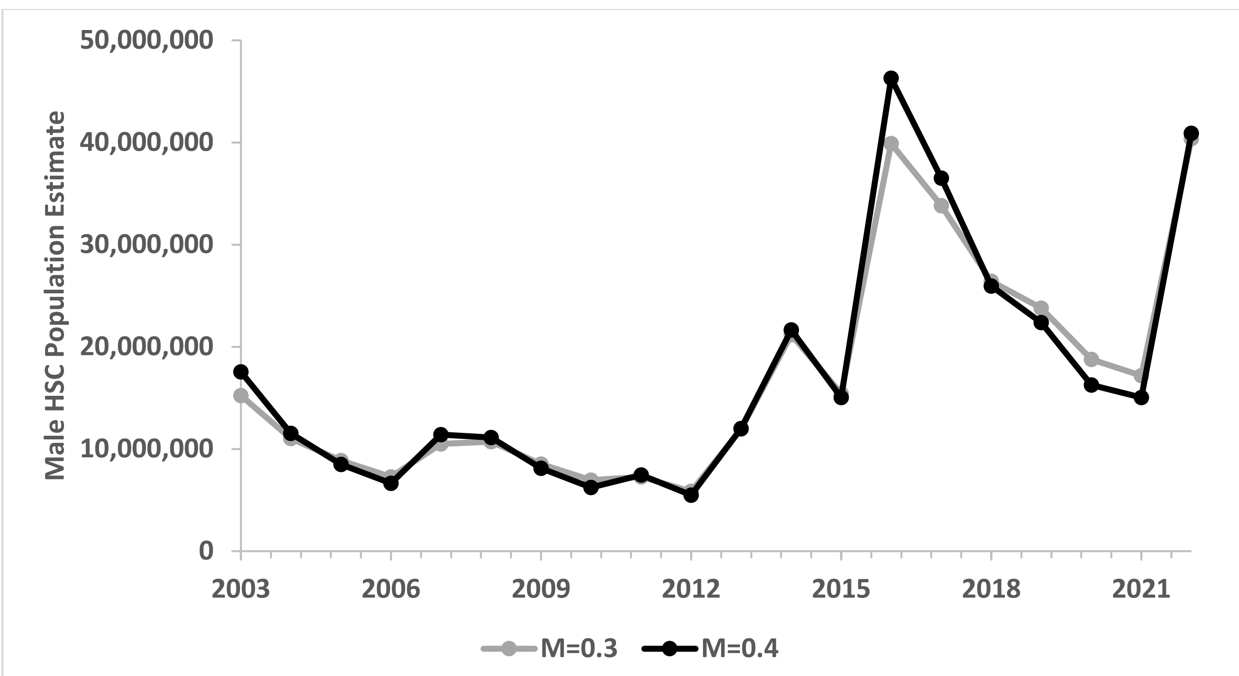


Figure 25. Comparison between population estimates from the CMSA for mature females (top) and males (bottom) using two natural mortality estimates and coastwide biomedical data.

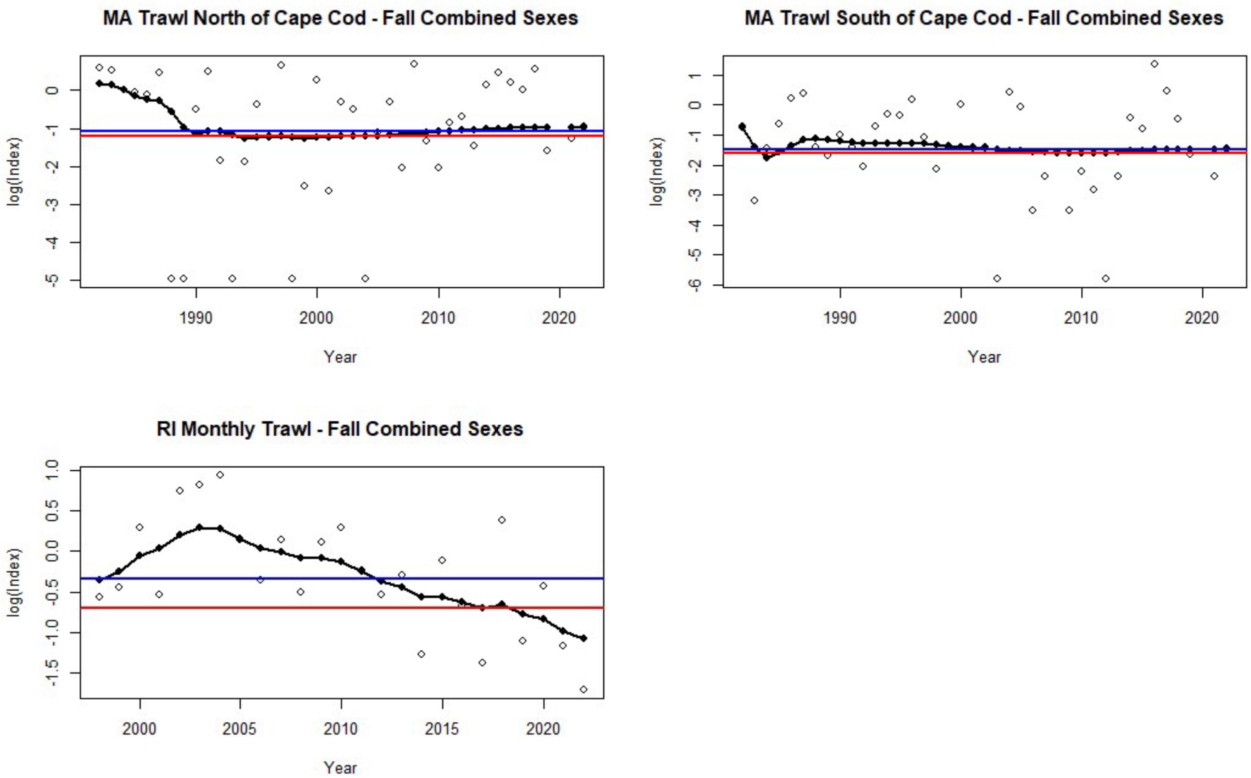


Figure 26. ARIMA model fits to horseshoe crab indices Massachusetts and Rhode Island Trawl Surveys in the Northeast Region. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.

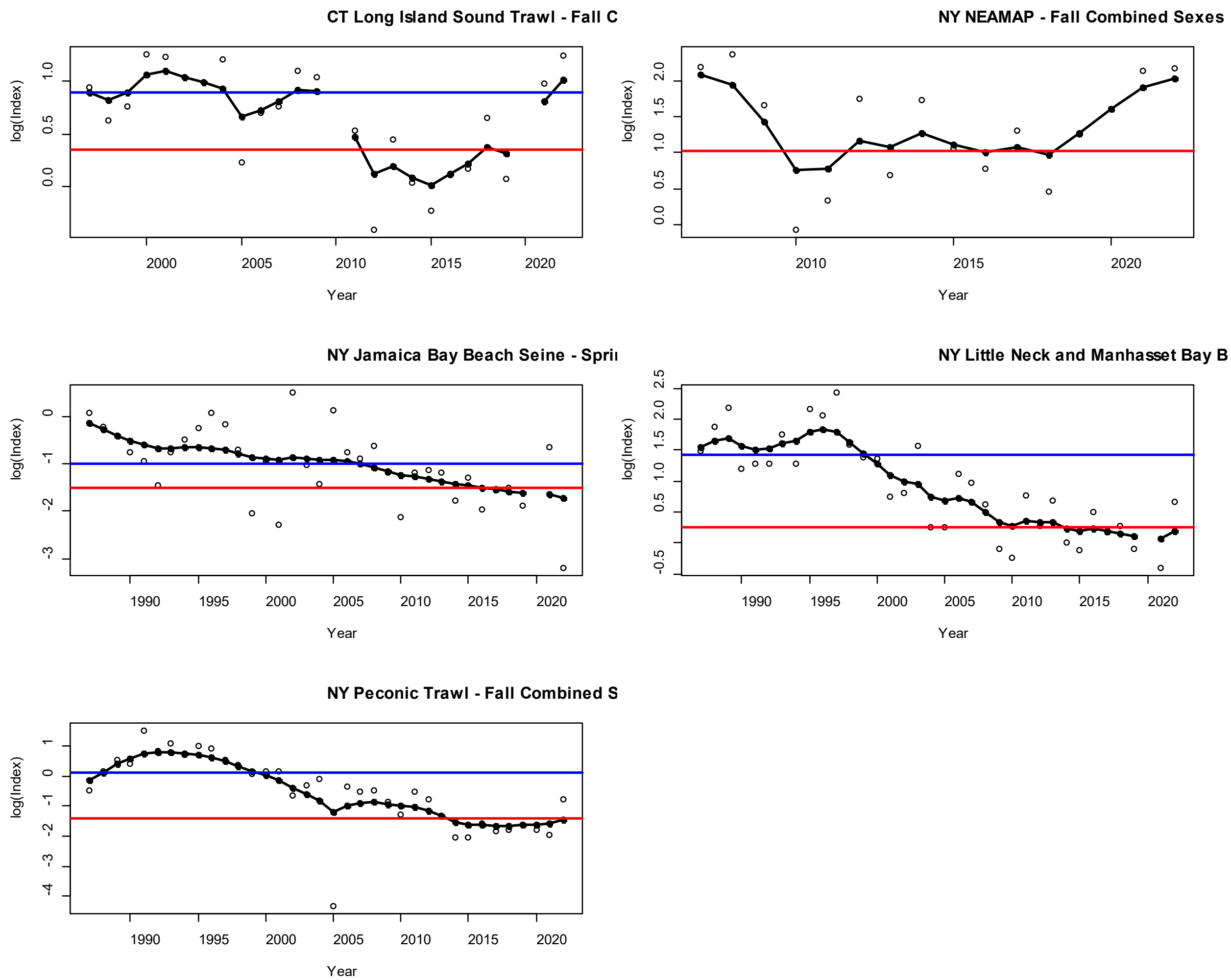


Figure 27. ARIMA model fits to horseshoe crab indices in the New York Region. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.

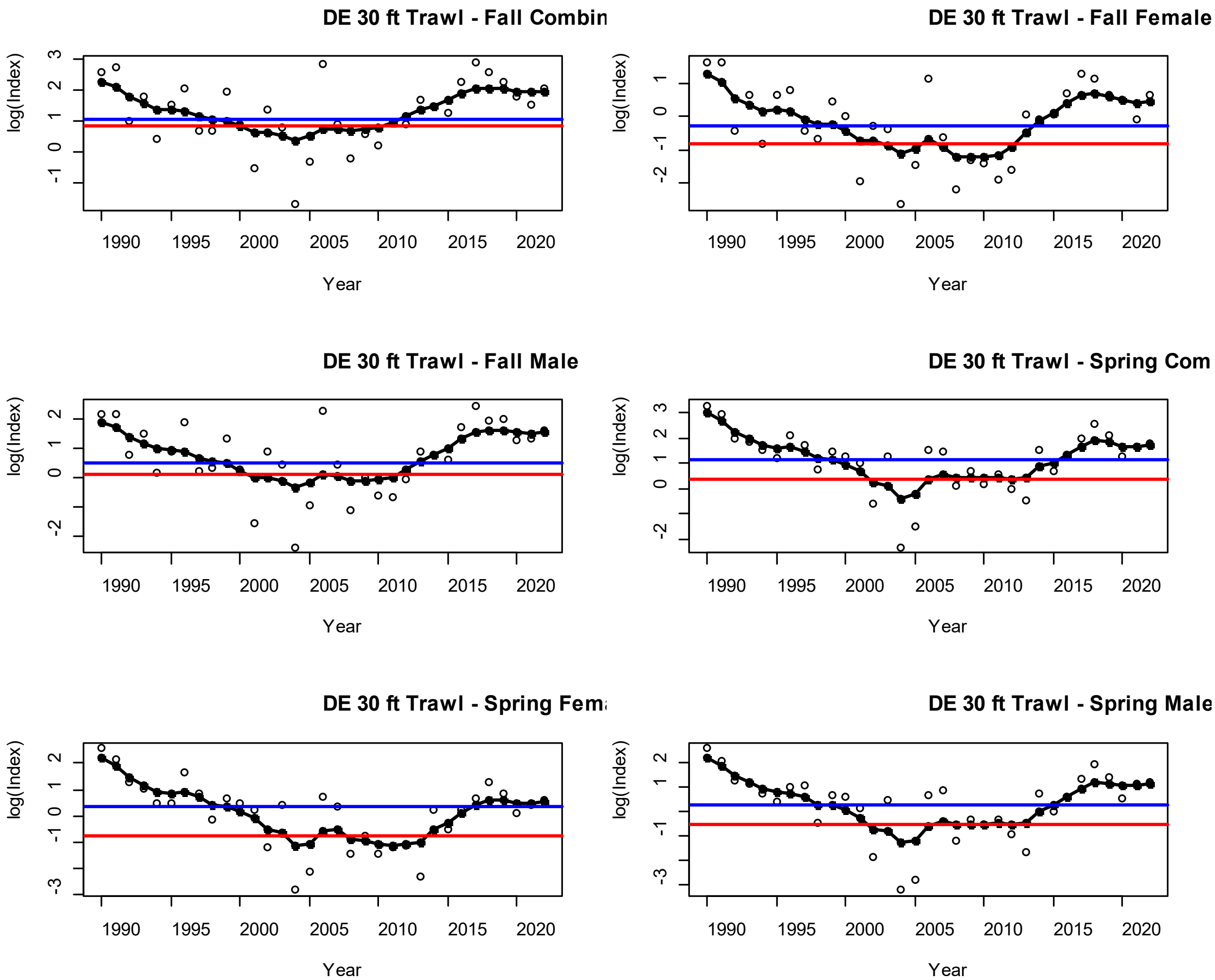


Figure 28. ARIMA model fits to horseshoe crab indices from the Delaware Trawl Survey in the Delaware Bay Region. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.

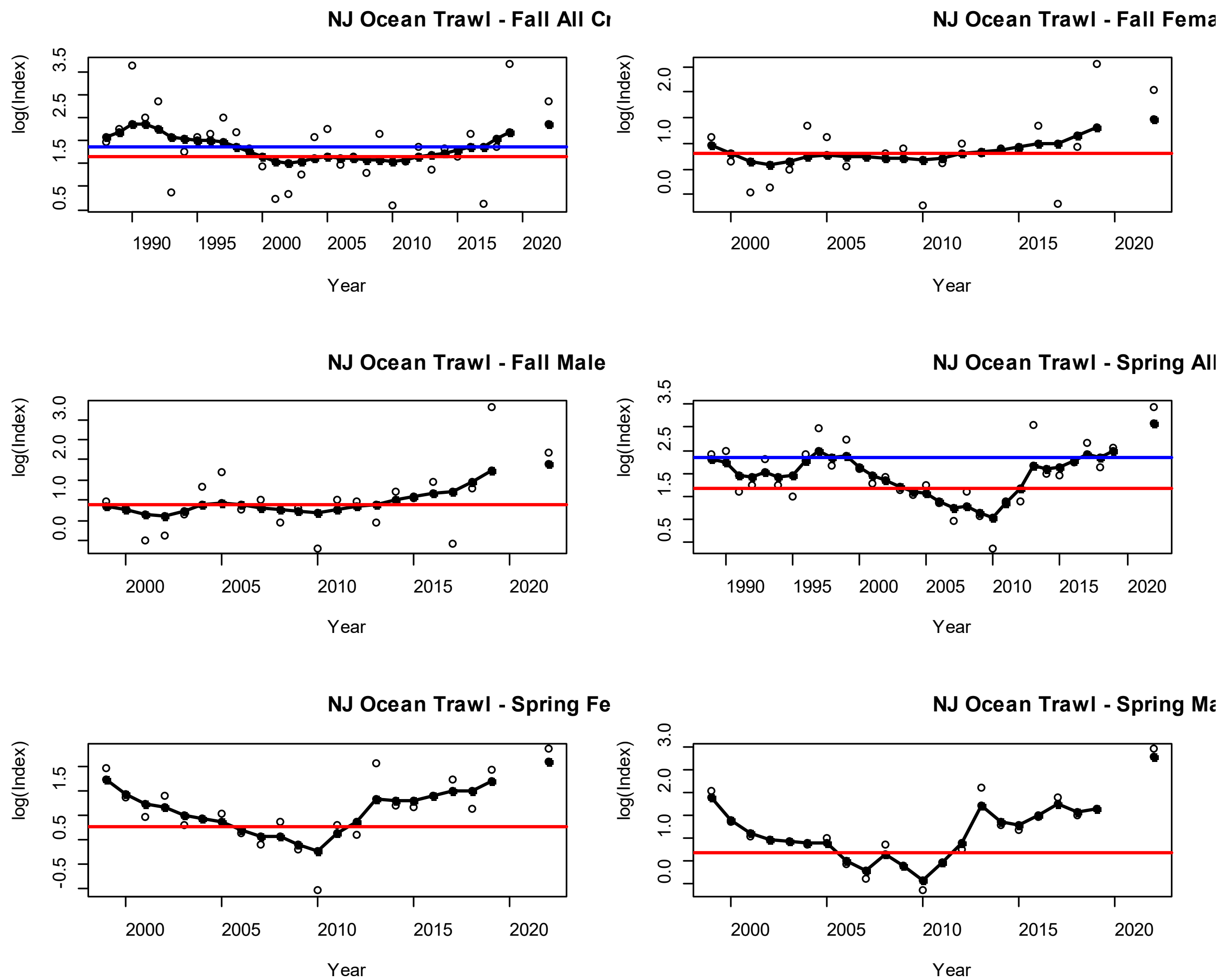


Figure 29. ARIMA model fits to horseshoe crab indices from the New Jersey Ocean Trawl Survey in the Delaware Bay Region. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.

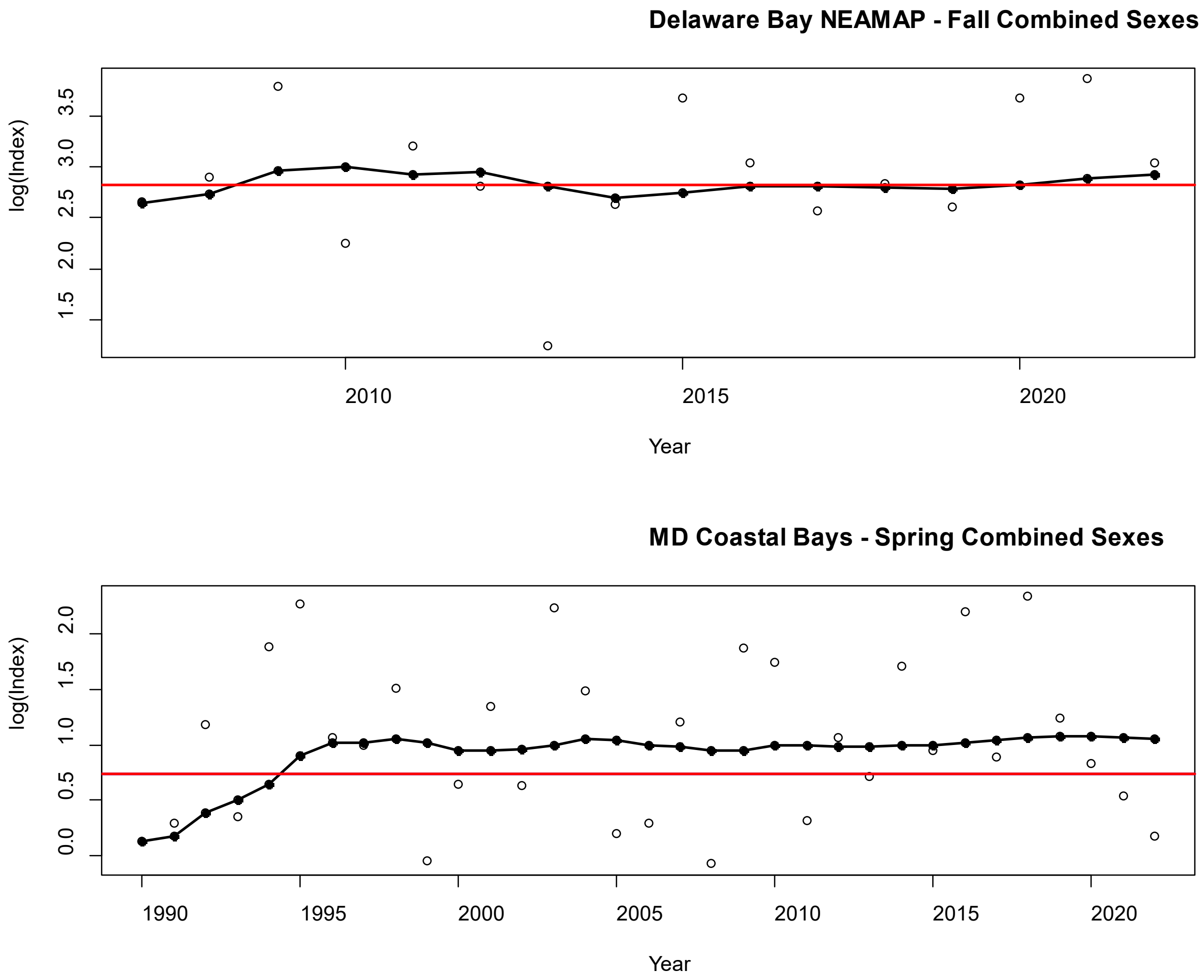


Figure 30. ARIMA model fits to horseshoe crab indices from Delaware Bay NEAMAP and Maryland Coast Bays Surveys in the Delaware Bay Region. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point. For the Maryland Coastal Bays survey, red and blue lines overlap.

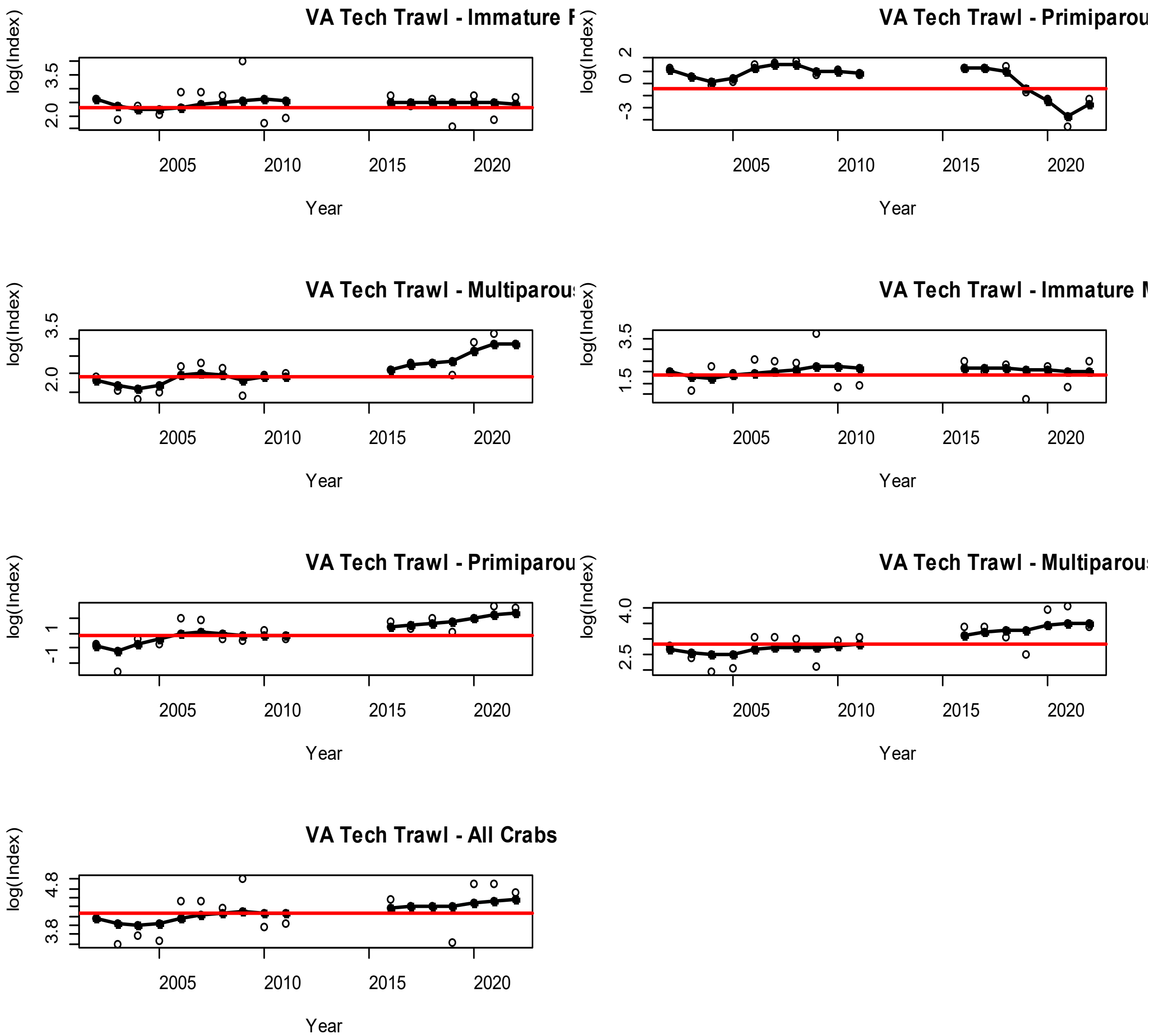


Figure 31. ARIMA model fits to horseshoe crab indices from the Virginia Tech Trawl Survey in the Delaware Bay Region. The red horizontal line represents the Q_{25} reference point.

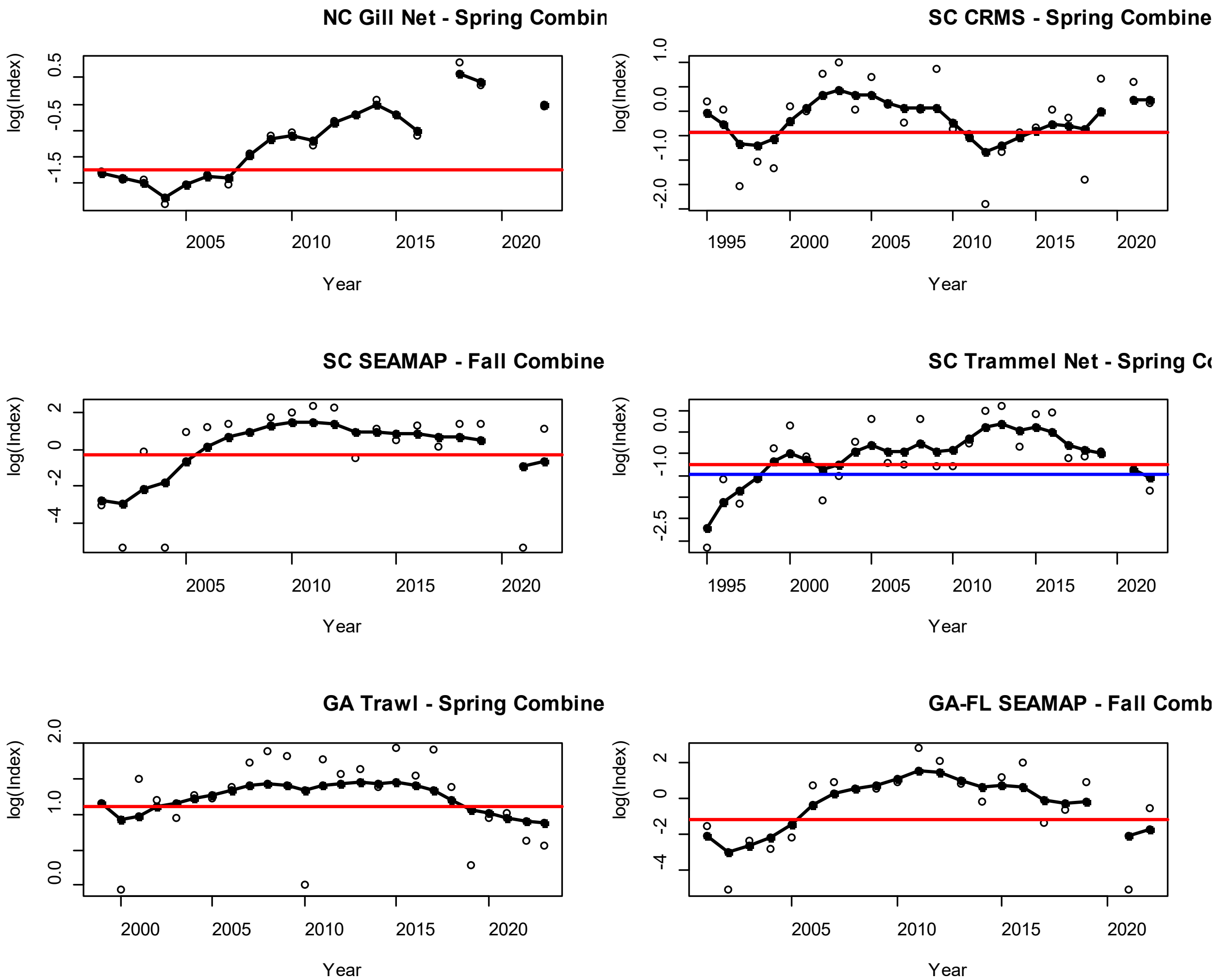


Figure 32. ARIMA model fits to horseshoe crab indices from the surveys in the Southeast Region. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.

APPENDICES

a. Appendix Tables

Table A1. Models used for generalized linear model (GLM) standardization of fixed station surveys and covariates used to estimate the abundance index. * Since ASMFC 2019, the South Carolina Crustacean Research and Monitoring Survey (CRMS) has been renamed as the Estuarine Trawl Survey but this update uses the older name for consistency with the benchmark.

Survey	Model	Covariates in Model
Rhode Island Monthly Trawl	Negative binomial (NB) GLM	Year, Station, Month
New York Western Long Island Sound (WLIS) Beach Seine - Jamaica Bay	NB GLM	Year, Station, Month
New York WLIS Beach Seine - Little Neck and Manhasset Bays	NB GLM	Year, Station, Bottom Temperature
Delaware Adult 30' Trawl	NB GLM	Year, Station
Maryland Coastal Bays	NB GLM	Year, Site
* South Carolina Crustacean Research and Monitoring Survey (CRMS)	NB GLM	Year, Salinity, Region
South Carolina Trammel Net	NB GLM	Year, Temperature, Stratum, Depth
Georgia Ecological Monitoring Survey	NB GLM	Year, Temperature, Station

Table A2. Number of tows by strata in the South Carolina Trammel Net Survey, 1995-2022. Strata used in the index were limited to ACE Basin/St. Helena Sound (AB), Charleston Harbor (CH), Muddy and Bulls Bays (MB), and Romain Harbor (RH) and the months March, April, and May.

Year	AB	CH	MB	RH	Total
1995	26	20			46
1996	21	28			49
1997	33	30			63
1998	35	30	32	36	133
1999	33	30	34	24	121
2000	34	30	35	35	134
2001	22	30	35	31	118
2002	34	30	30	35	129
2003	35	29	33	34	131
2004	32	28	30	31	121
2005	34	27	28	32	121
2006	32	29	36	33	130
2007	29	29	33	31	122
2008	32	29	36	34	131
2009	28	26	32	34	120
2010	31	30	23	32	116
2011	34	29	34	36	133
2012	35	28	35	34	132
2013	34	27	31	31	123
2014	22	29	32	32	115
2015	31	27	33	32	123
2016	32	30	29	35	126
2017	28	25	11	26	90
2018	30	25	33	32	120
2019	31	28	33	28	120
2020	13			12	25
2021	23	33		12	68
2022	20	7	21		48

Table A3. Number of tows by state in Southeast Area Monitoring and Assessment Program (SEAMAP) Survey, 2001- 2022. Two indices were developed from this data: South Carolina and Georgia-Florida for the months October and November.

Year	SC	GA	FL
2001	26	26	19
2002	25	28	19
2003	25	28	19
2004	25	25	19
2005	25	25	19
2006	26	26	20
2007	30	25	19
2008	29	27	19
2009	36	26	20
2010	30	28	23
2011	26	28	25
2012	28	25	26
2013	26	23	23
2014	25	23	16
2015	26	25	26
2016	26	23	24
2017	26	19	22
2018	25	19	18
2019	26	20	6
2020			
2021	27	19	11
2022	19	2	5

Table A4. Number of tagged horseshoe crab recaptures based on release year and recapture year from 2009-2022 by region. Annual recapture percent is based on the total number of recaptures for a given release year for the entire time period. Average recapture percent over time is split from 2009-2019 (pre-pandemic) and 2020-2022 (pandemic affected years). All recaptures listed are horseshoe crabs reported alive and greater than 90 days following their release. Table continues on next few pages (source: USFWS tagging database).

Northeast Region

Release Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total Recaptures	Total Releases	Annual Recapture %	Average Recapture %
2009	25	794	381	96	118	79	54	46	10	6	11	4	4		1,628	14,954	10.9%	
2010		18	881	184	229	106	74	40	15	17	29	10	9	3	1,615	17,197	9.4%	
2011			15	300	352	174	95	57	38	34	27	29	10	6	1,137	16,487	6.9%	
2012				8	358	134	81	53	28	18	22	14	8	8	732	11,154	6.6%	
2013					3	187	109	60	33	31	31	19	11	16	500	7,616	6.6%	
2014						6	107	42	28	26	20	16	15	16	276	3,802	7.3%	8.40%
2015							1	126	41	37	54	26	21	12	318	3,726	8.5%	
2016								5	86	62	58	31	34	17	293	3,964	7.4%	
2017									2	63	52	34	36	19	206	1,869	11.0%	
2018										2	155	59	33	32	281	2,937	9.6%	
2019											1	101	54	30	186	2,275	8.2%	
2020												3	64	22	89	1,345	6.6%	
2021													1	71	72	1,225	5.9%	4.20%
2022														2	2	1,174	0.2%	

Table A4 Continued.

Coastal NY-NJ

Release Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total Recaptures	Total Releases	Annual Recapture %	Average Recapture %
2009	2	87	61	21	16	6	8	2	4		2		1		210	3,331	6.3%	
2010		4	67	21	12	10	4	4	2	2		1			127	2,194	5.8%	
2011			1	35	20	10	11	2	1	1	4	1	2		88	2,130	4.1%	
2012				5	117	55	36	12	9	13	2	3	4		256	7,075	3.6%	
2013					1	81	55	19	13	8	18	14	6	7	222	4,568	4.9%	
2014						1	59	19	29	8	16	11	7	6	156	2,913	5.4%	4.80%
2015							3	39	28	20	27	7	11	9	144	3,868	3.7%	
2016								3	58	32	56	21	13	36	219	4,343	5.0%	
2017									3	70	49	25	23	27	197	4,570	4.3%	
2018										3	123	53	42	55	276	4,850	5.7%	
2019											1	74	73	65	213	5,435	3.9%	
2020													80	38	118	2,560	4.6%	
2021													2	193	195	4,645	4.2%	3.00%
2022														4	4	5,617	0.1%	

Delaware Bay

Release Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total Recaptures	Total Releases	Annual Recapture %	Average Recapture %
2009	0	11	20	11	6	1	2	1							52	546	9.5%	
2010		1	90	53	57	21	19	18	4	6	5				274	1,976	13.9%	
2011			2	89	105	40	37	27	14	6	4	4			328	3,625	9.0%	
2012					91	43	36	27	18	7	10	3			235	2,277	10.3%	
2013					2	33	22	15	4	4	12	5		1	98	1,314	7.5%	
2014							131	71	79	44	30	10	9	5	379	4,222	9.0%	8.50%
2015							1	68	60	61	36	28	21	4	279	4,231	6.6%	
2016								1	103	76	73	49	32	11	345	5,625	6.1%	
2017									3	162	141	87	42	20	455	5,597	8.1%	
2018											211	101	71	32	415	5,640	7.4%	
2019											3	137	122	46	308	4,966	6.2%	
2020												0	0	0	-	30	0.0%	
2021													3	72	75	2,784	2.7%	0.90%
2022														4	4	4,937	0.1%	

Table A4 Continued.

Coastal DE-VA

Release Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total Recaptures	Total Releases	Annual Recapture %	Average Recapture %
2009	2	87	45	18	32	18	10	8	2		1				223	4,721	4.7%	
2010			105	15	25	17	6	9	10	1	6				194	5,413	3.6%	
2011			3	88	86	36	26	24	9	6	3	1	1		283	6,844	4.1%	
2012				9	235	82	38	17	16	12	8	1	4	1	423	9,873	4.3%	
2013						53	40	23	16	14	16	5	6	4	177	6,813	2.6%	
2014							69	18	17	5	8	1	8	2	128	4,237	3.0%	3.60%
2015							4	27	14	12	13	5	4	7	86	3,574	2.4%	
2016								2	49	17	13	11	5	2	99	4,170	2.4%	
2017									1	103	48	31	19	19	221	5,193	4.3%	
2018										7	113	43	41	14	218	5,018	4.3%	
2019											6	98	57	37	198	5,897	3.4%	
2020													33	23	56	4,042	1.4%	
2021													7	118	125	6,166	2.0%	1.20%
2022														9	9	7,382	0.1%	

Southeast Region

Release Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total Recaptures	Total Releases	Annual Recapture %	Average Recapture %
2009	1	1	5	2	3										12	325	3.7%	
2010		1	77	45	10	11	3								147	2,588	5.7%	
2011				20	5	11		1	1						38	957	4.0%	
2012						2									2	442	0.5%	
2013					2	11		3					1		17	412	4.1%	
2014						1	8	3	2	1					15	1,757	0.9%	2.00%
2015							1	10	7	2	3			1	24	2,015	1.2%	
2016								1	6	2	7				16	1,865	0.9%	
2017										1				1	2	418	0.5%	
2018										1		1	2		4	502	0.8%	
2019												1			1	608	0.2%	
2020															-	65	0.0%	
2021														6	6	1,206	0.5%	0.20%
2022														1	1	773	0.1%	

Table A5. Total mature (newly mature plus mature) horseshoe crab population estimates in millions by sex and estimation method (catch multiple survey model or Virginia Tech Trawl Survey), 2003-2022.

	Females (in millions)			Males (in millions)		
Biomedical Data:	**Zero**	**Coastwide**	**N/A**	**Zero**	**Coastwide**	**N/A**
Estimation Method:	**CMSA**		**VT Trawl**	**CMSA**		**VT Trawl**
2003	6.1	6.1	6.5	15.1	15.2	12.1
2004	5.3	5.3	4.2	11	11	8.1
2005	4.2	4.2	3.1	8.9	8.9	5.9
2006	3.7	3.7	3.6	7.3	7.3	6.4
2007	5	5	8.7	10.4	10.5	18.9
2008	5.1	5.1	10.1	10.7	10.7	18.9
2009	4.9	4.9	8.9	8.5	8.5	15.4
2010	4.4	4.4	3.9	7	7	7
2011	4.9	4.9	6.5	7.2	7.3	15.4
2012	4.3	4.3	6.1	5.9	5.9	15.8
2013	10.7	10.7		11.9	11.9	
2014	8.4	8.5		21.1	21.2	
2015	6.5	6.6		15.4	15.4	
2016	11.2	11.2		39.7	39.9	
2017	10.2	10.2	7.6	33.7	33.8	24.5
2018	9.1	9.1	8.7	26.4	26.4	22.2
2019	8.2	8.2	9.1	23.7	23.8	19.1
2020	10.6	10.7	5.4	18.8	18.8	10.2
2021	11.2	11.2	10.9	17.2	17.2	34
2022	16.1	16.2	15.5	40.3	40.3	44.9

b. Appendix Figures

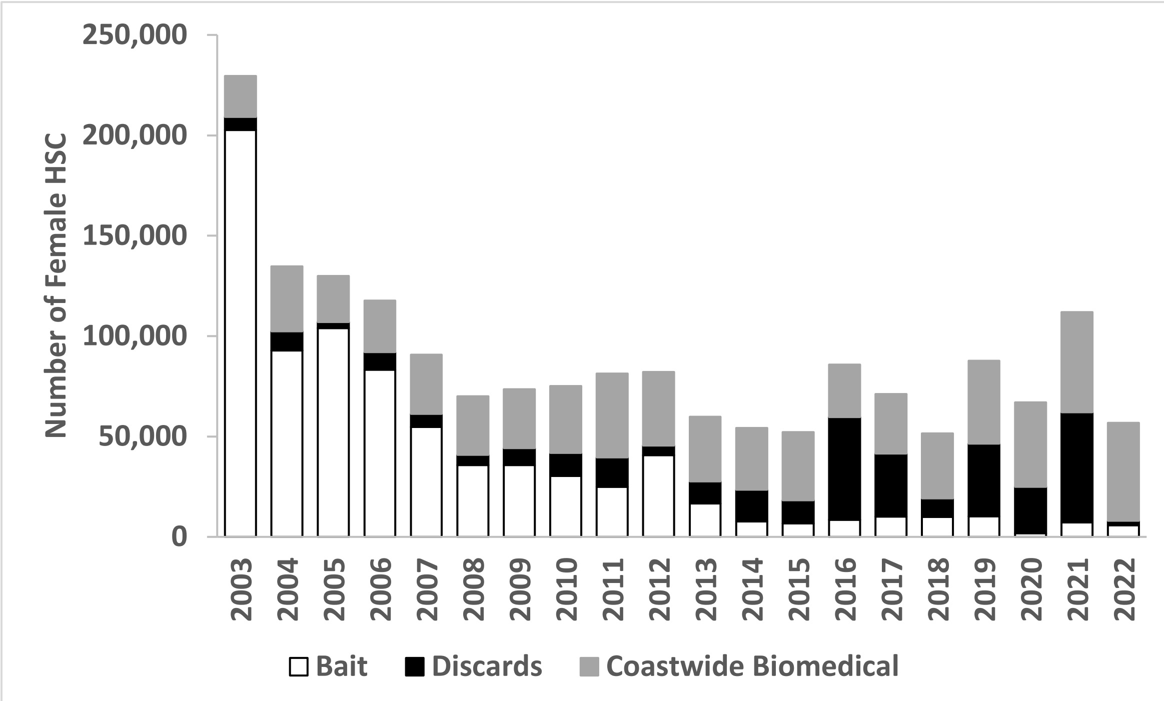


Figure A1. Total female horseshoe crab harvest by source in the Delaware Bay, 2003-2022, for use in the CMSA.

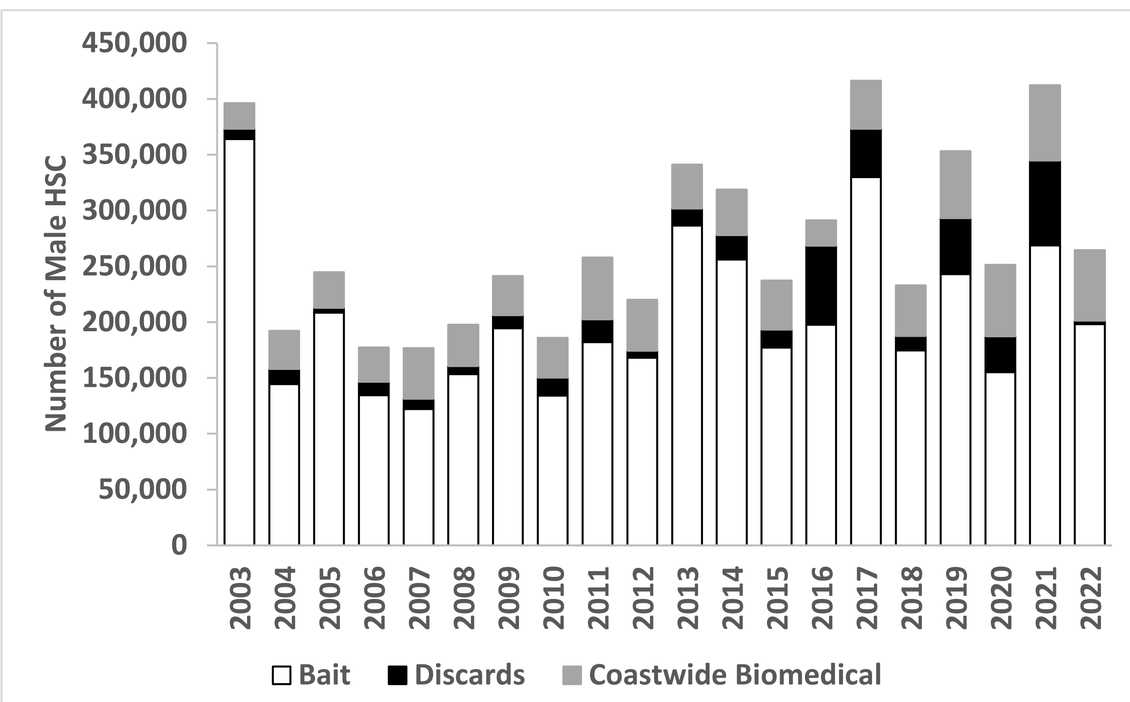


Figure A2. Total male horseshoe crab harvest by source in the Delaware Bay, 2003-2022, for use in the CSMA.

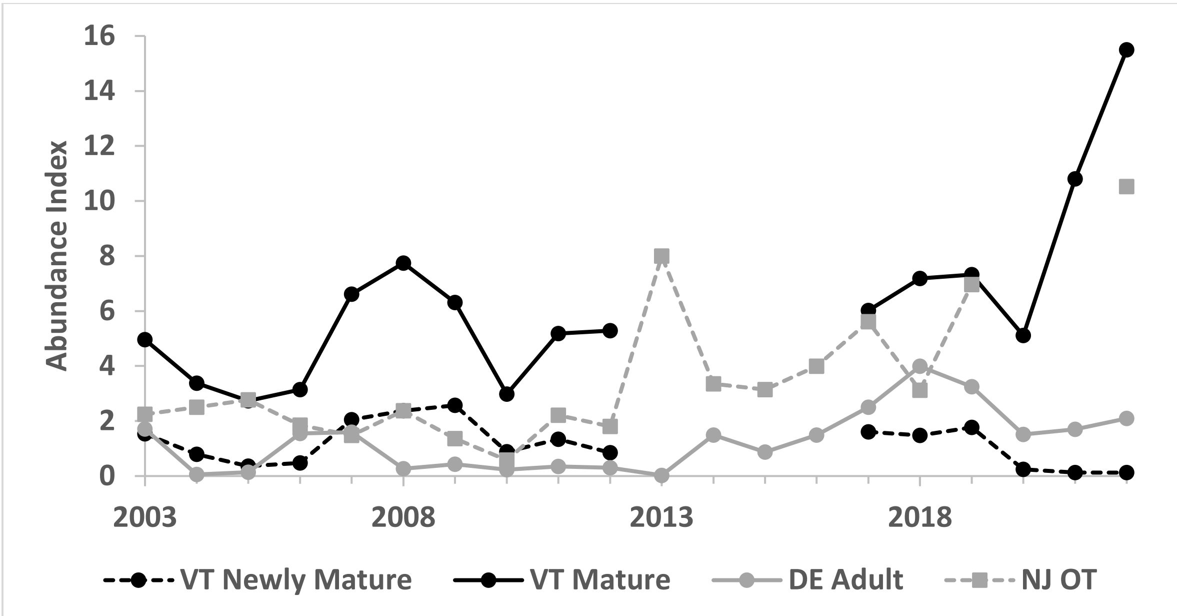


Figure A3. Female horseshoe crab abundance indices used in the CMSA. The Virginia Tech (VT) indices are in millions of newly mature and mature crabs while the Delaware Adult (DE Adult) and New Jersey Ocean Trawl (NJ OT) are in catch-per-tow.

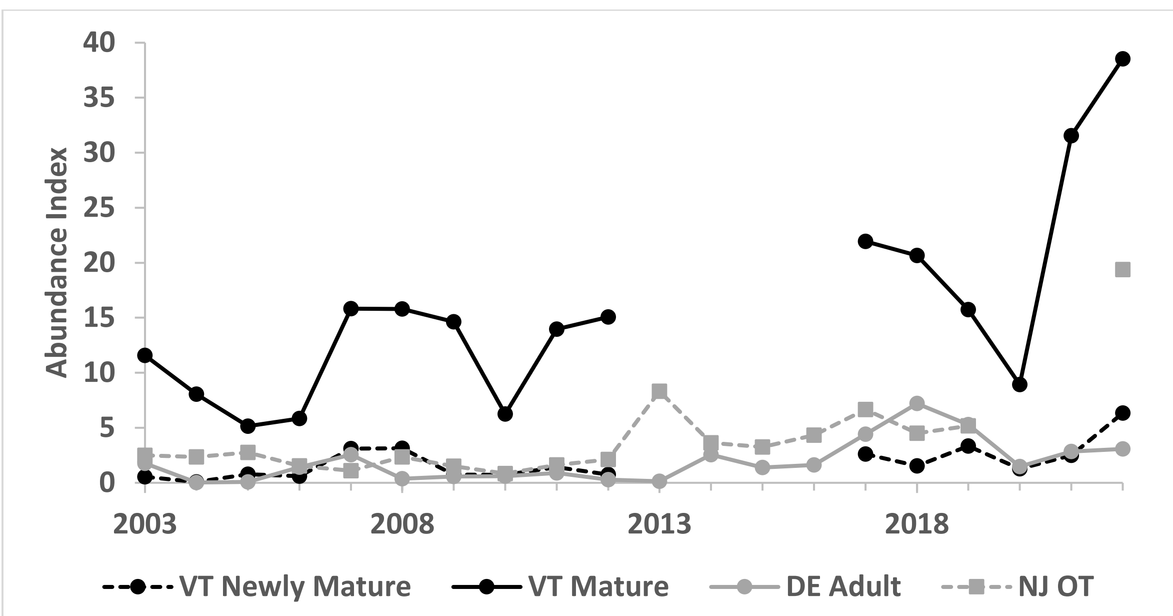


Figure A4. Male horseshoe crab abundance indices used in the CMSA. The Virginia Tech (VT) indices are in millions of newly mature and mature crabs while the Delaware Adult (DE Adult) and New Jersey Ocean Trawl (NJ OT) are in catch-per-tow.

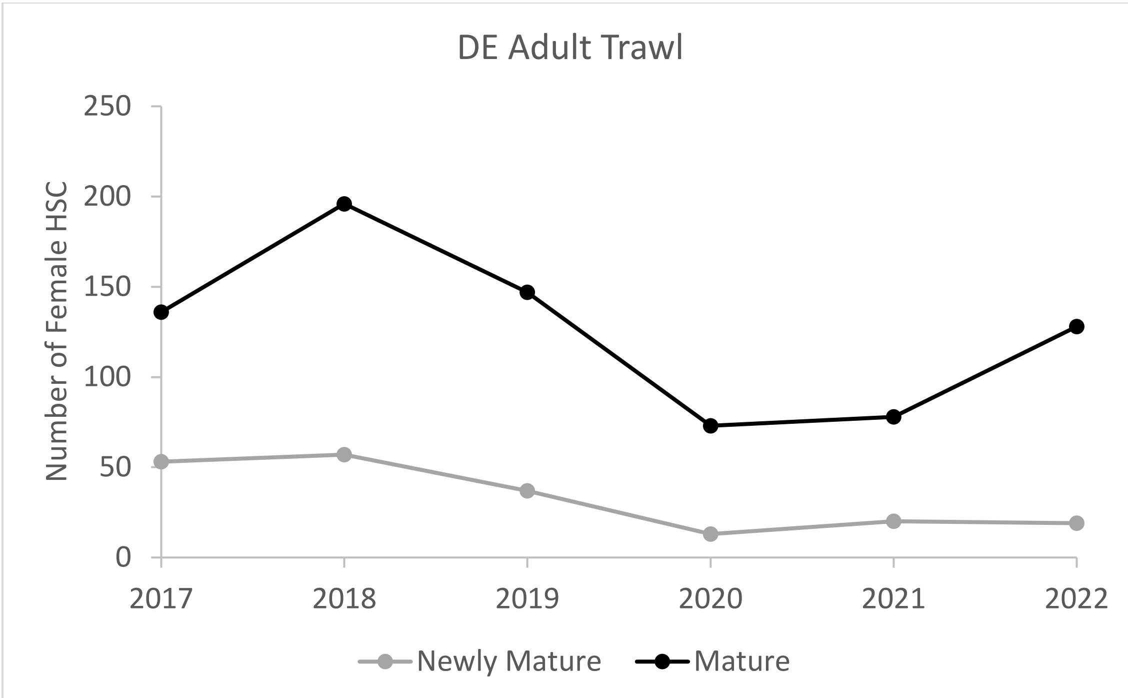


Figure A5. Mature and newly mature female horseshoe crabs caught in the Delaware Adult (30 foot) Trawl, 2017-2022.

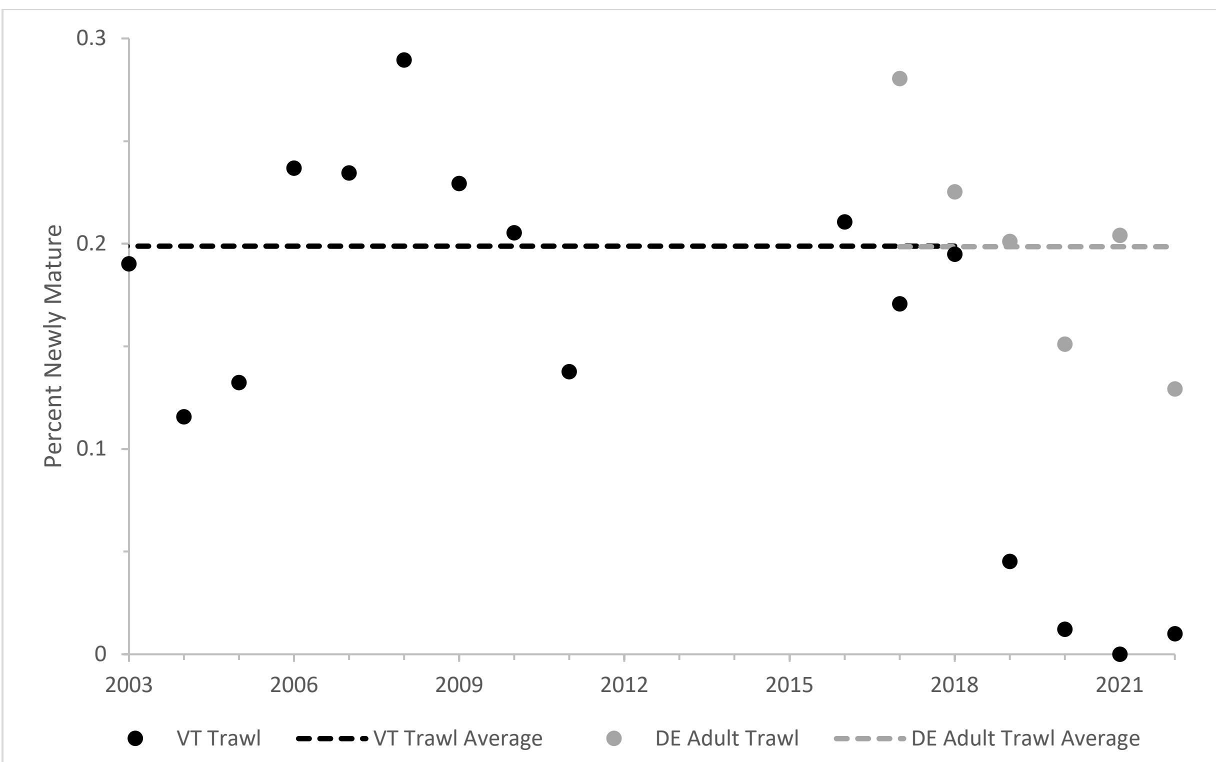


Figure A6. Percent of newly mature female horseshoe crabs in the Virginia Tech and Delaware Adult Trawls. The low years of newly mature female horseshoe crabs (2019-2022) were not included in the average for the Virginia Tech Trawl.

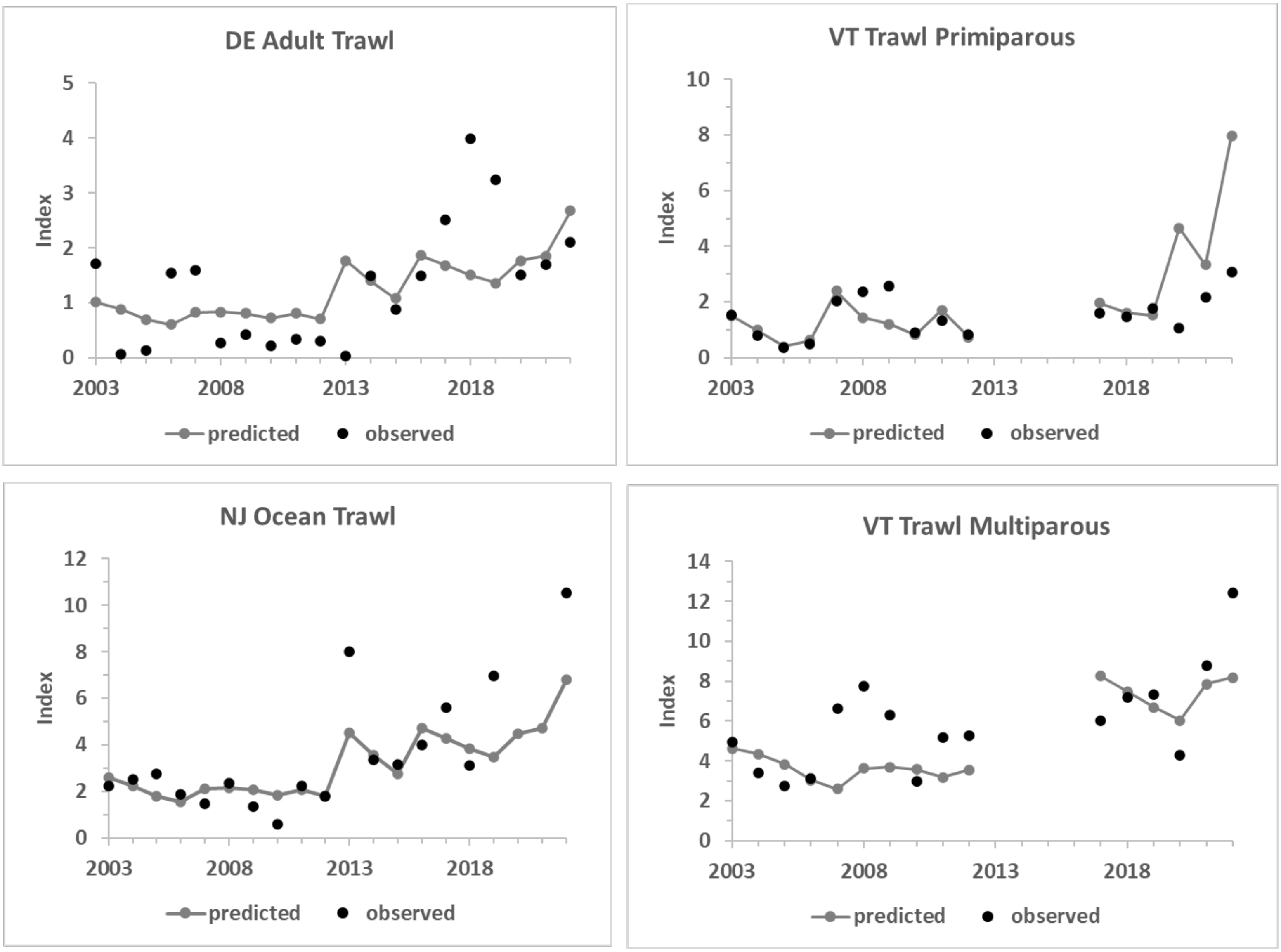


Figure A7. CMSA model fit to the indices of female horseshoe crab abundance.

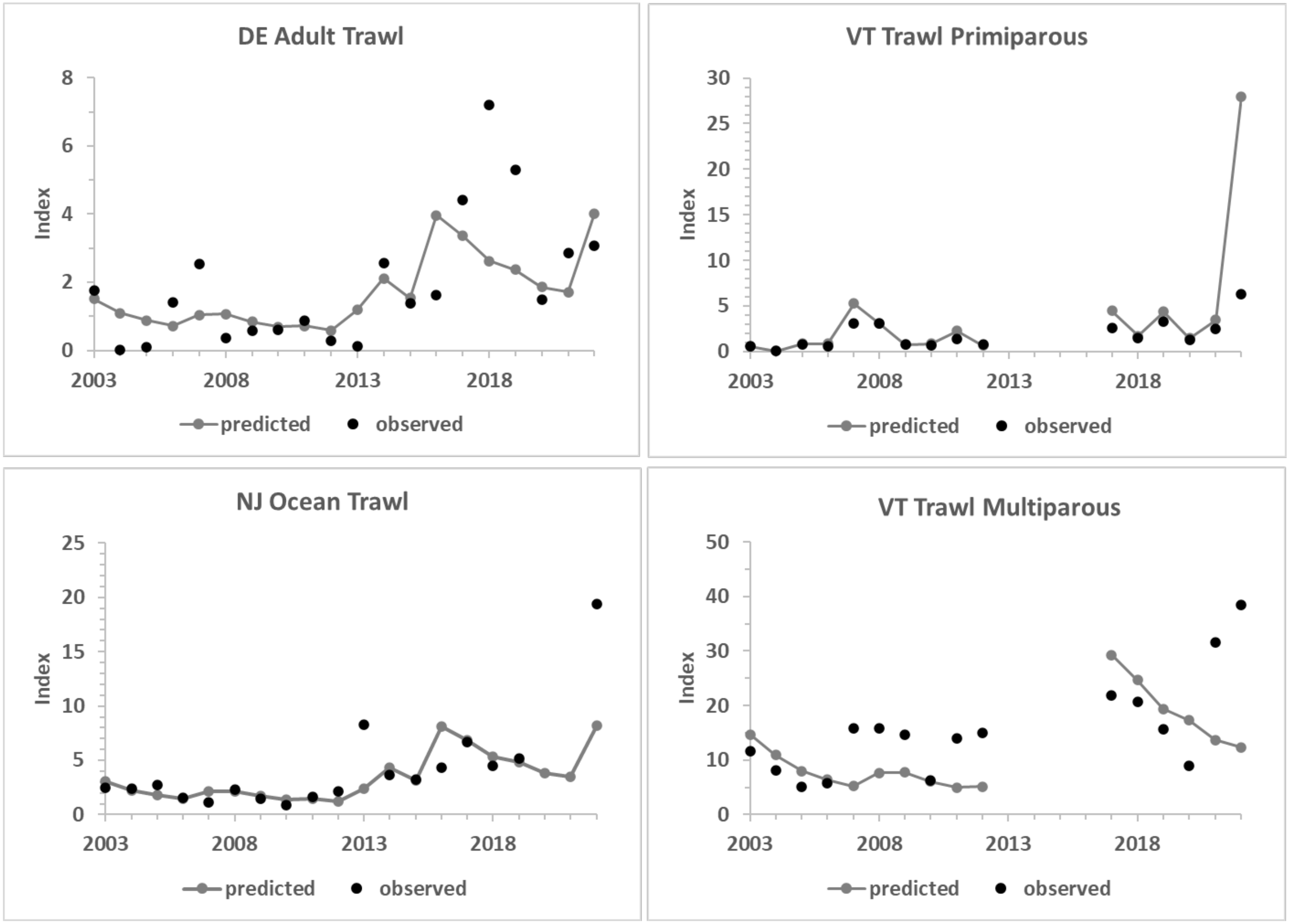


Figure A8. CMSA model fit to the indices of male horseshoe crab abundance.

c. 2019 Benchmark Research Recommendations

The following is the complete list of research recommendations from the benchmark assessment (ASMFC 2019). Comments have been added in italics to list initiated research or published papers since ASMFC 2019. Research recommendations which have been addressed or partially addressed are also described in TOR 7.

Research recommendations have been categorized as future research, data collection, and assessment methodology and listed in order of priority. The SAS and TC recommend that during the years between this assessment and the next, members remain proactive about maintaining surveys and research programs and continuing to initiate or participate in activities that accomplish some of the research recommendations listed below.

Future Research

- Determine relationship between age, stage, and size for horseshoe crabs.
- Compare densities of horseshoe crabs nearshore, offshore, and in bays, compare different stages (i.e., primiparous and multiparous), and look at movements among embayments within regions (i.e., around Cape Cod, Long Island).
    - *Bopp et al. (2019) describes survival and movement between regions of Long Island, New York.*
- Characterize the proportion of states' landings that comprise crabs of Delaware Bay origin. This can be done through a directed tag/release study, genetics/microchemistry study, or both.
- Collect more life history information, particularly for juveniles, on growth, molt timing, and distribution.
    - *Several papers have been published on juvenile ecology, trophic niches across stages and location, and spawning in salt marshes (Cheng et al. 2021; Kendrick et al. 2021; Colon et al. 2022; Bopp et al. 2023; Sasson et al. 2024).*
- Evaluate the effect of warming temperatures on distribution and timing of spawning for horseshoe crabs.
    - *Cheng et al. 2022 evaluated the temperature and salinity preferences of horseshoe crabs in New Hampshire and the effects of warmer water on their heart rates.*
- Address the issue of gear saturation for spawning beach surveys and/or explore analyses that would be less sensitive to gear saturation. Explore the methodology and data collection of spawning beach surveys and the ability of these surveys to track spawning abundance.

- Determine if there is illegal take-and-use at sea, transfer at sea, and poaching from spawning areas for horseshoe crabs and estimate the amount if possible.

Data Collection

- Continue to fund and operate the full Virginia Tech Trawl Survey annually.
    - *The Virginia Tech Trawl Survey has continued to be funded annually since ASMFC 2019 and is currently funded through 2024.*
- Conduct a gear efficiency study of the Virginia Tech Trawl Survey given the importance of using swept-area estimates of abundance in modeling the Delaware population.
- Better characterize the discards, landings, and discard mortality by gear.
    - *The discard estimates were revised and peer reviewed in ASMFC 2022 as part of the revision to the ARM Framework. While there are still large confidence intervals associated with the discard estimates, the ASMFC 2022 estimates are an improvement over the ASMFC 2019 estimates and have been used in this report.*
- Increase the priority of maintaining and managing horseshoe crab data in and among states, both fishery-dependent and –independent, and improve communication between data providers.
- Continue current biosampling for sex and weight and expand where possible.
- Develop a standardized biosampling protocol to cover different seasons and obtain weights, ages, stages, and widths of horseshoe crabs using a random sampling design.
- Expand or implement fishery-independent surveys (e.g., spawning, benthic trawl, tagging) to target horseshoe crabs throughout their full range including estuaries. Highest priority should be given to implementing directed surveys in the Northeast and New York regions.
- Collect sex and stage data in fishery-independent surveys. Surveys should consider using similar methods as the Virginia Tech Trawl Survey and collect biological data by sex and stage, particularly by primiparous and multiparous.
    - *Delaware, New Jersey, and South Carolina have all begun to collect stage information from their trawl surveys following the methods from Virginia Tech Trawl Survey.*
- Continue to evaluate biomedically bled crabs' mortality rates. Consider a tagging study of biomedically bled horseshoe crabs to obtain relative survival and collaborations

between researchers and biomedical facilities that would result in peer-reviewed mortality estimates.

  - *Several studies on biomedical mortality have been published since ASMFC 2019 (Owings et al. 2019, 2020; Smith et al. 2020; Tinker-Kulberg et al. 2020a, 2020b, 2020c; Watson et al. 2022; Litzenberg 2023).*

- Maintain consistent data collection and survey designs for spawning beach surveys each year and encourage spawning beach surveys to conduct the data collection for the survey and tagging resights separately.

Assessment Methodology

- The ARM working group should consider using the population estimates from the CMSA model as an input to the ARM model as well as estimated mortality from discards and the biomedical industry.

  - *The CMSA was incorporated into the revised ARM Framework and peer reviewed as part of ASMFC 2022. Additionally, the CMSA was peer reviewed and published (Anstead et al. 2023).*

- Further develop the catch survey analysis and apply assessment modeling beyond the Delaware Bay region, which would require more stage-based data collection.

- Develop a stage-based or length-based model specific for horseshoe crabs that addresses their life history characteristics.

- Estimate the survival of early life stages (e.g., age-zero, juveniles) and growth rates.

- Explore the possibility of using a delay-difference model for future assessments. Because of the life history of horseshoe crab, this would require 20-30 years of data before it could be developed.

- Continue to evaluate tagging data by fitting capture-recapture models that include a short-term (1 year) bleeding effect, account for spatial distribution of harvest pressure, account for capture methodology, and account for disposition of recaptured tagged individuals. Potential methodological approaches include use of time-varying individual covariates to indicate which crabs are 1 year from bleeding and use of hierarchical models to estimate interannual variation in survival within time periods defined by major regulatory changes.