Atlantic States Marine Fisheries Commission

Horseshoe Crab Management Board

April 30, 2024
3:00 – 5:15 p.m.

Draft Agenda

The times listed are approximate; the order in which these items will be taken is subject to change; other items may be added as necessary

1.	Welcome/Call to Order *(J. Davis)*	3:00 p.m.
2.	Board Consent • Approval of Agenda • Approval of Proceedings from October 2023	3:00 p.m.
3.	Public Comment	3:05 p.m.
4.	Consider 2024 Horseshoe Crab Stock Assessment Update *(K. Rodrigue)* **Action**	3:15 p.m.
5.	Discuss Horseshoe Crab Bait Demand *(C. Starks)* • Possible Impact of State Harvest Regulations on Bait Demand	4:00 p.m.
6.	Adaptive Resource Management Subcommittee (ARM) Report *(J. Sweka)* • Technical Response to External Review of ARM Framework Revision	4:15 p.m.
7.	Update on Horseshoe Crab Management Objectives Workshop *(C. Starks)*	5:00 p.m.
8.	Elect Vice-Chair **Action**	5:10 p.m.
9.	Other Business/Adjourn	5:15 p.m.

The meeting will be held at The Westin Crystal City, 1800 Richmond Highway, Arlington, VA; 703.486.1111, and via webinar; click here for details.

MEETING OVERVIEW

Horseshoe Crab Management Board
April 30, 2024
3:00 – 5:15 p.m.

Chair: Justin Davis (CT) Assumed Chairmanship: 02/24	Technical Committee Chair: Ethan Simpson (VA)	Law Enforcement Committee Rep: Nick Couch (DE)_
Vice Chair: Vacant	Advisory Panel Chair: Brett Hoffmeister (MA)	Previous Board Meeting: October 16, 2023
Voting Members: MA, RI, CT, NY, NJ, PA, DE, MD, DC, PRFC, VA, NC, SC, GA, FL, NMFS, USFWS (16 votes)		

2. Board Consent
- Approval of Agenda
- Approval of Proceedings from October 2023

3. Public Comment – At the beginning of the meeting, public comment will be taken on items not on the agenda. Individuals that wish to speak at this time must sign-in at the beginning of the meeting. For agenda items that have already gone out for public hearing and/or have had a public comment period that has closed, the Board Chair may determine that additional public comment will not provide additional information. In this circumstance, the Chair will not allow additional public comment on an issue. For agenda items that the public has not had a chance to provide input, the Board Chair may allow limited opportunity for comment. The Board Chair has the discretion to limit the number of speakers and/or the length of each comment.

4. Consider 2024 Horseshoe Crab Stock Assessment Update (3:15-4:00) Action
Background • A stock assessment update for horseshoe crab was initiated in 2023 and scheduled for completion in late 2024. • The SAS completed the stock assessment update ahead of schedule, and the TC approved it for consideration by the Board **(Briefing Materials).**
Presentations • Horseshoe Crab Stock Assessment Update by K. Rodrigue
Board actions for consideration at this meeting • Accept assessment update for management use

5. Discuss Horseshoe Crab Bait Demand (4:00-4:15 p.m.)
Background • At the October 2023 Board meeting, the Board tasked staff with compiling information from the states with horseshoe crab fisheries on bait landings, exports, and demand, and on regulations restricting horseshoe crab harvest. • Staff collected and summarized the information from the states to better understand possible impacts of restrictive regulations in one state on bait demand and fishing pressure in other states **(Supplemental Materials).**

Presentations

- Summary of state horseshoe crab bait fisheries and regulations by C. Starks

6. Adaptive Resource Management Subcommittee (ARM) Report (4:15-5:00 p.m.)

Background

- Since the ARM Revision was completed in 2021 there has been widespread public concern regarding the possibility of female horseshoe crab harvest. Earthjustice, a non-profit public interest organization, hired experts to do their own technical review of the ARM Revision in 2022 and again in 2023 before the annual meeting of the Board to set harvest specifications for the Delaware Bay region.
- In October 2023, the Board tasked the Adaptive Resource Management (ARM) Subcommittee with preparing a response to the September 2023 review of the ARM Framework by Dr. Kevin Shoemaker **(Briefing Materials)**.

Presentations

- Technical Response to External Review of the ARM Framework Revision by J. Sweka

7. Update on Horseshoe Crab Management Objectives Workshop (5:00-5:10 p.m.)

Background

- As part of its ongoing discussions regarding how best to manage Delaware Bay-origin horseshoe crabs and in response to the 2023 Stakeholder Survey, the Board agreed to hold Horseshoe Crab Management Objectives Workshop. The Workshop will include a small group of managers, scientists, and stakeholders to explore different management objectives for the Delaware Bayorigin horseshoe crab, with a focus on multi-year specification setting and modeling approaches when selecting no female harvest.
- The Workshop has been scheduled for July 2024. A report from the workshop including recommendations will be provided to the Board at the October 2024 meeting so that it can be considered during the 2025 specification setting process.

Presentations

- Update on Horseshoe Crab Management Objectives Workshop by C. Starks

8. Elect Vice Chair (5:10-5:15 p.m.) Action

Background

- The vice chair seat is empty since Justin Davis has assumed the role of chair.

Board actions for consideration at this meeting

- Elect Vice Chair

9. Other Business/Adjourn (5:15 p.m.)

DRAFT PROCEEDINGS OF THE

ATLANTIC STATES MARINE FISHERIES COMMISSION

HORSESHOE CRAB MANAGEMENT BOARD

Beaufort Hotel
Beaufort, North Carolina
Hybrid Meeting

October 16, 2024

These minutes are draft and subject to approval by the Horseshoe Crab Management Board.
The Board will review the minutes during its next meeting.

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1. **Approval of Agenda** by consent (Page 1).

2. **Approval of Proceedings of May 3, 2023** by consent (Page 1).

3. **Move to accept the 2024 Adaptive Resource Management harvest specifications with 500,000 males and no female harvest on Delaware Bay-origin crabs. In addition, the 2:1 offset will be added to MD's and VA's allocations due to no female harvest** (Page 5). Motion by Shanna Madsen; second by Craig Pugh. Motion passes by unanimous consent (Page 5).

4. **Move to use the Stakeholder Survey Report as a basis for a Horseshoe Crab Management Objectives workshop, which would include a small group of managers, scientists, and stakeholders to explore different management objectives for the Delaware Bay-origin horseshoe crabs. This workshop should focus on multi-year specification setting and modeling approaches when selecting no female harvest. The intent would be to provide a report to the full Board in time for the 2025 specification setting process** (Page 11). Motion by Shanna Madsen; second by Joe Cimino. Motion passes by unanimous consent (Page 11).

5. **Move to approve the FMP Review, state compliance reports, and de minimis requests for South Carolina, Georgia, and Florida for the 2022 fishing year** (Page 12). Motion by Mike Luisi; second by Emerson Hasbrouck. Motion passes by unanimous consent (Page 12).

6. **Move to approve Advisory Panel nomination for Sam Martin from Maryland** (Page 16). Motion by Mike Luisi; second by Shanna Madsen. Motion passes by unanimous consent (Page 16).

7. **Move to task the Adaptive Resource Management Subcommittee with preparing a response to the September 2023 review of the ARM Framework by Dr. Kevin Shoemaker** (Page 16). Motion by Bill Hyatt; second by Mike Luisi. Motion passes by unanimous consent (Page 18).

8. **Move to adjourn** by consent (Page 18).

ATTENDANCE TO BE FILLED ON A LATER DATE

The Horseshoe Crab Management Board of the Atlantic States Marine Fisheries Commission convened in the Rachel Carson Ballroom via hybrid meeting, in-person and webinar; Monday, October 16, 2023, and was called to order at 3:15 p.m. by Chair John Clark.

CALL TO ORDER

CHAIR JOHN CLARK: Welcome to the Horseshoe Crab Board. I think most of the Board is here and getting to the table. We are running behind, so I will talk fast. Welcome everybody. I am the Chair for the meeting, I'm John Clark from Delaware. I'm joined up here by Program Plan Coordinator extraordinaire, Caitlin Starks.

We have from the Law Enforcement Committee, Captain Nick Couch from Delaware, and we also have our Assessment Wonder Team here of John Sweka and Kristen Anstead here, so we are well represented up front.

APPROVAL OF AGENDA

CHAIR CLARK: Let's move right into the Consent Agenda. The agenda, right now there will be a change in the agenda you have.

The Item Number 5 will be considered before Item Number 4, so Item 5 becomes Number 4. In addition, we will have an Other Business Item, actually I think there is a couple of Other Business items that will come up, so we will get to that at the Other Business section of the agenda. Are there any other revisions to the agenda? Seeing none; the agenda is approved by consent.

APPROVAL OF PROCEEDINGS

CHAIR CLARK: Are there any changes or revisions to the proceedings from the May, 2022 meeting of this Board? Seeing none; the proceedings are approved by consent.

PUBLIC COMMENT

CHAIR CLARK: Do we have any public comment? Okay, this is public comment for items that are not on the agenda. Is there anybody in the room that has any comment? Not seeing any hands, we do not have comments.

SET 2024 DELAWARE BAY HARVEST SPECIFICATIONS

CHAIR CLARK: Now we'll move right into Agenda Item 4, which is Item 5 on your agenda. Take it away, John.

DR. JOHN SWEKA: As you all remember, the ARM Framework was revised and accepted for management use back in 2022. Under Addendum VIII, the ARM Framework will be used annually to produce state harvest recommendations to the Delaware Bay. Within that Addendum we have a maximum harvest that can be recommended of either 210,000 females and 500,000 males. Last year 125,000 females and 475,000 males were recommended for the 2023 harvest season.

However, the Board did elect to implement a 0 female harvest last year. Within the ARM Framework, the overall objective statement, as you've all seen before, is to manage harvest of horseshoe crabs in the Delaware Bay to maximize harvest, but also to maintain ecosystem integrity, provide adequate stopover habitat for migrating shorebirds, and ensure that the abundance of horseshoe crabs is not limiting the red knot stopover population or slowing recovery. The data that go into the ARM on an annual basis that we use then to make a decision, includes the red knot population estimates from a mark-resight analysis. This is conducted by Jim Lyons of USGS, and is based on visual counts of birds along Delaware Bay beaches, along with the number of birds that showed unique flags or marks on their legs.

The horseshoe crab population estimates come from three trawl surveys, the Virginia Tech Trawl Survey, the Delaware Adult Trawl, and the New Jersey Ocean Trawl Surveys. These trawl surveys then are incorporated into what is known as our Catch Multiple Survey Analysis Model, which also includes bait landings, dead discards and biomedical mortality, to ultimately come up with a population estimate of horseshoe crabs.

REVIEW HORSESHOE CRAB AND RED KNOT ABUNDANCE ESTIMATES AND MODEL RESULTS FROM THE ADAPTIVE RESOURCE MANAGEMENT FRAMEWORK REVISION

DR. SWEKA: Here we have the red know population estimates through time, dating back to 2011. These are the mark-resight population estimates that as I mentioned, Jim Lyons calculates these each year for us. In 2023, there were 39,361 red knots with confidence intervals ranging from 33,000 to 47,000. In 2022 there were 39,800 red knots, with confidence intervals ranging from 35,000 to 51,000.

When we make an annual harvest recommendation, for this year we will actually use the 2022 estimate, and this aligns the bird count, along with the population estimate of horseshoe crabs from 2022, which is the time period for which we have complete data for. Don't worry, there is two-year delay between when we have our population estimates from 2022, when harvest would be implemented in 2024.

That two-year time lag was incorporated in the ARM optimization. For female harvest of horseshoe crabs, this is a time series going back to 2003. You can see in more recent years the female harvest in the bait landings has declined greatly, because of the annual ARM recommendation of 0 female harvest.

The black portion of these bars are the dead discards, and in 2016 to 2021, the dead discards went up for females quite a bit, and that was because we had a very high dredge ratio, which influences the overall estimates. Now we must admit that our estimates of dead discards are pretty uncertain. There is a lot of variability, and just reporting issues within the NEFOP data to generate those.

The gray bars here represent biomedical mortality, and in the interest of protecting confidential data, here we represent the biomedical mortality as the total coastwide biomedical mortality, assuming it all comes from Delaware Bay. This graph just shows the male harvest through time. You can see since 2013 the bait landings are obviously much higher than that for males than they are for females, because we have consistently recommended 500,000 bait harvest.

But in reality, even the bait harvest, even though the ARM had recommended 500,000, still are a few hundred thousand less than the actual ARM implementation through time. Again, in black there are the dead discards, and in gray the coastwide biomedical mortality. Moving on to the indices of abundance. These are the female indices of abundance of horseshoe crab from the various trawl surveys. The first line I want to draw your attention to is the black solid line. That represents the fully mature or the multiparous animals from the Virginia Tech Trawl Survey. You can see in the last two years we've hit our greatest number over the course of the time series. The black dash line represents the newly mature, or the primiparous crabs in the Virginia Tech Trawl Survey.

Over the last couple years, it's been very low, and in fact it was 0 in 2022. I'll discuss this more as we move on in the presentation. The other trawl surveys there, the gray dash line represents New Jersey Trawl Survey, and it had some missing years due to COVID pandemic, but came back online in 2022.

The most recent values through New Jersey Trawl Survey happens to be the highest value over the time series, dating back to 2003. Then finally, the solid gray line is Delaware Trawl Survey, and since approximately 2010, 2011, it has shown a consistent increase through time. Likewise, the male horseshoe crab indices, again Virginia Tech in black there.

The two highest values occurred in the last two years for the multiparous for mature individuals. The newly mature or primiparous individuals, they were more than what the females were. You can see in 2022 was actually the highest value for newly mature individuals from the Virginia Tech Trawl Survey.

Then likewise, the Delaware and New Jersey Trawl Surveys, they generally showed an increase since about 2010. I mentioned the Virginia Tech had 0 primiparous, or newly mature individuals in 2022. Well, this is a problem. This is a problem for our catch multiple survey analysis, and we had to come up with a way to address it.

In 2022, 0 primiparous or newly mature individuals. The catch multiple survey analysis is really a simple state-structured model that sums the newly mature plus the mature animals. Subtract the harvest and natural mortality, and then predict the population next year. If you have a 0 in there, the model will not run.

This is concerning, and we've discussed it among the Technical Committees, three possible hypotheses for why the Virginia Tech Trawl Survey ended up with a 0 year. One of them could be catchability. Perhaps the catchability between the fully mature and newly mature individuals has changed, or suddenly changed through time, and the trawl survey just don't encounter them.

Second hypothesis is a recruitment failure. Perhaps approximately ten years ago something caused a decline in the new female horseshoe crabs that has then become evident here in recent years, or the third thing is possibly an identification issue within the Virginia Tech Trawl Survey. Perhaps many of the newly mature individuals are being misidentified as fully mature individuals.

Of these three possible hypotheses, it seems to me that the recruitment failure one is probably the least likely, because it is difficult to think of some sort of a mechanism, where newly mature males continue to increase, where females all of a sudden tanked and dropped off to 0. You know what would it be that would affect immature female crabs and not immature male crabs. This is an issue that the Technical Committees have given quite a bit of thought to and discussion. One way that we could deal with this, we had to come up with a method to fill in this gap from 2022, with a 0. We looked back at the time series of data from 2003 to 2019. The newly mature portion of the female population is approximately 20 percent of the total mature, you know the newly plus the mature.

That was very consistent up until 2019, and then all of a sudden, the newly mature animals just seemed to kind of disappear. We also have some corroborating evidence from the Delaware Trawl Survey, which in recent years also started to stage crab. From 2017 to 2022, Delaware comes up with nearly the same proportion of newly mature individuals at 19.86 percent. Both lines of evidence how that typically there is about 20 percent newly matured animals in the mature population.

The ARM and the Delaware Bay Ecosystem TC decided to adjust the 2020 to 2022 data, so that the newly mature females are approximately 20 percent of the total mature population. This maintained a total number of mature crabs, but this also allows us then to continue to run the catch multiple survey analysis.

This is also supported by the biology of the horseshoe crab. It doesn't seem like we could possibly get the increase in mature females, without some level of newly mature females also being in the population. It doesn't make sense that they would increase, but you didn't have any newly mature entering the population.

This graph just shows the Delaware adult trawl survey partitioned into mature and newly mature individuals. You can see how the two track each other through time. Here we have just a percent newly mature in the Virginia Tech Trawl Survey and also the Delaware Trawl Survey. As you can see from 2003 up through 2018, on average we're right about 20 percent in the Virginia Tech Survey.

But then all of a sudden in 2019 it declines greatly. Whereas, in the Delaware Trawl Survey we're still on average around 20 percent there. When we take all this information and put it into the catch survey analysis model, this is the population estimate for mature females in the Delaware Bay through time, starting in 2003 up through 2022.

You can see our point estimate at this point in time is the highest it has been yet. In the Catch Multiple Survey Analysis, we conducted two ways to show publicly. We consider coastwide biomedical mortality, and then absolutely no biomedical mortality, and kind of bracket where the truth is. You can see that the inclusion or exclusion of biomedical mortality makes very, very little difference, and in fact these lines are basically on top of one another.

Here we have the population estimates coming out of the catch multiple survey analysis model for males. Then again, the point estimate is at an all time high, and really no affect of inclusion or exclusion of coastwide biomedical mortality. Just for a direct comparison, because everybody got used to the Virginia Tech Trawl Survey and the swept area estimate of abundance being the way that we assessed the horseshoe crab. This graph just shows how to do a direct comparison to the Virginia Tech Trawl Survey here in gray, and then the Catch Multiple Survey Analysis in black, in the black dash line. You would see in the few most recent years our analysis, they line up very, very closely between Virginia Tech and the Catch Multiple Survey Analysis. There are some years where the CMSA was higher, some years when it was lower than the Virginia Tech estimate. This is the same comparison, the CMSA in black and the Virginia Tech Trawl Survey in gray for the male horseshoe crab abundance.

It's interesting that in the most recent years the Virginia Tech Survey actually gave us a higher abundance estimate than what the CMSA does. But they are still, both of them are at their highest levels in the most recent year. Taking this information, we then can make a harvest recommendation based upon the current state of the system, so that means the abundance of male and female crabs along with red knots.

Coming out of the ARM Framework and our optimization we have what were known as harvest policy functions. These harvest policy functions then allow us to take the abundance of both species, and recommend an optimal harvest. AS per Addendum VIII, the recommended harvest is then rounded down to the nearest 25,000 crab.

This is in an effort to protect confidential biomedical data, because if we put out the exact population estimate, somebody could work backwards and essentially solve for what the biomedical harvest was in Delaware Bay.

SET 2024 SPECIFICATIONS

DR. SWEKA: For 2024, the recommended harvest coming out of the ARM Framework would be 500,000 males and 175,000 females.

This is based off 39,800 red knots in 2022, approximately 16 million female horseshoe crabs, and approximately 40 million male horseshoe crab.

When we then take these harvest recommendations and apply the allocation scheme that was part of the Addendum VIII, and also maintain, you know we partitioned horseshoe crab based on their proportions are actually Delaware Bay origin, and also institute an Addendum IV cap for Maryland and Virginia.

These are the harvest quotas that would ultimately result for 2024. You can see of Delaware Bay origin, you sum the crabs up across the state, 500,000 males, 175,000 females. For the total quota, it’s slightly more with 513,000 total male and 185,000 total female. With that I can take any questions on the 2023 results and the 2024 harvest recommendations.

CHAIR CLARK: Before we take those questions, I’m going to turn it over to Caitlin to put up a couple slides.

MS. CAITLIN STARKS: Just to start the conversation off for the Board’s consideration today is to set the 2024 Delaware Bait harvest specifications. I just provided this as an alternative as well, considering what was approved last year. This is here as well, if it needs to be used or discussed.

CHAIR CLARK: Thank you, Caitlin, and with that we’ll take questions for John, or comments about the harvest specifications. Any questions? Okay, I’m not seeing any, oh, Shanna Madsen.

MS. SHANNA MADSEN: I was seeing no questions, so I was prepared to make a motion.

CHAIR CLARK: Very good, in that case, go right ahead, Shanna.

MS. MADSEN: All right, I'll wait for a second, because I know I've got it up there. The motion is **move to accept the 2024 Adaptive Resource Management harvest specifications with 500,000 males and no female harvest on Delaware Bay-origin crabs. In addition, the 2 to 1 offset will be added to Maryland's and Virginia's allocations due to no female harvest**.

CHAIR CLARK: Thank you, Shanna, do I have a second? Craig Pugh seconds. Any discussion on the motion? Shanna, did you want to say anything about it?

MS. MADSEN: Sure, yes, I can make a couple of comments on the motion. My justification for making this motion is similar to the one that we made last year. You know I think that we've heard from the public that right now there is not an appetite for female harvest, so the Mid-Atlantic states have decided to continue utilizing the offset, and only having male harvest.

I do think that setting the specifications this way leads very well into our next agenda item, and some ideas that I have moving forward, on how to handle years where we're going to continue to only have male harvest, even though the ARM recommends to us that we can also harvest females.

CHAIR CLARK: Craig, did you have any comments you would like to add?

MR. CRAIG PUGH: Yes, I agree, at this time I know we've explored the female harvest, but it's obvious to us, the people of the state of Delaware really don't want to accept that. They have no appetite for that. This seems to be the most reasonable solution, and we're willing to accept it.

CHAIR CLARK: Any further comments on the motion? I see Joe Cimino.

MR. JOE CIMINO: Thank you, John, for the presentation. I'm encouraged by the recent numbers, but it was a long time getting here, so I fully support this motion, because I think we need to get a few more years under our belt, before we really start seeing stuff. In fact, I know we can't make motions, that we have to revisit this every year and can't make a motion for no female harvest into the future. But I certainly hope that others around the Board would support that until we see this positive trend increasing for a fair amount of time.

CHAIR CLARK: Thanks, Joe, and I think that will probably segway into a topic we'll be touching on. But for the meantime, because I don't see any more hands, are there any hands online? None online, so in that case I don't think anybody needs to caucus. Is there any need to caucus? Seeing none; why don't we try doing this the easy way.

Is there any objection to the motion? Seeing none; the motion is passed by consent. Before we leave this topic, anybody want to talk about the specifications going into the future? Okay, we'll get back to that after we talk about the results of the survey.

CONSIDER RESULTS OF STAKEHOLDER SURVEY ON DELAWARE BAY MANAGEMENT OBJECTIVES

CHAIR CLARK: I'm going to turn it back over to Caitlin, to cover the stakeholder survey.

MS. STARKS: I'm going to try and go quickly through this given the time. I hope you all had a chance to read the report. But in this presentation, I'm going to cover the background on the survey, the methods used, the results and then talk about next steps. To start, the ARM Framework was established back in 2013, implemented in 2013, and that has been used to set bait harvest specifications for horseshoe crabs of Delaware Bay origin, with consideration of abundance of horseshoe crab and red knots.

That was peer reviewed in 2020, the revision was peer reviewed in 2021, and approved by the Board for use in 2022, and officially adopted for setting Delaware Bay specifications under Addendum VIII. During the public comment process for Addendum VIII, the public expressed significant concerns and over 30,000 comments about the status of the red knot population in the Delaware Bay and the potential impacts that could have with the limited female harvest that was allowed for under the revised ARM.

In light of those concerns, the Board set the 2023 specifications with 0 females and using the 2 to 1 offset. This May, the Board discussed approaches for evaluating the current goals and objectives for the Delaware Bay horseshoe crab fishery and ecosystem, and they decided to form a workgroup to develop a survey that would be distributed to stakeholders of the region, including bait harvesters and dealers, biomedical fishery and industry participants, and environmental groups in the Delaware Bay Region.

The purpose of the survey was to provide the Board with information to help them evaluate this current management objectives. The workgroup met four times in June through September, to develop the survey. These are the overarching questions that the group aimed to get insight into through this survey.

A key question that could help inform management is whether or not there is demand for the harvest of female crabs in the fishery. Knowing that many feel female harvest should not be allowed at present from those public comments, what are the conditions that would make stakeholders comfortable allowing female harvest?

What management goals for the Delaware Bay Region are important to stakeholders, and ultimately, should the Board consider changes to the management program for the Delaware Bay bait fishery. The survey was developed by the workgroup and reviewed by a social science researcher, to improve the questions and remove sources of bias.

The workgroup then identified a pool of stakeholders from the Delaware Bay states of New Jersey, Delaware, Maryland and Virginia, collected their contact information, and were able to send the survey out to 107 individuals through Survey Monkey at the end of August. The table here is showing the numbers of stakeholders in the target stakeholders' group and state.

Now I'll move on to the results. We had a 38 percent response rate to the survey, with 40 responses. The largest numbers of respondents were from New Jersey, and the largest number for primary field of work were from commercial fisheries. As you'll see later, the groups that were identified from their responses in Question 2 about field of work, were used to break out the responses to some of the later survey questions, to see how the stakeholder group responded. Additionally, the commercial fisheries group was administered a specific set of questions that were aimed to get a better understanding of the fishery, and the perspective of the commercial industry. First the commercial fisheries group was asked what the horseshoe crabs they harvest or sell are used for.

Most said bait or both bait and biomedical, and one said they did not know. Fourteen respondents also said they have harvested female horseshoe crabs in the past, and five had not. When asked how important it is to be able to harvest or sell female horseshoe crabs for bait in the future, the majority said it was very important, and the next largest group said of average importance, and then absolutely essential, and only two of those respondents said it was of little or no importance to them.

A strong majority of the commercial harvesters or dealers also agreed that female horseshoe crabs are worth more than males, and similarly a strong majority disagreed with the statement that there is no market demand for female horseshoe crab. When asked to choose between two quota scenarios, one where they would have a larger overall quota of only male horseshoe crabs, and another where they would have a smaller overall quota, including some female horseshoe crabs, there was an even split in the responses.

When you look at them by state, you will see that the respondents from New Jersey tended to the majority prefer the larger overall quota, but respondents from Virginia all preferred the smaller overall quota, including females, and there were insignificant trends in the other states. That was the end of the slides that were administered only to the commercial fisheries group.

The rest of these were applied to all of the survey responding. These next few slides are showing the results of Question 8 in the survey, which asks participants to respond to six statements about different components of the Delaware Bay ecosystem, with their level of agreement on a scale of one to five, where one is strongly agree and five is strongly disagree.

On this slide are the results to two statements, the first is the Delaware Bay population of horseshoe crabs is healthy, and the that's on the left. Then on the right the number of horseshoe crabs in the Delaware Bay population is increasing. The general thing to note with these graphs is how the responses are distributed for each of the respondent's groups, which are shown as different colors in those bars.

For some groups the answers are generally similar among all the respondents in that group, but in some cases, there is not as much agreement, and those responses are more spread out. One challenge that is to be noted for all of these questions, is that we don't have equal numbers of respondents in each of those groups, and some of those groups did not have very many respondents, so that makes it difficult to look at those trends.

These are the responses to the statement the horseshoe crab bait fishery is negatively impacting the Delaware Bay population of horseshoe crab on the left, and on the right horseshoe crab bait fishery is negatively impacting red knots in the Delaware Bay. Then these are responses to fishermen should be allowed to harvest female horseshoe crabs from the Delaware Bay population if it is at a healthy level, and fishermen should not be allowed to harvest male horseshoe crabs from the Delaware Bay population if it is at a healthy level. When you look at the average response to each of those statements by group, which is what's shown in each cell of this table, you can see that there is a lot of disagreement between groups on each of the statements. In this table, the cells are color coated with the averages that fall on the side of agreement shaded in green, and the averages that fall in the side of disagreement shaded in red, and averages that are more in the neutral range are white.

You can see as it alternates back from green to red to white to green, there is not a lot of agreement going across a row with each individual statement by each group. The next two questions were focused on the perception of different impacts on the horseshoe crabs and red knots. Here we see that of climate change, horseshoe crab harvest and human development of the shoreline.

The average response from these individuals they ranked to be human development of the shoreline as having the greatest impact on the Delaware Bay population of horseshoe crab. That is again the average of all responses. It should be noted that some of the group responded differently, so the respondents in the environmental group and the academia or research group ranked horseshoe crab harvest as having the greatest impact on the horseshoe crab population. Then the pattern in the results for the second question are quite similar to the last.

When they ranked the impact of these three things on the red knots that stopover in the Delaware Bay, so we ranked climate change, reduced egg availability due to horseshoe crab harvest, and human development of the shoreline by the level of impact. The environmental and academia group both ranked reduced suitability due to the horseshoe crab harvest as the highest impact, and the commercial fisheries and biomedical groups ranked human development of the shoreline as having the highest impact.

The next set of questions focused on the importance of different management objectives to the respondents. First, they were asked how important each of these seven items on the left were on a scale of one to five, from not important at all to absolutely essential. When all of the responses were averaged, that is what is showing in this bar graph. The two most important issues were using the best available science to inform management and maintaining a healthy population of horseshoe crab.

Again, it should be noted that there were differences when this is broken out by groups. To test this question another way, the responses were also asked to rank the first five of those objectives by their importance, and in this case the results more distinctly show the pattern where maintaining a healthy horseshoe crab population is on average the most important of the five objectives.

This matrix shows that the breakdown from that last question, when the responses were averaged by group. Green is indicating a higher rank was assigned, on average. Red is indicating a lower rank was assigned on average, and yellow is an average that falls more in the middle. You can see here that three of the five stakeholder group on average, ranked maintaining a healthy horseshoe crab population as most important. There was a tie for the biomedical group with allowing horseshoe crabs to be used in the biomedical industry for human health. Then three out of five groups on average ranked maximizing horseshoe crab bait harvest as the least important objective. Then protecting female horseshoe crabs ranked in the middle for four out of the five groups, based on group average. But the rank of the other two issues were less consistent among the group.

The next question was asking the respondents if the ARM model should be modified, and of the 36 responses, 47 percent said yes, 20 percent said no, and 33 percent said, I don't know. The respondents who answered yes to this question were then presented with another question, which asks why they think it should be modified, and 16 open-ended responses were given to this.

There was a wide range of responses, but among the commercial fishery members who responded, there was a theme that stuck out, which was the idea that the ARM is underestimating the number of horseshoe crab. Then seven responses, mostly from the academic or environmental conservation respondents spoke about issues with the model and built in assumptions in the framework.

Then two comments stated that the horseshoe crab population should be large before the harvest is allowed to be increased. Question 15 then asks survey participants if they thing a limited amount of female horseshoe crab bait harvest should be allowed at this point in time, and 35 responses, we had and 49 percent said yes, 37 percent said no, and 14 percent said, I don't know.

This graph is showing how the responses were distributed within each group in the chart. This next question aimed to understand the stakeholder opinions on whether female horseshoe crabs should be collected for biomedical purposes, and again we had 35 responses, 46 percent said yes, 43 percent said no, and 11 percent said, I don't know. Again, the trends were different in how the numbers of each of those groups responded as shown in the graph.

Then the last question in this survey was an open-ended question, and it provided an opportunity for the respondents to add information that might not have been considered in the other survey questions. They asked, what you think is the most important, what is most important for managers to consider when making decisions about the management of the Delaware Bay horseshoe crab population.

The more prominent themes in the responses about what is most important were the health of the horseshoe crab population, basing management decisions in robot science, allowing sufficient bait harvest, and impacts on fishermen in coastal communities. Then some other mentions included the larger ecosystem as a whole. Allowing for biomedical use, switching to synthetic alternatives to LAL and bait, and making sure there are adequate spawning beaches, and improving the data that are used for management.

To wrap up, I have summarized some of the key takeaways form the survey that respond to the overarching questions posed by the workgroup. First, the commercial industry respondents did show with their responses that there is demand for female horseshoe crabs, and they are considered more valuable than males. The majority of the commercial industry respondents also thought female harvest should be allowed now, but the majority of other respondents did not. Maintaining a healthy horseshoe crab population is considered one of the most important goals across the stakeholder groups, and many of the respondents do think the current ARM Framework should be modified, but there are varying reasons behind that option or opinion. Lastly, in general, stakeholders highly value the use of the best available science to inform management. In response to the survey results. If the Board wishes to consider any next steps moving forward, these are a few potential paths. The Board could task the workgroup with going back and developing additional recommendations based on these results.

The Board could also direct staff to conduct a more in-depth process involving stakeholders from these various groups, like we outlined when we proposed the options for investigating this issue. If the Board does want to make a change to the management program that was established under Addendum VIII, then a new addendum or amendment would be required. With that I can take any questions.

CHAIR CLARK: Thank you very much, Caitlin, I think the survey did a great job of confirming what we suspected the different groups think about this. Before we get further in the discussion, I just wanted to acknowledge the phenomenal amount of work that Caitlin put in to bring this survey together, get it out, and compile that great report. Very much appreciated, Caitlin. With that do we have any questions or comments about the survey? I see Dan McKiernan, go ahead, Dan.

MR. DANIEL McKIERNAN: Caitlin, is there any explanation for why females horseshoe crabs are considered more valuable?

MS. STARKS: The survey did not address that question.

MS. McKIERNAN: Is there anyone in the room who could?

CHAIR CLARK: Dan, the horseshoe crab, well, Craig can get that. But I think it will be about eels, right, Craig?

MR. PUGH: Well, it's not just the eels. The female horseshoe crab is used for bait for conchs, catfish and eels as well. Where your most marketed difference is in landing is when the female horseshoe crab was eliminated in American eel landings. I know that they consider that as depleted resource, but for most of us that fished it, understood why the landings were tremendously lower after they eliminated that from our options.

Anybody that is my age, I consider myself one of the new old guys, and I've said that here before. I'll repeat it again, if you have fished with that, and I would say most of the fellows of that age group would be between 50 to 70, understand, because they've used that bait in the past, and they know that there is nothing comparable to that bait for that type of fishery.

It works better than anything else that is out there. You know trial and error, there is no artificial bait that can even match it, not touch it. It would be like putting a piece of sandpaper in there, anything else other than that. It is that extreme in its catchability, especially when they are producing eggs. Even the frozen, we used to freeze them, cut them, harvest them, pack them, freeze them up for bait, so that we could use them through the winter and fall months as well. Because of that their value was well over 100 percent of what the male was, and much, much well over any artificial bait that you could ever imagine. But yet, it was a huge resource for us that was taken away about 20 years ago or so. In saying that and giving you what my age is, some of the newer fellows that are in our fisheries that are in their 20s, in their 40s, have not experienced that.

They don't know the catchability of that product and what it will do. Their standards are a little lower than ours because of that, but value wise, yes, without a doubt. It was highly prized, highly valued. But I think as our groups of fishermen age out, it looks as though the appetite for this is somewhat extinguished.

CHAIR CLARK: Thanks, Craig, and I confirm what Craig said there. The year after females were banned in Delaware, from 2007 to 2008, our eel landings dropped by 50 percent. It really is an amazing bait for eels in the Delaware Region. Mike Luisi, and then Shanna.

MR. MICHAEL LUISI: I also wanted to acknowledge Caitlin's hard work. You stole the words out of my mouth, as Chair. Being part of the working group, not only was it amazing to watch Caitlin put together the survey, but to deal with the five or six of us was another challenge all of its own, whether tracking us down or dealing with John, Mr. grumpy.

You know, you can't find him and then he's grumpy about things, so Caitlin did an amazing job. I do want to say and I do want to say this for the record, and I've made this point a number of times before, in regard to the female horseshoe crab harvest for bait. I don't know how many years it has been now, but we slowly went from a female crab majority of the harvest down to a 50/50 down to a 2 to 1, down to nothing, as far as female harvest in Maryland.

I don't want the Board to get the impression that there is no interest in the female crab for harvest and for use of bait, it's just that the fishermen right now, given the amount of interest in the topic of horseshoe crab, shorebirds and other things, would just rather leave things alone. Although they would make more money, and probably for eels and conch pots, would probably do a little better if they were able to buy and sell the females.

I just wanted to make it clear that there is an interest there, and I don't know what the best word is, but the drama around it is more than what the fishermen are willing to deal with, so they would rather just make use of what they have with the males. I think in moving forward, if we're taking this survey and thinking of it as giving us a push towards next steps. I think there should be something, if a modification to the ARM is the way we go.

There should be something there so that when the modeling is telling us that something is allowed to be harvested sustainably, that it's not a fight, it's the best available science. This is what it's telling us we can do, and that next level of argument would be unnecessary, and maybe our fishermen, if the populations of the birds and the crabs were high enough, would be able to benefit from that.

CHAIR CLARK: Shanna Madsen.

MS. MADSEN: I have a question for, I guess the dynamic duo, as you called them, Dr. Sweka and Anstead. I want to preface this question with saying that the reason that I'm asking it is not because the ARM "sucks." It's because I have a question regarding what we could potentially consider moving forward. I would like to know if the ARM team or the Assessment Team has started to consider any modeling approaches or information that you could give the Board, if we continue to decide to only harvest males.

DR. SWEKA: We haven't really discussed it formally amongst the ARM Workgroup. I certainly have a few ideas that if we're going to continue with male only harvest, essentially the process could be a lot simpler, and rely on a lot less data. But again, there is the conversation. You know I have some thoughts. They haven't been discussed with the entire committee or with other stakeholders yet.

CHAIR CLARK: Further questions, discussions? Okay, I believe at this point, is there anybody online, Caitlin? Okay. Do you want to put the slide back up that had possible actions here for this, Caitlin? Caitlin outlined the next steps, and Shanna, you have a proposal.

MS. MADSEN: Yes, I actually have a motion prepared, which is in essence bullet point 2, which Caitlin has up on the screen, and I'll wait until the motion gets up and I will speak to it. Okay, great, thank you. My motion is, **move to use the Stakeholder Survey Report as a basis for a Horseshoe Crab Management Objectives workshop, which would include a small group of managers, scientists, and stakeholders to explore different management objectives for the Delaware Bay-origin horseshoe crabs**.

This workshop should focus on multi-year specification setting and modeling approaches when selecting no female harvest. The intent would be to provide a report to the full Board in time for the 2025 specification setting process.

CHAIR CLARK: Thank you, Shanna, do we have a second? Joe Cimino. Would you like to speak to the motion, Shanna?

MS. MADSEN: Sure, thank you, John. I would also like to echo my big thanks to Caitlin. I think that the survey was definitely the correct move forward. However, the results of the survey lead me to believe that we definitely need to start to have more open conversations about what our management objectives should be. If we are not going to continue to harvest female horseshoe crabs, I think that the Delaware Bay states have had conversations.

Like Mike just commented, it's not that our harvesters don't wish to harvest females, or don't have a market for harvesting females, but at the time right now, you know the public is very interested in us not moving forward with harvesting females. In that case I think it's incredibly important for stakeholders, managers and scientists that have an interest in this Delaware Bay origin stock to have a discussion on what our management objectives should be, and find those.

They are going to oftentimes be conflicting, but make that determination on what we do when we don't harvest female crabs, and hopefully can move forward in a multi-year specification setting process. The Board can make a decision, hopefully ahead of time, as to the period of time that they would like to select, not harvest female horseshoe crabs and move forward with that. I think that this really mirrors what we did for Atlantic menhaden, and that turned out incredibly well. It was really, really helpful to have everyone in the room discuss how to move forward. I look forward to hopefully getting this process up and going, if the Board agrees.

CHAIR CLARK: Joe, did you have anything you wanted to add to that?

MR. CIMINO: Just quickly. I think unfortunately we're saying that impact of climate change progressing possibly faster than we thought. Certainly, we're at a level far beyond what we experienced when we first started this process. I am proud of this process, and I just think this is a next step forward for it.

CHAIR CLARK: Do we have further discussion of this motion? Anybody have anything you would like to add? Not seeing any, is there any need to caucus? Not seeing any, let's see if we can to this the easy way again. **Are there any objections to the motion from the Board? Not seeing any; the motion is approved by consent**.

CONSIDER APPROVAL OF FMP PLAN REVIEW AND STATE COMPLIANCE FOR 2022 FISHING YEAR

CHAIR CLARK: We're going to move on now to Item Number 6, which is Consider Approval of the Fishery Management Plan Review and State Compliance Reports for the 2022 Fishing Year.

MS. STARKS: Again, I'm going to move quickly, to try and make up our time. This is our management history for horseshoe crabs. The most recent edition is of course, Addendum VIII in 2022. Then this figure shows the annual values of reported horseshoe crab bait harvest in orange, and biomedical collections in light blue, and estimated biomedical mortality in dark blue, and values are in millions of crabs.

The total reported bait harvest in 2022 was 570,988 crabs, and this excludes confidential landings from Rhode Island and Florida. The 2022 landings were a 23 percent decrease from 2021, and still well below the Commission's coastwide quota, which is 1.59 million crabs, and the total state-imposed quota, which is 1.03 million crabs.

The states of Delaware, Massachusetts, New York, Virginia and Maryland made up 99.7 percent of the 2022 coastwide landings, with Delaware, Maryland and New York harvesting the highest numbers. Then for biomedical, in 2022 the number of crabs that were selected for the sole purpose of LAL production was 911,826 (my brain is going today) crabs, and this is a 26.8 percent increase from 2021.

The estimated biomedical mortality was 145,920 crabs, and this number includes the observed mortalities reported by each state, as well as an additional 15 percent of the total crabs that were bled and are assumed to die. In 2022 the biomedical mortality represents about 20 percent of the total directed mortality for horseshoe crabs, which is about 717,000 crabs. Compared to 2021, in 2022 the biomedical mortality estimates increased, but the overall total removals, including bait harvest, decreased.

This graph is just showing the total coastwide mortality of horseshoe crabs by year, broken out by bait and biomedical mortality, so you can see the relative magnitude of each of these sources of mortality. For de minimis states, states can qualify if their combined average bait landings for the last two years are less than 1 percent of the coastwide total for the same two-year period. In 2022, requests from South Carolina, Georgia and Florida were submitted, and they meet their criteria for de minimis status. The PRT made a few recommendations based on the review of the annual compliance reports. First, as usual is to seek long term funding for the Virginia Tech Trawl Survey, which is critical data for our current management program. Then they also recommend working towards getting annual estimates of horseshoe crab discard removals.

Then with regard to the state compliance, the only minor issue noted by the PRT is that reports from Massachusetts and Connecticut were not submitted by the deadline, and other than that all states and jurisdictions appear to be in compliance. The PRT recommends approval of the state compliance reports, de minimis requests and the FMP review for the 2022 fishing year. I'll take any questions.

CHAIR CLARK: Any questions for Caitlin about the FMP review? Roy Miller.

MR. ROY W. MILLER: Caitlin, do we have any information on what percent of the biomedical take and/or mortality are female horseshoe crabs as opposed to males?

MS. STARKS: We do. It would take me a minute to track down the numbers of male and female percent for the biomedical mortality. That's what you're looking for? Okay, I can look that up.

CHAIR CLARK: Okay, while Caitlin is doing that are there any other questions about the FMP review? Seeing none; in that case, would somebody like to make the motion to approve? I have Mike Luisi.

MR. LUISI: Is there a motion?

CHAIR CLARK: Do you want to go ahead?

MR. LUISI: I'm part of the new/old, I'm getting close to the new/old.

CHAIR CLARK: Can you read that, is it big enough?

MR. LUISI: Of course, it is, John. **Move to approve the FMP Review, state compliance reports and de minimis requests for South Carolina, Georgia and Florida for the 2022 fishing year**.

CHAIR CLARK: Okay, we have a motion is there a second? Emerson Hasbrouck. Is there any discussion of this motion? Seeing none; **is there any objection to this motion? Seeing none; the motion is approved by consent.** Caitlin, you have the numbers for Roy?

MS. STARKS: I hope so. I have a massive spreadsheet, and I believe that in 2022 the males collected were 43.9 percent and the females were 34 percent, and the rest were unknown.

CHAIR CLARK: Okay, we finished Item Number 6.

REPORT ON STATUS OF SYNTHETIC ENDOTOXIN TESTING REAGENTS

CHAIR CLARK: Now we are on to the Number 7, which is Report on the Status of Synthetic Endotoxin Testing Reagents, and that is Caitlin also.

MS. STARKS: Give me one moment to catch up. All right, so I want to start off by saying that I'm obviously not an expert on this subject, but at the last meeting the Board requested a speaker from a nonbiased third party, like the FDA. I am not the FDA, but we did reach out and we weren't able to find a speaker for this meeting, so I pulled some information together and did my best to gather what might be helpful.

For some quick background. LAL has been used to detect pathogens from endotoxins in patients and medical devices and injectable drugs for over 40 years, and it's currently the standard endotoxin test in the U.S. As you all know, there has been building public interest in transitioning to synthetic tests in the U.S.

Alternatives to LAL that are not derived from horseshoe crab blood directly, they have already been developed, they are called Recombinant Factor C (rFC) and Cascade Reagents, which is (rCR), and these are available for use in the U.S., but they are subject to additional testing every time they are requested to be used., to validate that they are comparable to using the LAL test.

Part of this is related to the standards that are set by the U.S. Pharmacopeia and I'll state USP for short. This is an independent scientific nonprofit organization, and its purpose is to set standards for healthcare products in the U.S., collect information on those and disseminate it to providers and consumers on using the products.

The USP standards have legal recognition in the U.S. and they are also used in many countries around the world. At this time in the U.S., my understanding is that the two recombinant endotoxin tests (rFC) and (rCR) are considered alternative methods to the LAL test, and that means that using them requires demonstration that they are comparable to the LAL test for each and every product that they would be used for.

Recently, though, the USD has proposed adding a chapter to their compendium that would specifically provide standards for the use of these two recombinant tests, and as supposed under those standards that are in this new chapter, it would mean that moving forward if a manufacturer wants to use one of these two tests on the new biopharmaceutical products, that it would not require the comparability validation that is currently required.

However, for products that are currently being tested with LAL, they would need to demonstrate comparability in order to switch over to using the synthetic test. In summary, what I think this means is that if the proposed USD chapter is adopted by the Pharmacopeia, it would open up a pathway for more use of (rFC) and (rCR) in the U.S. and there may be additional requirements from the FDA related to its use, but it is a step forward.

It's clear from their information that it wouldn't mean that LAL would go away. It just means that manufacturers would have more options that are more easily accessible to that. This is a proposed chapter, and it has a comment period that will be open from November 1 through January 31, 2024. I can attempt to answer questions, but again, I'm not an expert, so I can always just write them down and bring answers back with it.

CHAIR CLARK: Thank you, Caitlin, very interesting. Just one thing that I wasn't clear about. Are (rFC) and (rCR) pretty much do the same thing? I mean are they like Coke and Pepsi?

MS. STARKS: Yes, my understanding is they are just different genetic combinations.

CHAIR CLARK: Okay, great. Are there any questions for Caitlin about the LAL and the synthetic endotoxins here? Oh, I see Dr. Rhodes in the back there.

DR. MALCOLM RHODES: Yes, I'm afraid I'm the one that brought this up at the time, because we did have a presentation quite a while ago where they were talking about these new combinations being used. This information is interesting, but it's basically just saying, if you want to change from the gold standard you have to prove it's as good as.

We haven't learned what the, as good as is. Maybe it is Coke and Pepsi, and we're dealing with Coke, which I still think is number one, and want to know if Pepsi is going to be as good as. I think the problem, if you're trying to look it up. There is lots of information about the recombinant testing agents, for want of a better word, that they tend to come from the industry, and you know each one is going to have their own bias about it, which would be the hard part.

At some point, and like I said at the meeting before, it might be a year from now, if we could get someone from NIH or a PharmD possibly that could come in and kind of explain the process and where we are. I mean it's great where we're at, but as far as I know, most drugs are still LAL. Every vaccine that is used in the United States, LAL is what is used to prove its safety, that it has no endotoxins in it at this point.

Just for our knowledge, since frequently every letter we get says, well why are you all still using this when there is a safe alternative? You know as far as I've read, it probably is, but probably isn't safe enough for the public, when we're talking about health concern. That is why I would like to see if at some point, you know we could get someone.

I would think it would probably be when we're in Washington, where we could get someone from one of the branches. I know how impossible it might be to do, but you know I would love to talk to you at some point, and see if we could get kind of, this is what it does. Because when you read about the specific tests, there are certain ones that have problems with drugs that have proteases, and some with glutens, and they have shortcomings, as does LAL.

But you know LAL is a huge step above the rabbit test that was before that. I won't go on and on about it. But you know, I appreciate getting that to this page, but it's more about, well, if you can prove this and you don't have to use it, as opposed to, is this as good as, which was what I was hoping for?

CHAIR CLARK: Thank you, Dr. Rhodes, it's a complicated issue, isn't it. We have a couple of online commenters. First up is Allen Burgenson.

MR. ALLEN BURGENSON: Good afternoon. My name is Allen Burgenson, and I am an author of several of those papers that folks have been discussing. One thing about recombinant Factor C and R, the r test aids, it's not Coke and Pepsi, it's Coke and lemonade, both satisfy your thirst but using different mechanisms, (rFC) it's just the recombinant of the detention protein, with a different measurement. It uses light, whereas the (rCR) also has the same enzyme system that LAL does, the complete cascade.

But it yields a turbidity or a chromogenic result. Now one thing that I published back in March of this year was in the Pharmacopeia Forum, which is the official journal of the United States Pharmacopeia, was a comparison of two standard LAL products against two of the (rFC) products. One thing to note, and folks have to understand, all the reagents don't work the same on every time.

In my study I showed that some reagents underpredict the amount of endotoxin in a sample, and this is natural endotoxin from a water system, which is what would be contaminating your products. Your product is not contaminated with the standard, which is known as RSE or reference standard endotoxins, or controlled standard endotoxin.

If you have either one of those in your product, you don't have contamination you have sabotage, because those two don't exist in nature. What does exist in nature is what is in your water system. I published a study using four different drugs and four different kits, and in some instances the recombinant product underpredicted the amount of endotoxin in a drug by more than a twofold, which means nothing if you are testing down around normal processing.

Very low levels of endotoxins, plus or minus a twofold is negligible. However, when you are up around the endotoxin relief level, or if you're testing at the maximum valid solution, which is the most you can dilute and still detect the endotoxin, and you have a plus or minus twofold difference, and you're underpredicting the amount of endotoxin by more than a twofold, then there is the potential health issue.

It concerns me that the USP has said that all new biopharmaceuticals, if this chapter is approved, do not have to do the comparability, because that is the most dangerous part right there. The company may recover their PBC spike, I'm sorry, I'm over time.

CHAIR CLARK: Thank you, Mr. Burgenson, that was very interesting. I think that gets to some of what you brought up, Dr. Rhodes, about that. Appreciate that, and we have another online commenter, and that is Joe Gresko. Go ahead, Joe.

MR. JOE GRESKO: Just a quick follow up to the Doctor's line of questioning, and to be clear, the synthetic alternatives would need to be validated by the FDA, right?

CHAIR CLARK: Is that true, Caitlin?

MS. STARKS: I am not an expert, again. I don't know if we can answer that question with certainty.

MR. BURGENSON: I can answer that if you want.

CHAIR CLARK: Is that a, no? It just has to be done by USP, not FDA?

MR. BURGENSON: No, it's done by the individual end user, the individual pharmaceutical company on a per product basis. They have to do the side-by-side comparisons and validate it, and then submit that validation data to the FDA, in the form of a regular FOIA application. The individual end user, the individual pharmaceutical company has to do the validation.

CHAIR CLARK: Thank you, thank you very much, Mr. Burgenson. I think that concluded that. Okay, I'm sorry, we have another online commenter, that is Karen Hedstrom. Go right away, Karen.

MS. KAREN HEDSTROM: Yes, thanks, I was late getting in there. I was just trying to gather my thoughts. Is it the Eli Lilly Company already has some products on the market that are using the (rFC) instead of the LAL? Can anybody, you know one of the doctors, comment on how they got to the point that they're at?

I understood that companies could independently pay for their own validations, but with the USP now is advancing to do is to actually take on some of that validation, and of course some of the cost of it, to allow companies that want to go down the route of using the synthetic, to just make it a little bit more viable for them to be doing it, economical and otherwise. Can somebody comment on that? Thank you.

CHAIR CLARK: Thank you, Karen. I don't know that we have anybody here that could answer that, but we will be returning to this issue in future meetings, I believe, so we will definitely be looking to get answers to that and other questions.

REVIEW AND POPULATE ADVISORY PANEL MEMBERSHIP

CHAIR CLARK: In trying to save time here, let's move on to our next item, which is to Review and Populate the Advisory Panel membership, and Tina, do you have that ready?

MS. TINA L. BERGER: I do, thank you, Mr. Chairman. I offer for the Board's consideration and approval the nomination of Sam Martin, a commercial mobile tending gear fisherman from Maryland. Sam's nomination form said that he was convicted of a felony. That is an error, and that was validated by the state, so simply ignore that. But I offer it for your consideration.

CHAIR CLARK: Mike, would you like to make this motion?

MR. MICHAEL LUISI: I sure can, you can put that back up, I'll go ahead and read it. **Move to approve Advisory Panel nomination for Sam Martin from Maryland.**

CHAIR CLARK: Do we have a second? Shanna Madsen. **Any objections to this nomination? Seeing none; the nomination is approved by consent.**

OTHER BUSINESS

CHAIR CLARK: Okay, that brings us on to Other Business. We definitely have a few items, but first I wanted to clear up, Caitlin, as far as the specifications, are we done with that? Did we want to discuss? I think it was kind of covered in the motion, right? Okay, so we're done with that. Dan, did you have something else that you want to bring up, because there is an "other business" motion also.

MR. McKIERNAN: I want to plant a question, it's a rhetorical question at this point. Maybe we could pick it up at the Policy Board. Are we doing enough around the table as Board members to estimate the use of horseshoe cabs in our various fisheries for other species, such as American eel, and of course whelk, which is not an ASMFC managed species. I would like to pick that question up at the Policy Board. I don't want to discuss it; I just want to plant a question.

RESPONSE TO EARTH JUSTICE/SHOEMAKER HORSESHOE CRAB ARM FRAMEWORK ANALYSIS

CHAIR CLARK: Okay, and then the Other Business item that I spoke of at the beginning of the meeting. I think everybody saw in the meeting materials that there was another item from Earth Justice. They went back to one of the scientists they had worked for, for the previous analysis of the ARM. This time he was supplied with the data from the trawl surveys, and he had the code, I believe, for the ARM model, right this time?

As you probably saw, he had several criticisms of the ARM that were then turned into a huge press release snafu, and I think there is clearly a debate within our Board, I'm sure, as to whether to respond and how to respond. To kind of kick this discussion off, I would like to turn it over to Bill Hyatt, who I think has a motion.

MR. WILLIAM HYATT: Yes, I do have a motion, and I believe you have it, if you could put it up, please. Very simple: **Move to task the Adaptive Resource Management Subcommittee with preparing a response to the September 2023 review of the ARM Framework by Dr. Keven Shoemaker.**

CHAIR CLARK: I have a second from Mike Luisi, and Bill, would you like to speak to that?

MR. HYATT: Sure. All of you had the opportunity to read Dr. Shoemaker's analysis in our meeting materials. His analysis is detailed, and it raises some serious questions regarding the ARM model. For me as a Board member, and I suspect from many others around the table as well, it's difficult to evaluate the credibility of this alternative analysis, without having a response from our own folks, and the folks who have developed the ARM model.

The management of horseshoe crabs is obviously far reaching and complex, that is what keeps us around this table for so long at these meetings. For all these and many other reasons, but particularly, so that we as Board members can better understand these issues. I believe it's important for the Commission to develop a response to Dr. Shoemaker's analysis. I'll add, and I think this speaks to some of the previous discussion on this topic. I'll add that I doubt that this response will be the end of this discussion, but I believe it's a very important first step.

CHAIR CLARK: I'm going to ask Mike as the seconder, and then I would like to take it over to John Sweka.

MR. LUISI: I seconded this, because what Bill said I truly believe in. I think when somebody goes out there, puts themselves out there and criticizes or, not to say that's the only reason we would respond is in a critical way. But if somebody is out there putting information together, expecting everyone to listen, and we don't have the opportunity to debate that. It really ends up a one-sided argument, and there is never any real accountability on the individual or individuals that have put together the document that now has generated what I used before, the drama around the issue. I just think it's a good idea. I think it's something we should do more of with other species that we manage, and that is why I seconded the motion.

CHAIR CLARK: Now I would like to turn it over to John, John and Kristen will have to spearhead the work on this, so take it away, John.

DR. SWEKA: Just a point of clarification if this motion should pass. I would like to remind the Board that Earth Justice also supplied comments from September, 2022, they were very lengthy as well, so just up for discussion. If this motion passes and we are to respond, do we restrict our comments to those from September, 2023, or September 2022 and '23 included?

CHAIR CLARK: Well, from my perspective, John, I think that if you're going to comment, including all I think would be very useful. Any other comments around the Board? Bill.

MR. HYATT: Yes, certainly, my intent was what was included in our September, 2023 for this meeting, meeting materials. In particular, I know that the Earth Justice letters and Dr. Shoemaker's analysis sort of parrot one another. But I think from my perspective, particularly interested in the detail within Dr. Shoemaker's report, as opposed to Earth Justice's cover letters, if you will.

CHAIR CLARK: Conor McManus.

MR. CONOR McMANUS: John, from the two sets of comments, to what degree is there overlap, or has some of the 2022 comments already been addressed via our work since then, I should say.

DR. SWEKA: Nothing has been addressed to the 2022 comments. With what was supplied in the Board materials, they had their new, recent 2023 comments, and then the 2022 comments tacked on as an appendix. I guess it's all there altogether, but no, as the ARM Workgroup we haven't done anything with those comments or discussed it or made any changes resulting from it.

CHAIR CLARK: Any further comments on this? Shanna Madsen.

MS. MADSEN: I'm certainly not going to oppose this motion, but I do just want to warn that I feel that a lot of the questions and concerns that are in Dr. Shoemaker's paper have also been addressed quite a bit in the minority report, if I remember correctly. I appreciate whatever Dr. Sweka and Dr. Anstead put together for us to review, directly in relation to this 2023 updated report.

But I just want to make sure we don't run down a path of continuously asking our incredibly busy TC and ARM group to make responses to what frankly equates to misinformation. Some of the information already contained in the report we can look at and know that they are incorrectly using some of the trawl information. I just wanted to kind of make that point, to not set a precedent for continuing to chase our tails on some of this information.

CHAIR CLARK: That is a point well taken, Shanna. But this is quite an extreme situation we're dealing with. Roy Miller.

MR. ROY W. MILLER: Quickly in response to Shanna's suggestion. I think that this particular response on our part is in a different category, because Dr. Shoemaker's response I think, is driving the impetus for consideration of additional legislation in one or more states, and therefore, I think it is incumbent upon us to respond to this particular set of comments.

CHAIR CLARK: Yes, it certainly has been resonant in our little state, that's for sure. Joe Cimino.

MR. CIMINO: Just a follow up. I mean for something like this it goes back to something Mike Luisi said about accountability. We had a chance to review the draft, since New Jersey's trawl data was included, noticed that the way it was run in Dr. Shoemaker's model was not comparable to what was used for the peer review assessment or ARM Framework, so we confronted Dr. Shoemaker on that, and he confirmed that he did not use the data in the same.

Not that if he had time he would go back and rerun that. I think you know for this kind of information to be at management level, it would also need an independent peer review, and go through the work. I don't see any other way around that. I certainly don't think it's there. I apologize to John and Kristen for having to do this work, but I think at least some review for the Board's sake will be valuable.

CHAIR CLARK: Are there any other questions, comments? Seeing none; does the Board need time to caucus on this? Seeing no need to caucus**, are there any objections to this motion? Seeing none;**

then the motion is approved by consent, and thank you very much, John and Kristen. The ARM has done phenomenal work. We're sorry to put extra work on you, but I think this is important to do. Thank you.

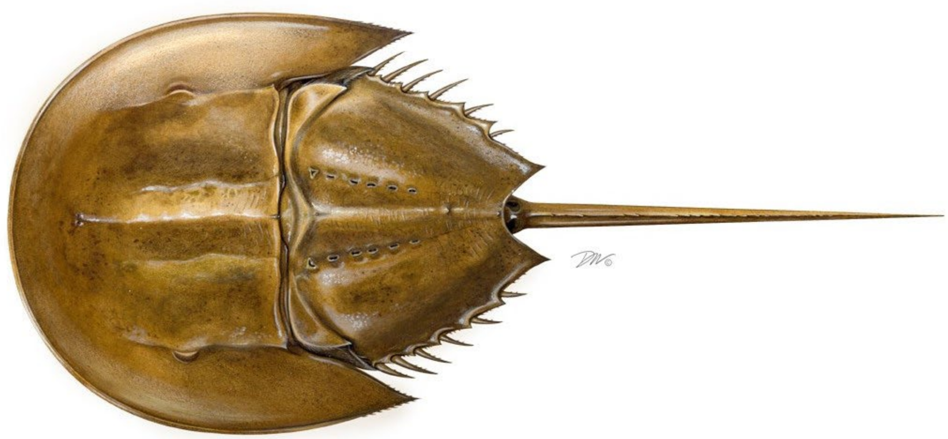
ADJOURNMENT

CHAIR CLARK: Okay, that was our main Other Business item, and is there anything else to come before the Board? Seeing none; then we are adjourned.

(Whereupon the meeting adjourned at 4:36 p.m. on October 16, 2023)

Atlantic States Marine Fisheries Commission

2024 Horseshoe Crab Stock Assessment Update



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:
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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.

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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-

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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.

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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.

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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

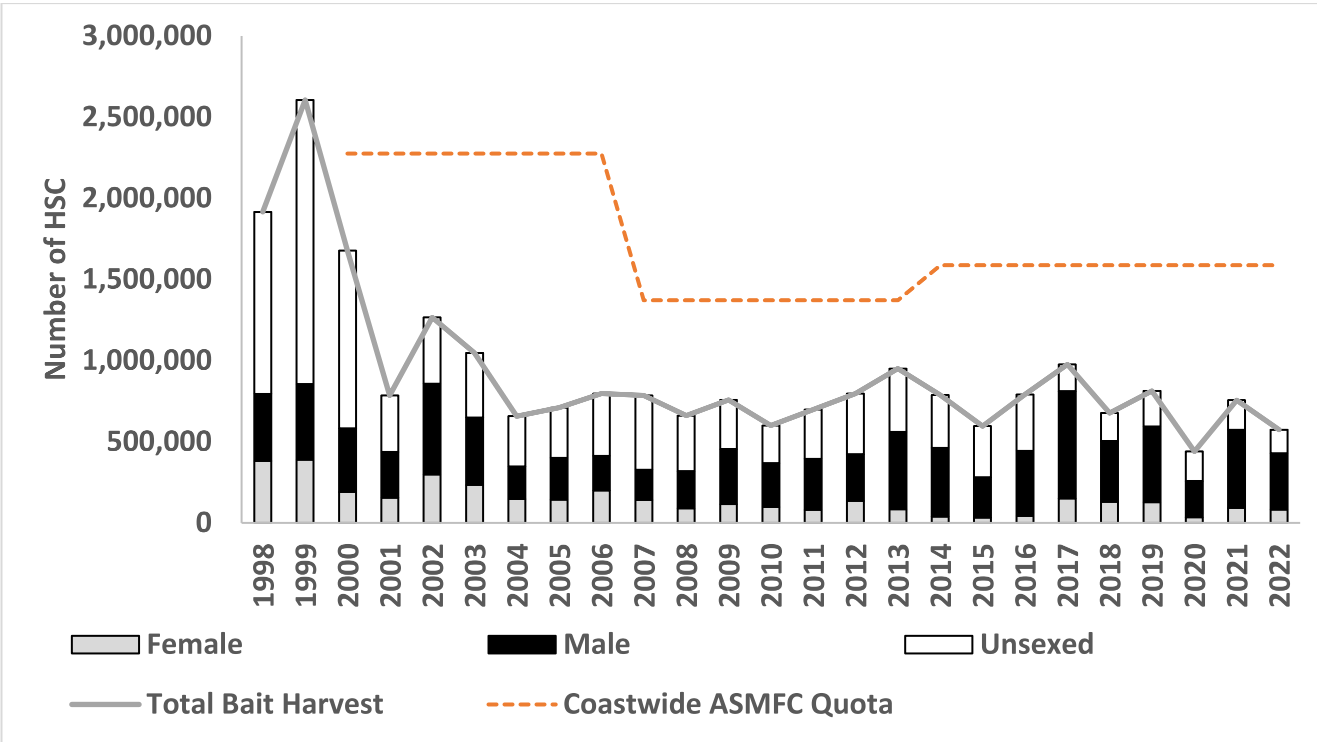


Figure 1. Coastwide horseshoe crab bait landings, 1998-2022, by sex where available. Coastwide ASMFC quota indicated in orange. Source: ACCSP.

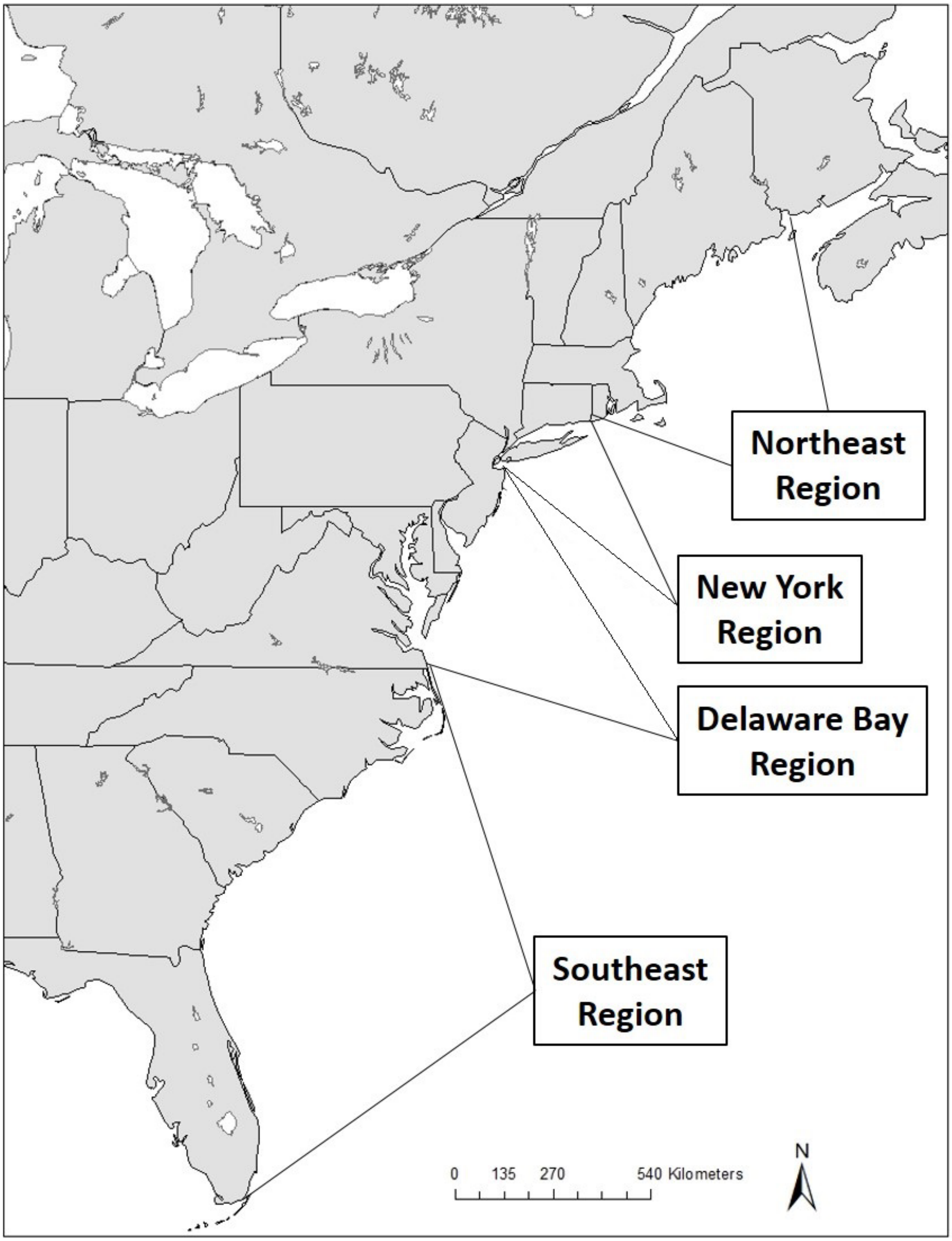


Figure 2. Map of the Atlantic coast showing the regions for horseshoe crab assessment.

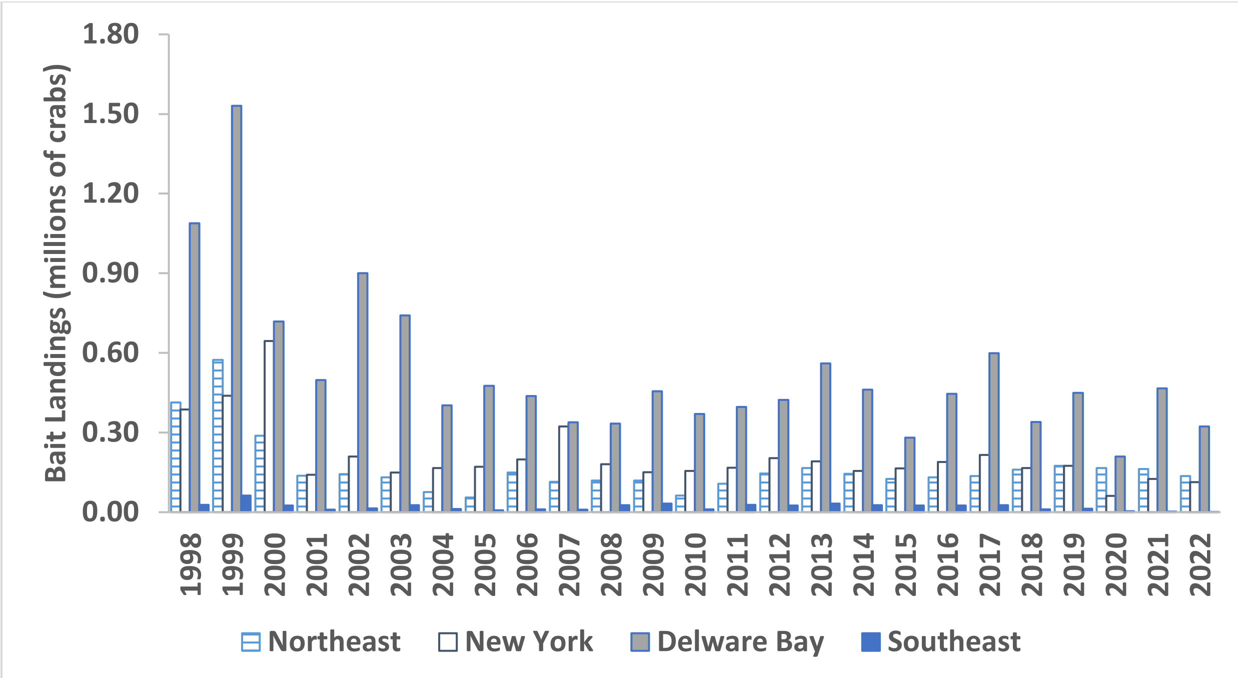


Figure 3. Horseshoe crab bait harvest by region, 1998-2022. The four regions are the Northeast (Maine-Rhode Island), New York (Connecticut-New York), Delaware Bay (New Jersey-Virginia), and Southeast (North Carolina-Florida).

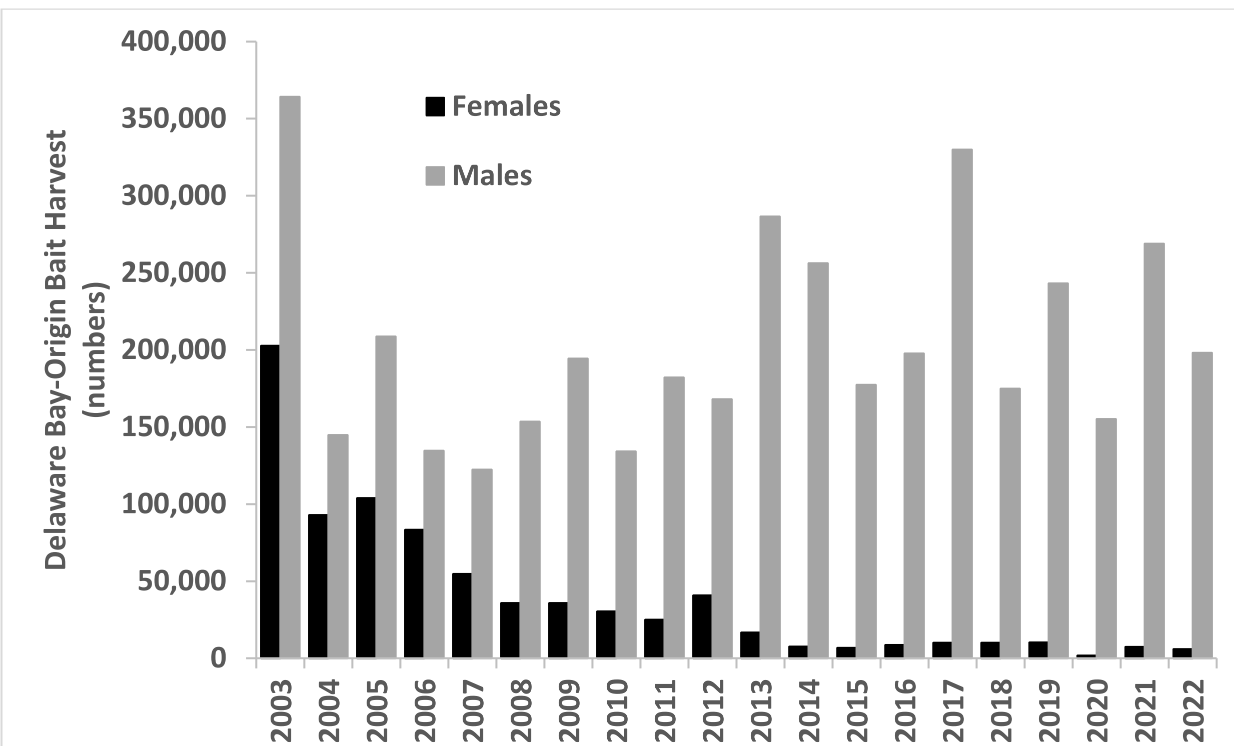


Figure 4. Horseshoe crab bait landings of Delaware Bay-Origin, 2003-2022, by sex for use in the CMSA. Source: ACCSP.

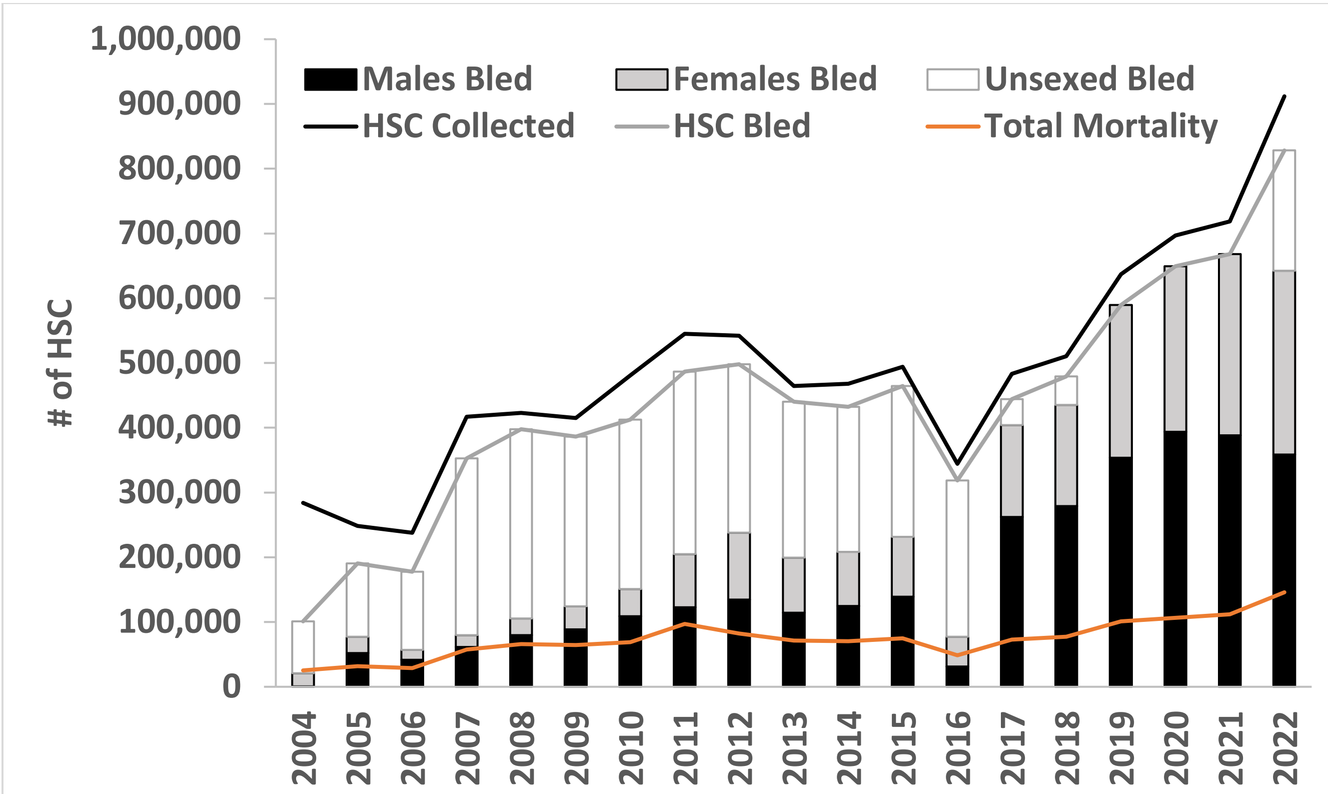


Figure 5. Coastwide number of horseshoe crabs (HSC) collected and bled by the biomedical industry and the total resulting mortality (observed mortality during the bleeding process plus 15% of those bled and released alive).

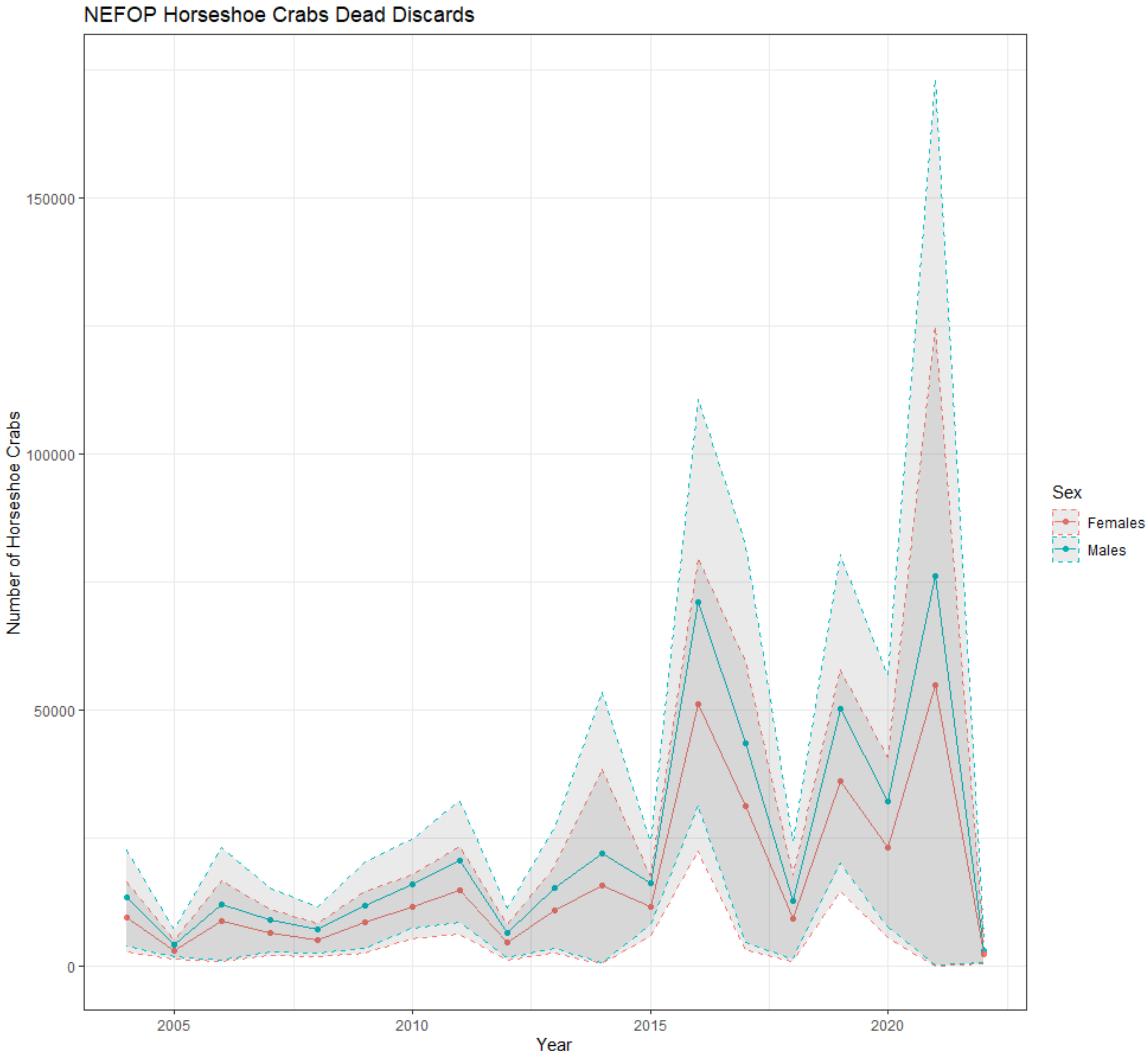


Figure 6. Estimated number of dead horseshoe crabs discarded in the Delaware Bay region from commercial fisheries, 2004-2022, by sex with 95% confidence intervals. Source: NEFOP.

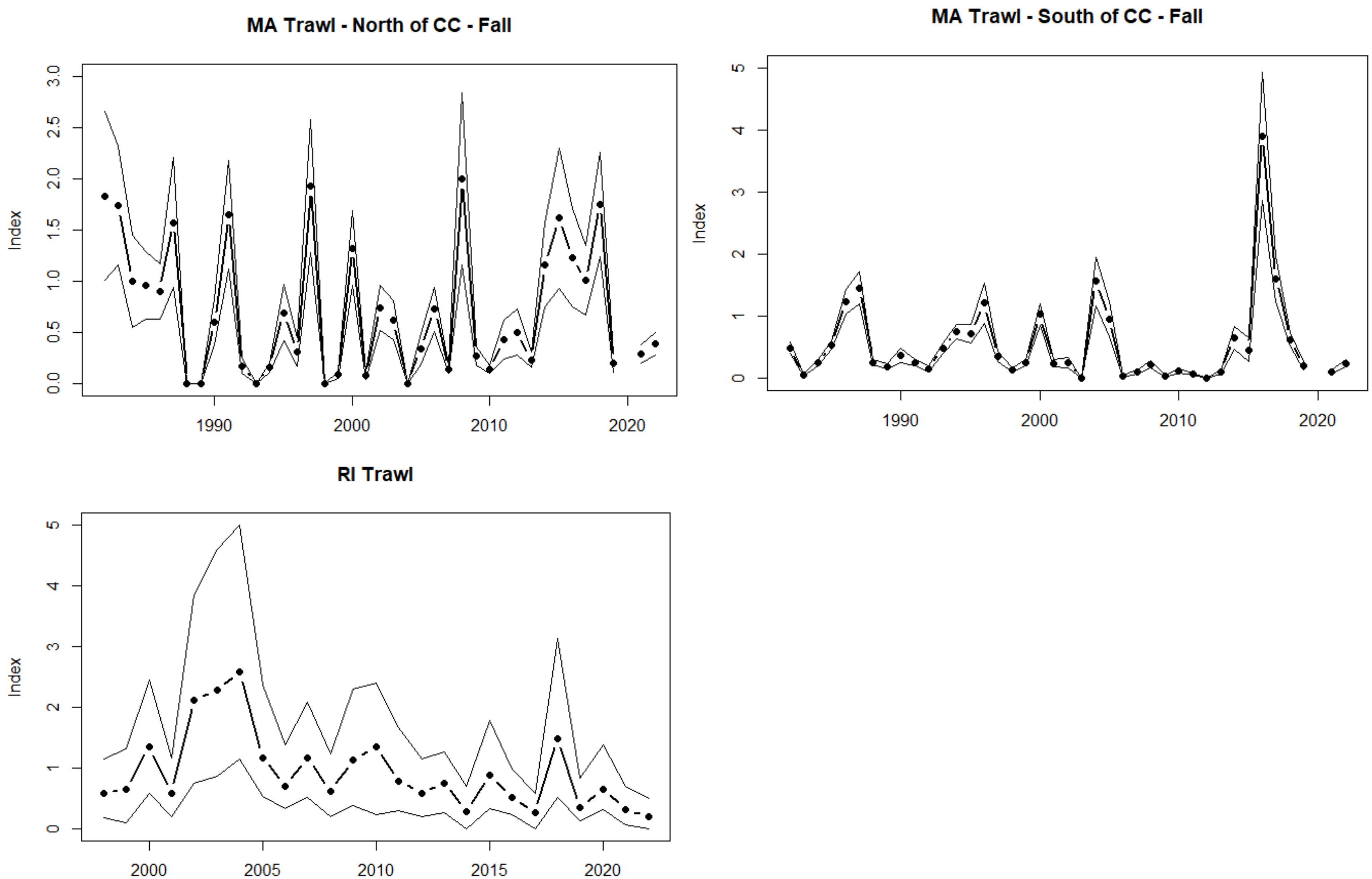


Figure 7. Indices of relative abundance of horseshoe crabs developed from the Massachusetts Trawl Survey for north and south of Cape Cod (CC) in the fall months and the Rhode Island Monthly Trawl Survey with 95% confidence intervals.

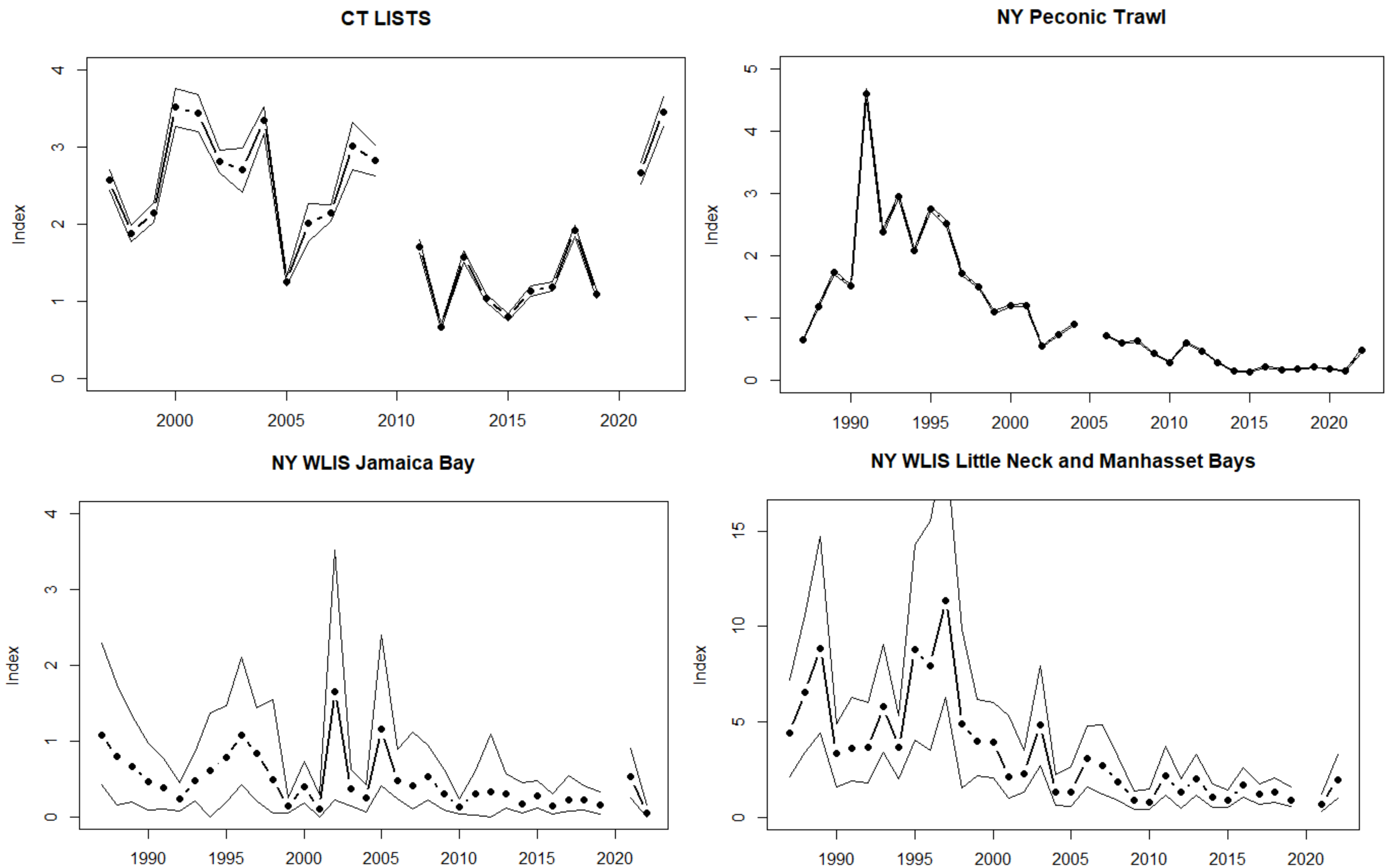


Figure 8. Indices of relative abundance of horseshoe crabs developed from the Connecticut Long Island Sound Trawl (CT LISTS), New York Peconic Bay Trawl, and New York Western Long Island Sound (WLIS) Surveys with 95% confidence intervals.

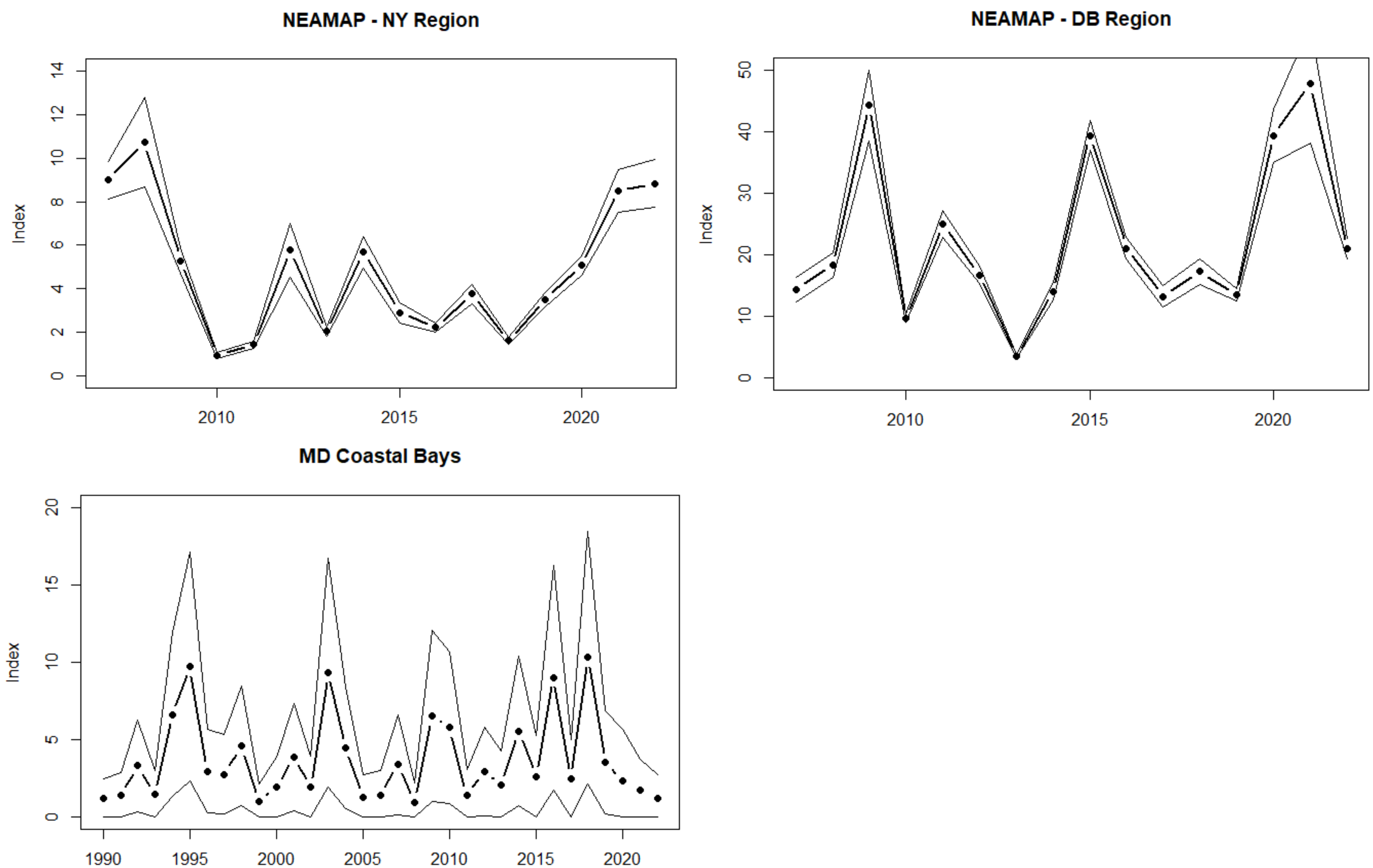


Figure 9. Indices of relative abundance of horseshoe crabs developed from the Northeast Area Monitoring and Assessment Program (NEAMAP) and Maryland Coastal Bays Surveys with 95% confidence intervals.

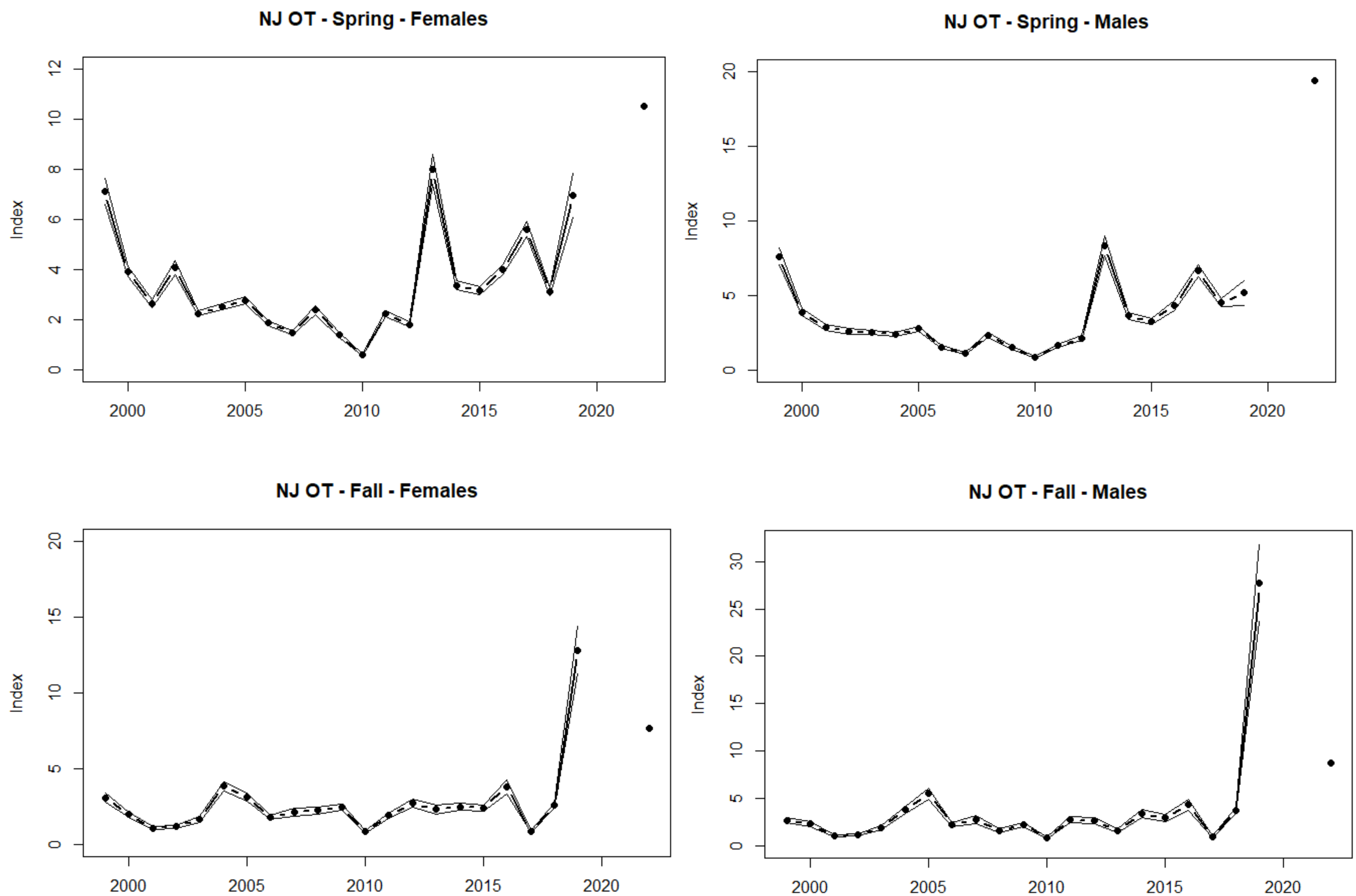


Figure 10. Indices of relative abundance of horseshoe crabs developed from the New Jersey Ocean Trawl (NJ OT) Survey by sex and season with 95% confidence intervals.

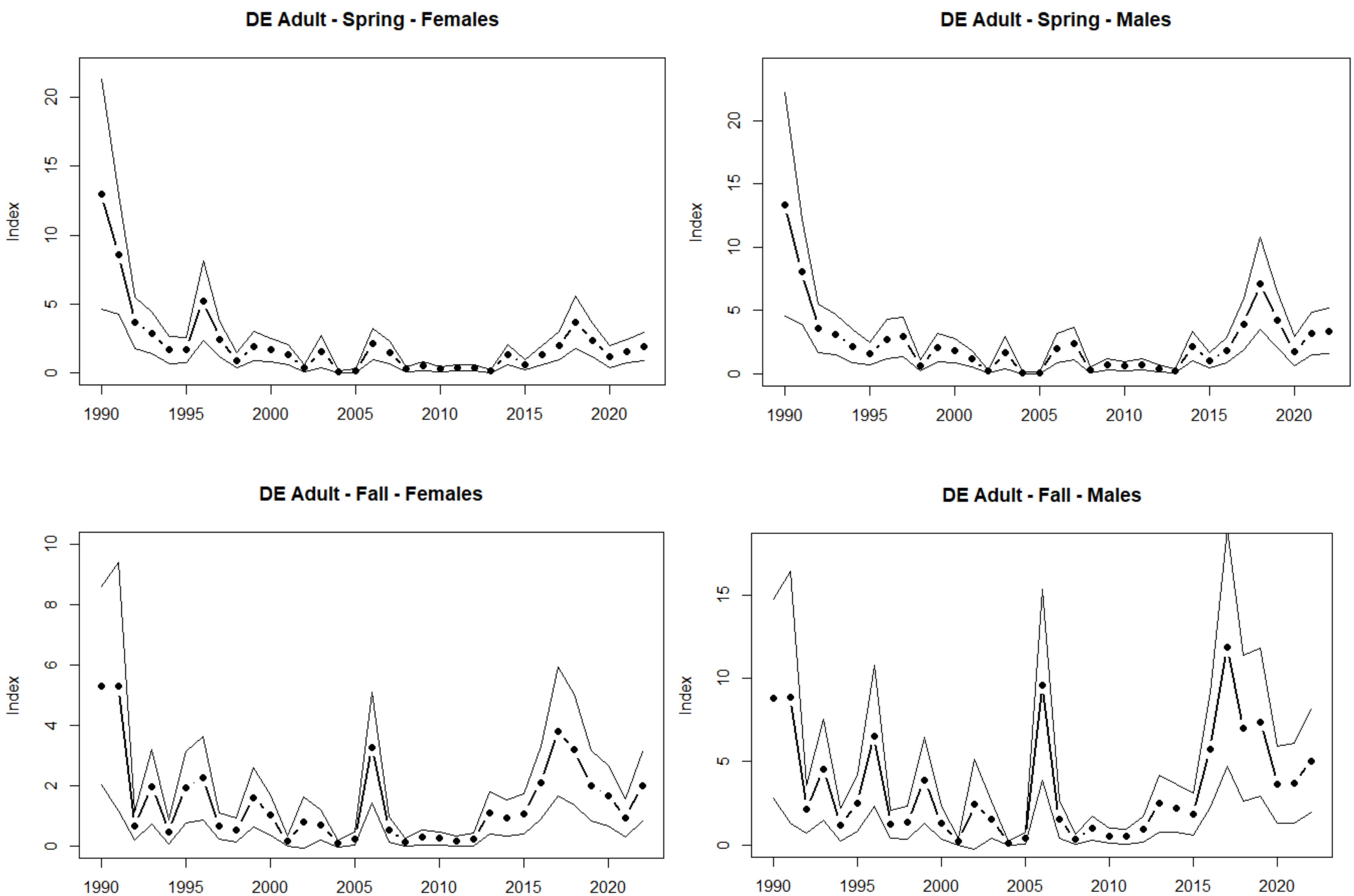


Figure 11. Indices of relative abundance of horseshoe crabs developed from the Delaware 30' Adult Trawl Survey by sex and season with 95% confidence intervals.

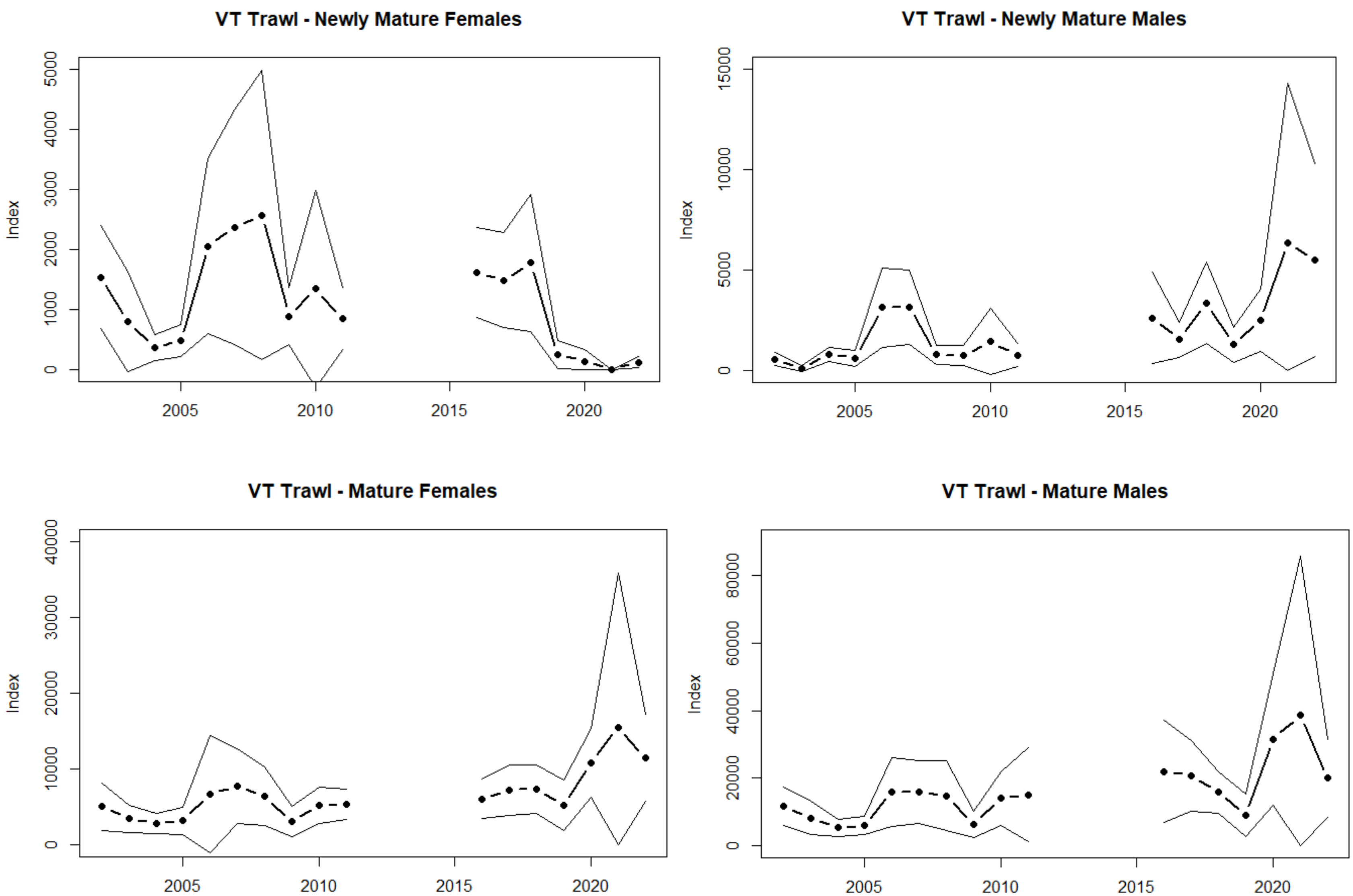


Figure 12. Indices of relative abundance of horseshoe crabs developed from the Virginia Tech Trawl Survey by sex and maturity stage with 95% confidence intervals.

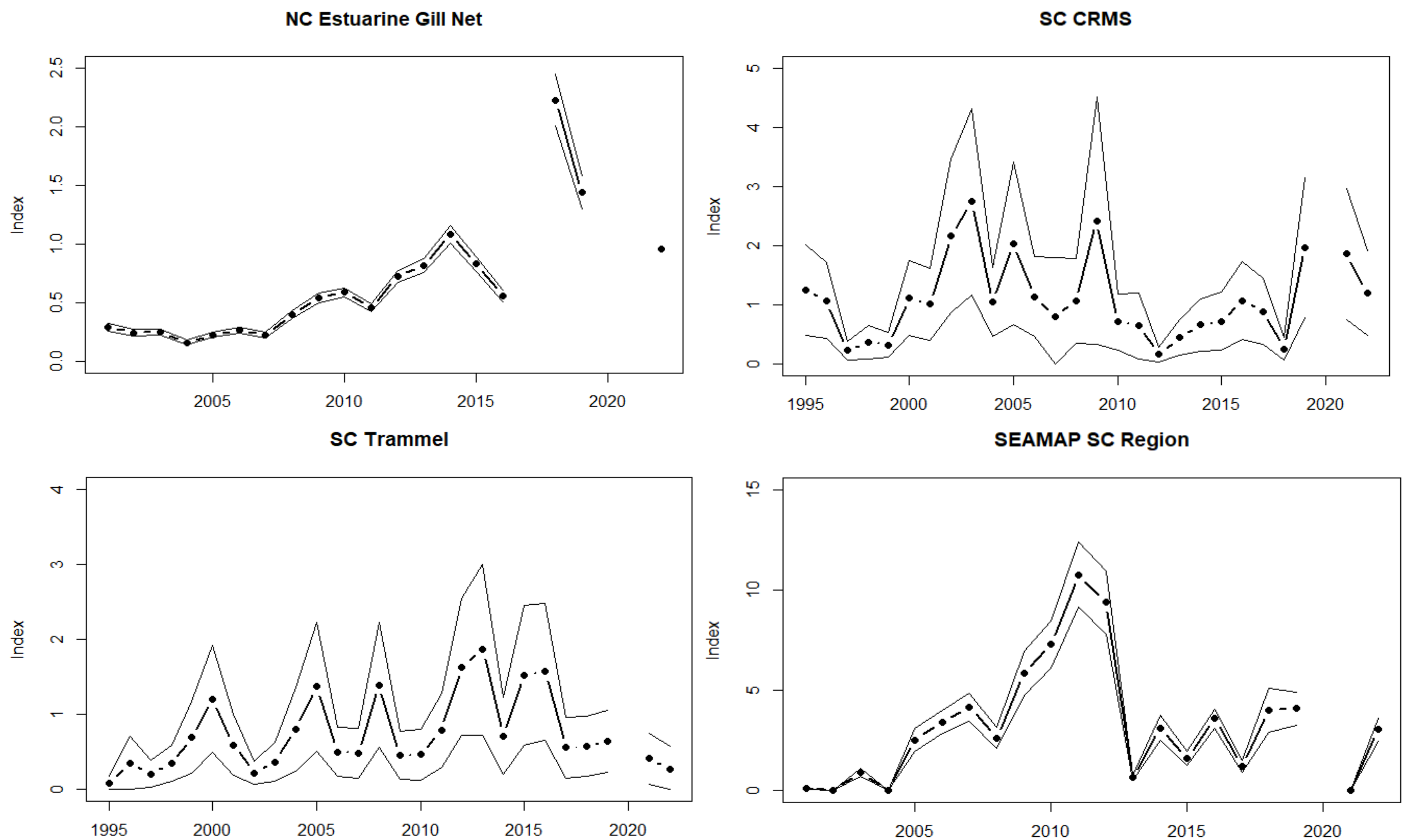


Figure 13. Indices of relative abundance of horseshoe crabs developed from the North Carolina Estuarine Gill Net, South Carolina Crustacean Research and Monitoring (CRMS; recently renamed as Estuarine Trawl Survey), South Carolina Trammel, and Southeast Area Monitoring and Assessment Program (SEAMAP)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

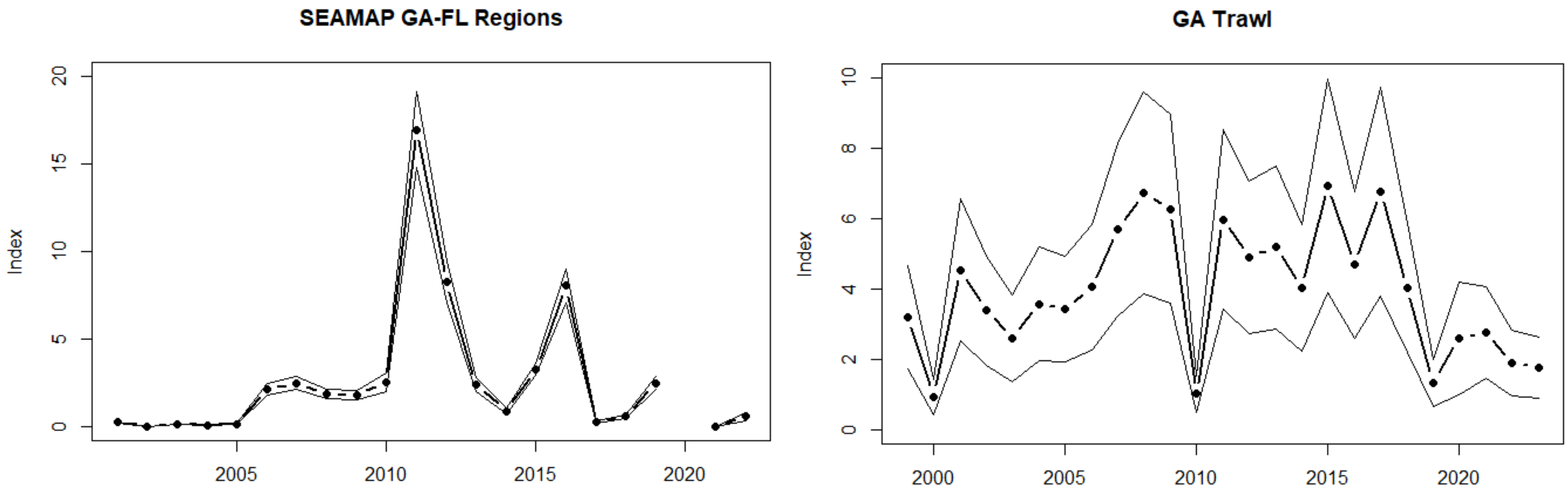


Figure 14. Indices of relative abundance of horseshoe crabs developed from the Southeast Area Monitoring and Assessment Program (SEAMAP) and Georgia Ecological Monitoring Trawl Surveys with 95% confidence intervals. SEAMAP had reduced sampling in the strata used in the index in 2021-2022 and therefore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

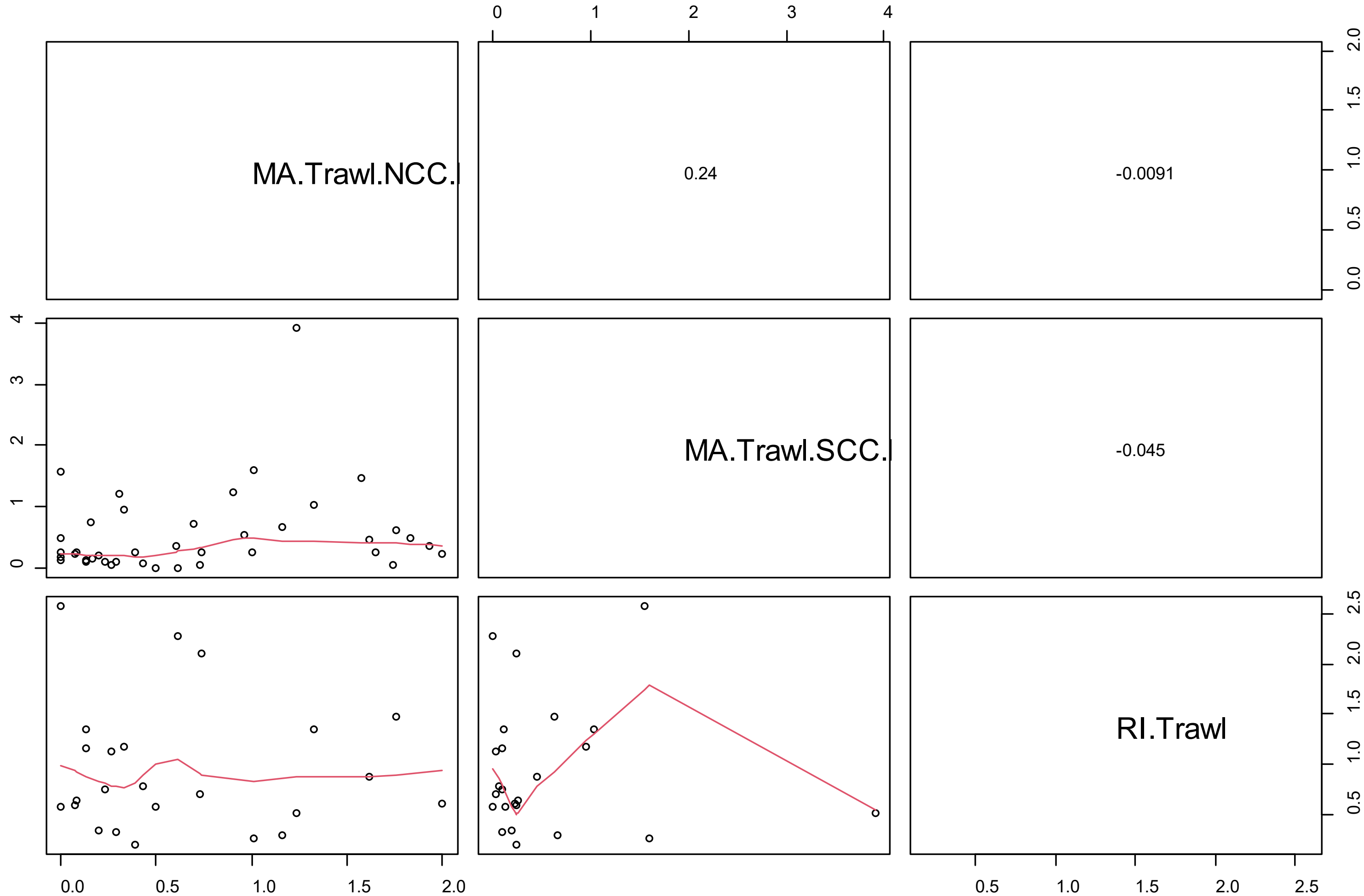


Figure 15. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the Northeast region. None of the correlations were significant (*P*<0.05).

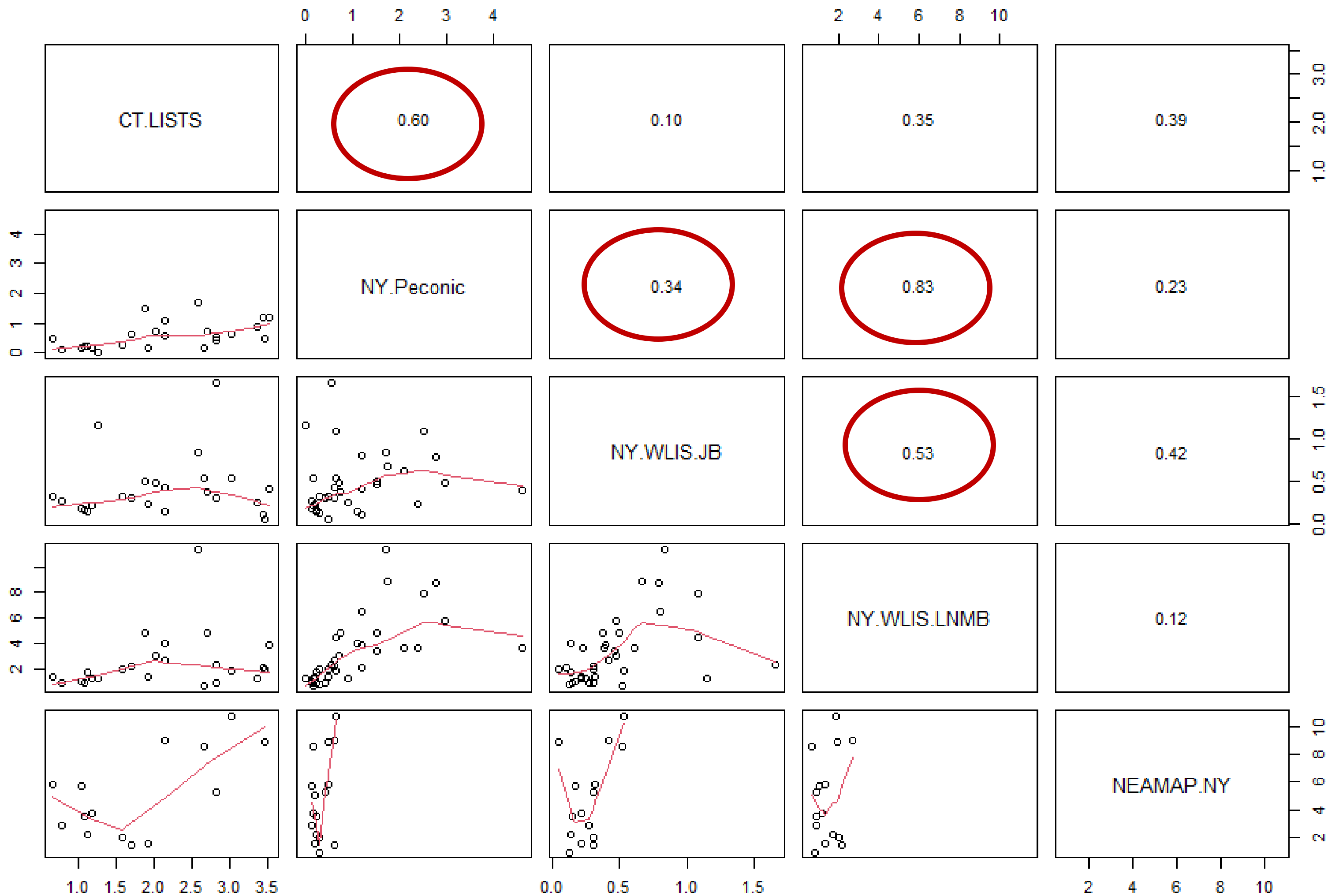


Figure 16. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the New York region. Significant correlations (*P*<0.05) are circled in red.

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.

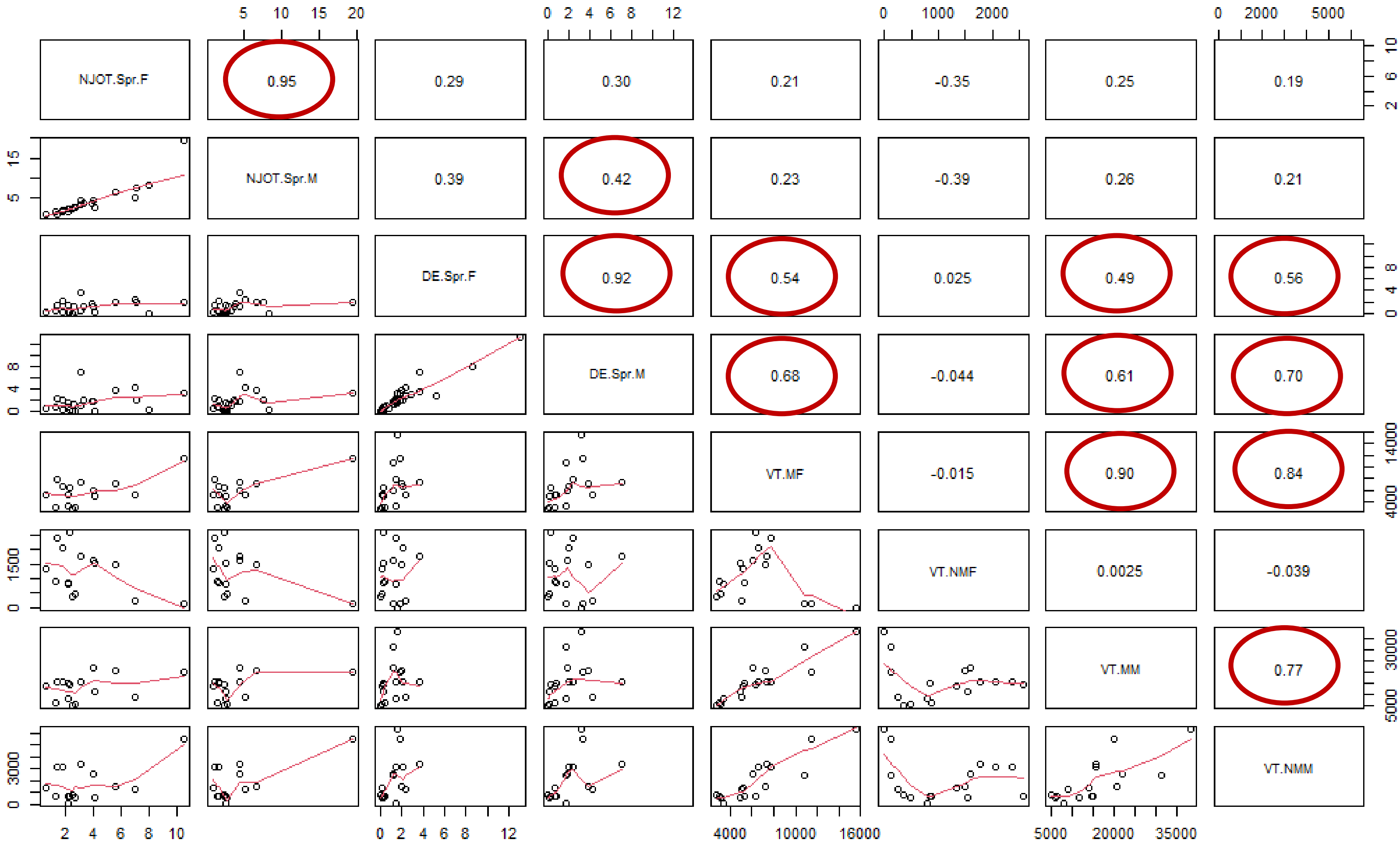


Figure 18. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the Delaware Bay region used in the ARM Framework, 2003-2022, where the Virginia Tech Trawl Survey has been lagged forward one year as it is in the CMSA. Significant correlations (*P*<0.05) are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

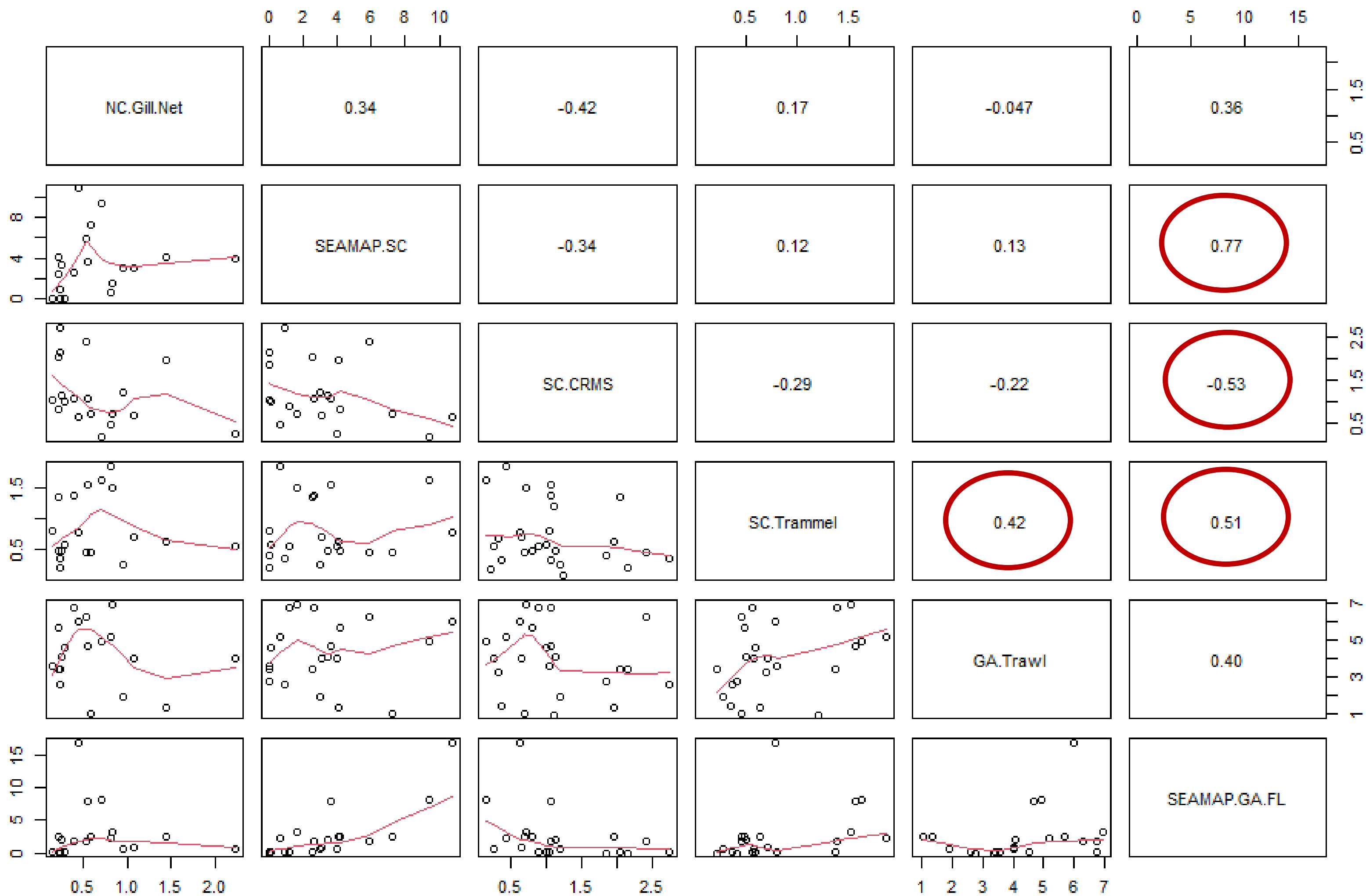


Figure 19. Spearman correlation coefficients and scatter plots for the horseshoe crab abundance indices in the Southeast region. Significant correlations (*P*<0.05) are circled in red.

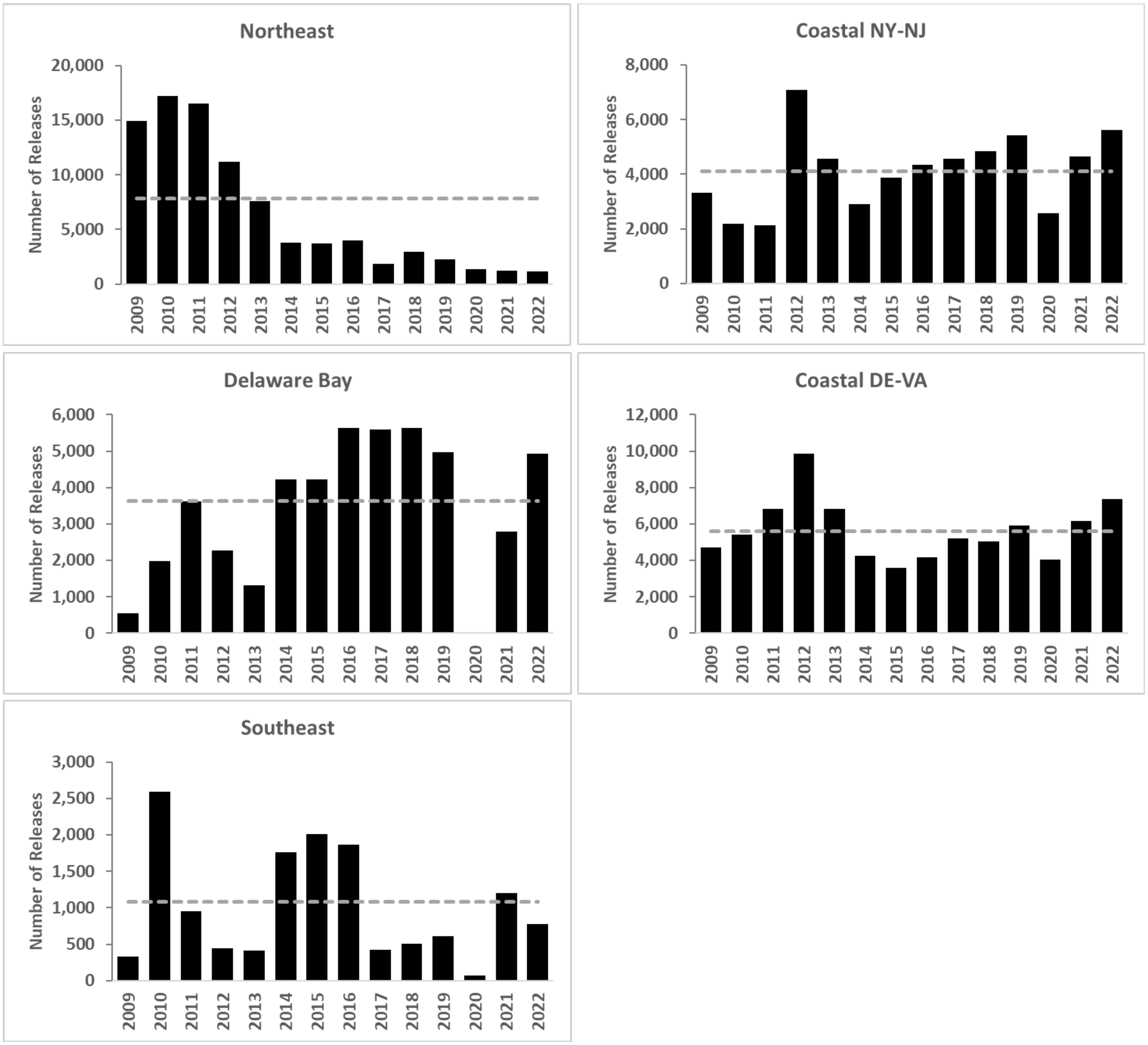


Figure 20. Number of tag releases by region, 2009-2022. Grey dashed line indicates the average number of tag releases from 2009-2019 (the years before COVID) by region (source: USFWS tagging database).

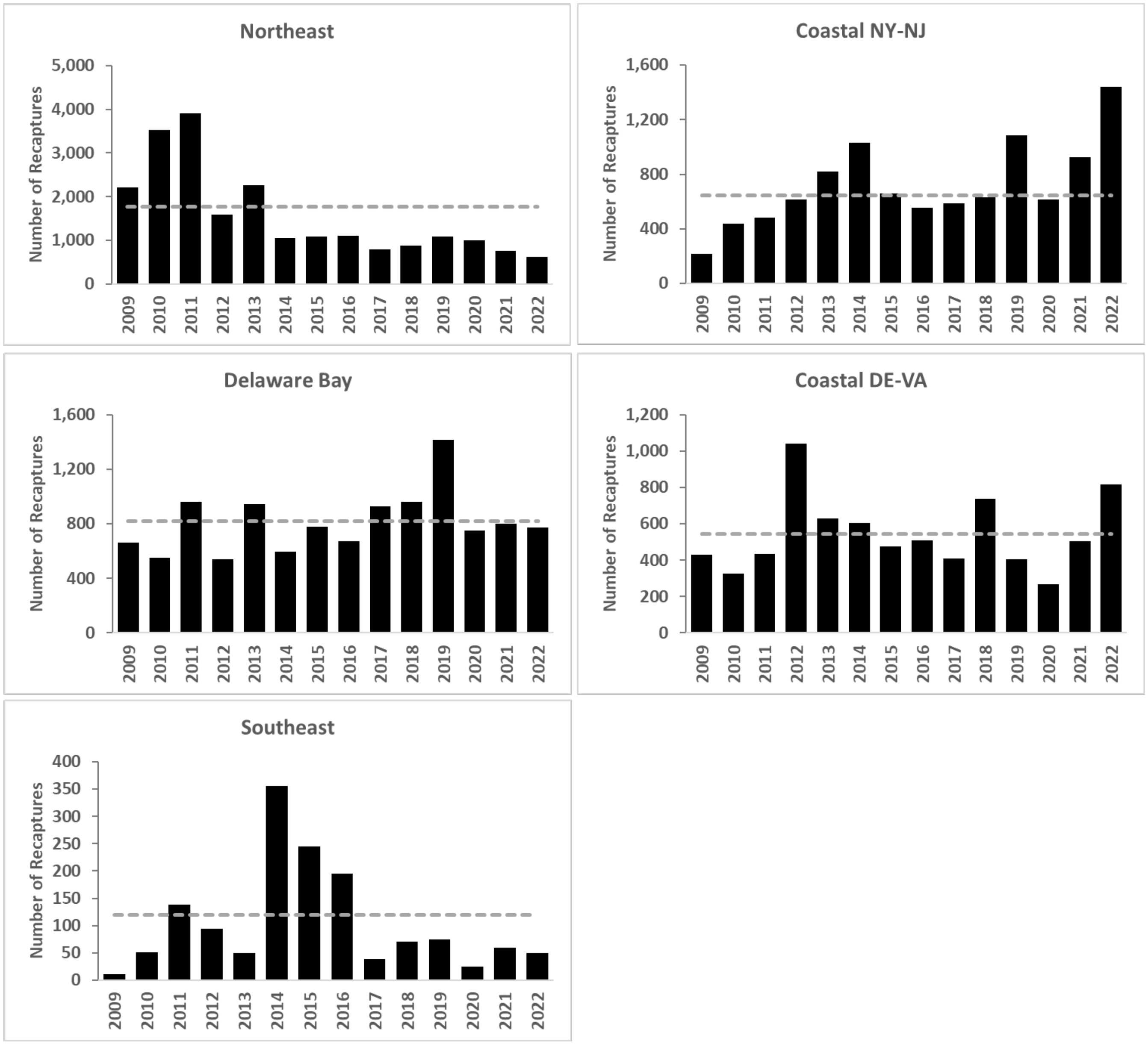


Figure 21. Number of tag recaptures by region, 2009-2022. Grey dashed line indicates the average number of tag releases from 2009-2019 (the years before COVID) by region (source: USFWS tagging database)..

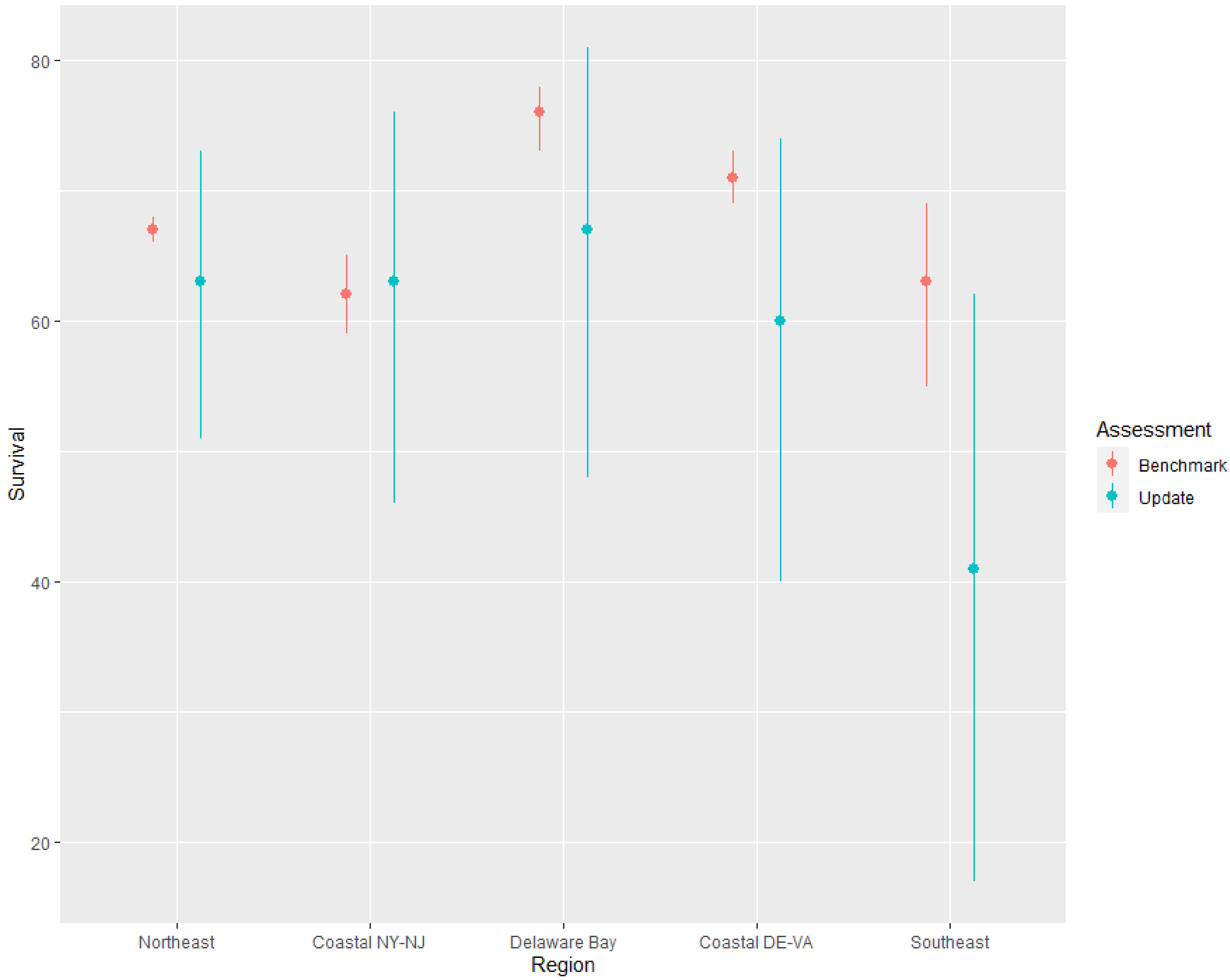


Figure 22. Comparison between the benchmark stock assessment (2019) and update (2024) estimates for survival rate (%) with 95% confidence intervals by region.

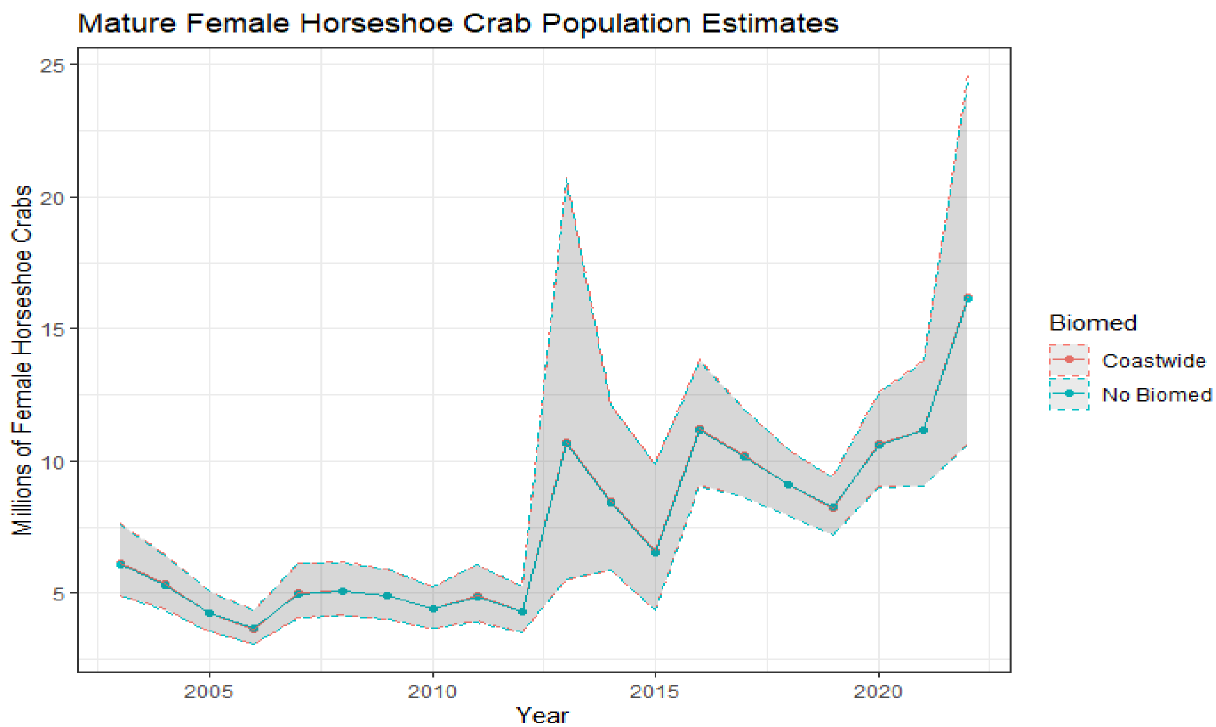


Figure 23. Population estimates from the CMSA for mature female horseshoe crabs with 95% confidence intervals. Delaware Bay biomedical data is confidential so population estimates using coastwide and zero biomedical data provide upper and lower bounds, although there is very little difference between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

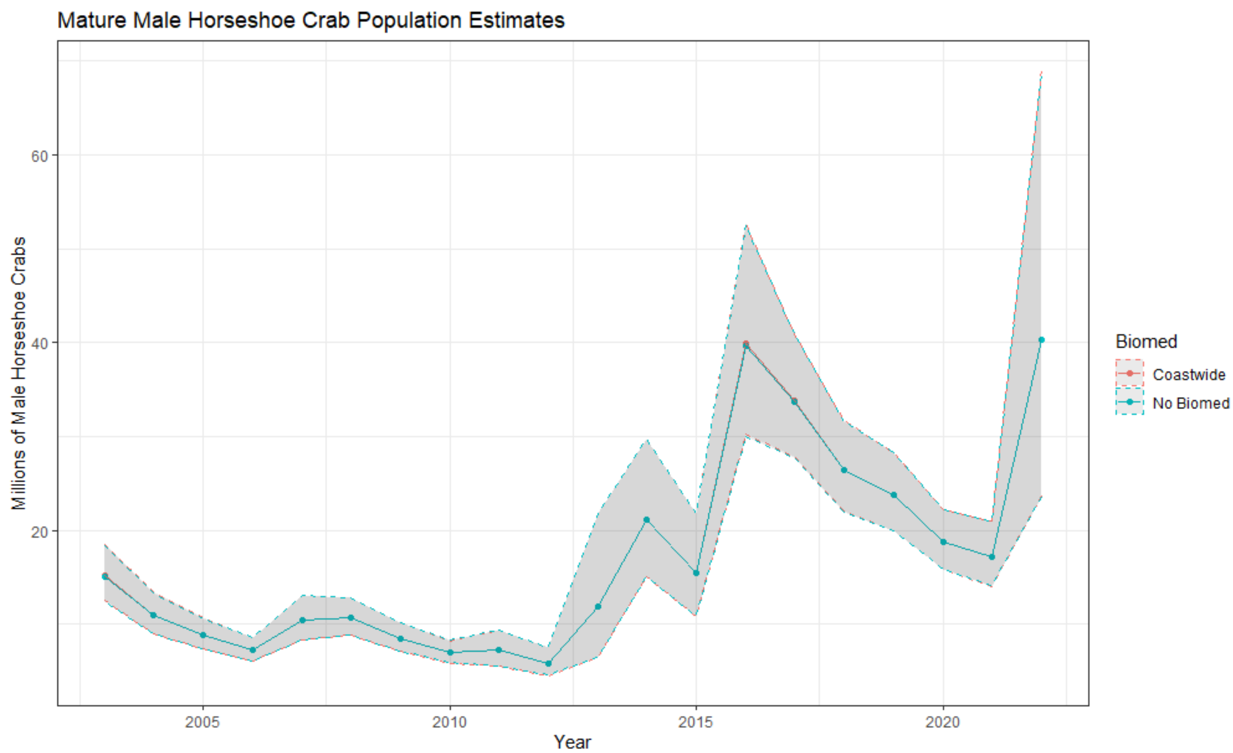
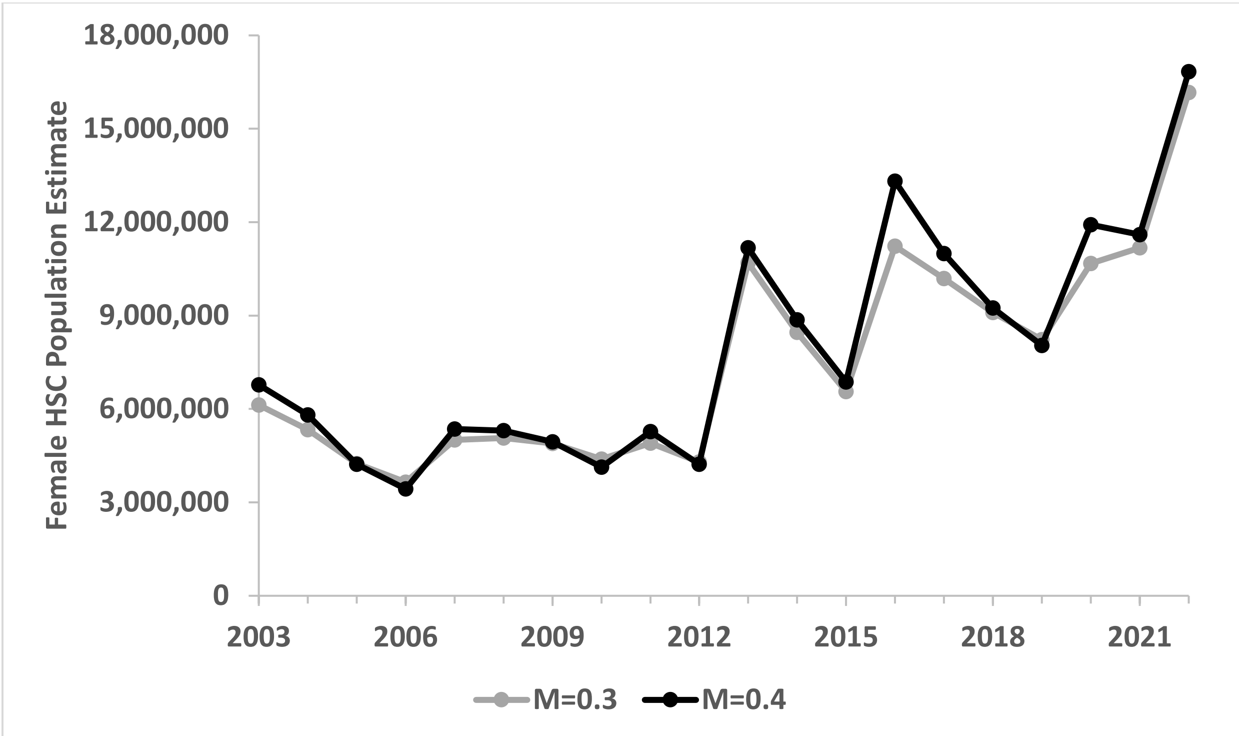


Figure 24. Population estimates from the CMSA for male horseshoe crabs with 95% confidence intervals. Delaware Bay biomedical data is confidential so population estimates using coastwide and zero biomedical data provide upper and lower bounds, although there is very little difference between the two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



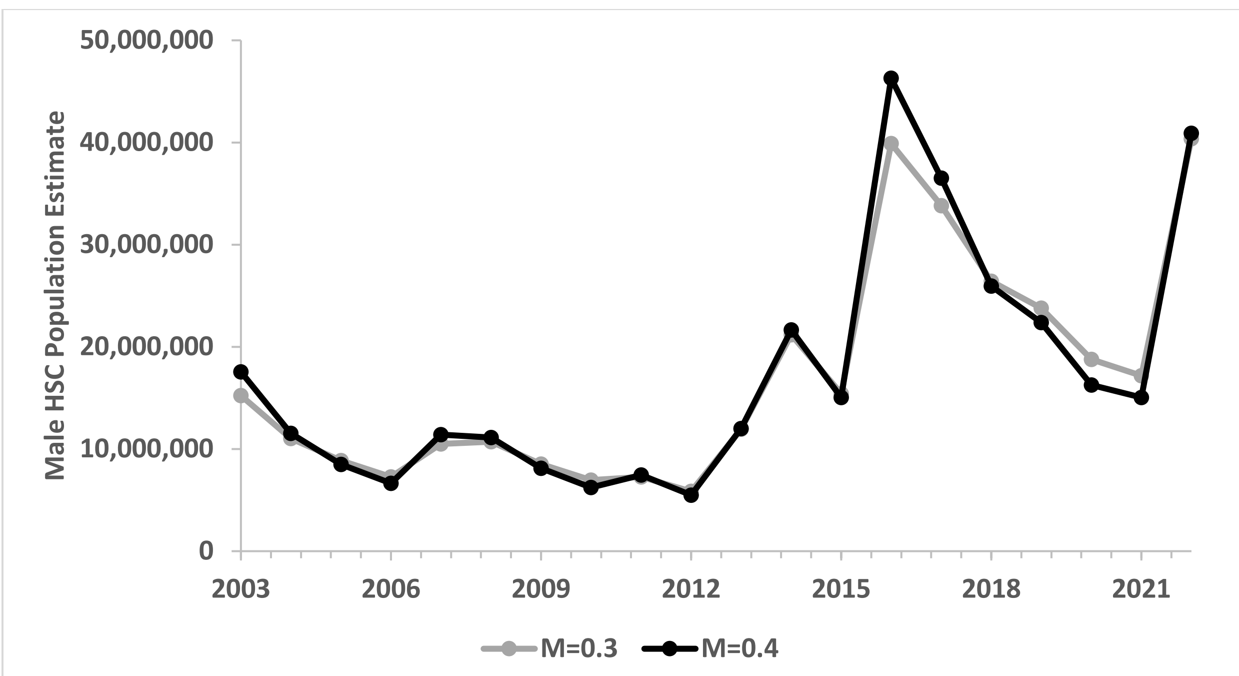


Figure 25. Comparison between population estimates from the CMSA for mature females (top) and males (bottom) using two natural mortality estimates and coastwide biomedical data.

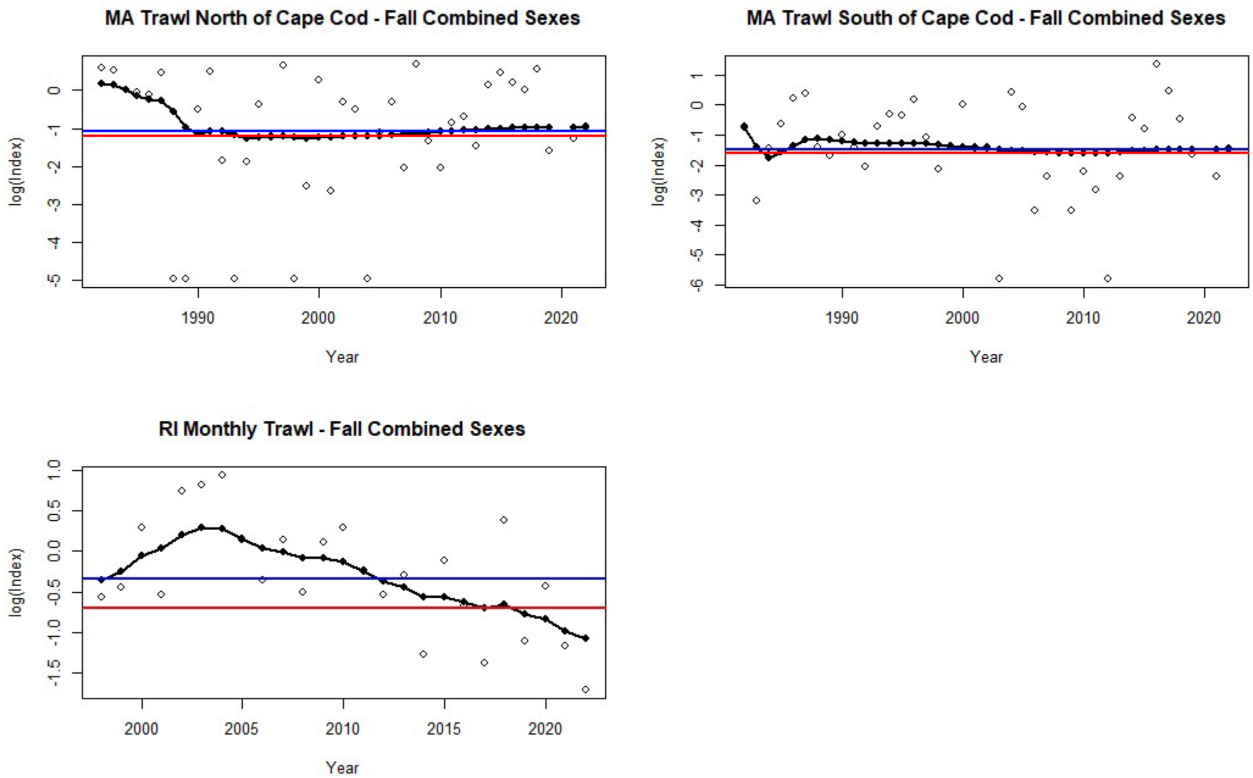


Figure 26. ARIMA model fits to horseshoe crab indices Massachusetts and Rhode Island Trawl Surveys in the Northeast Region. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.

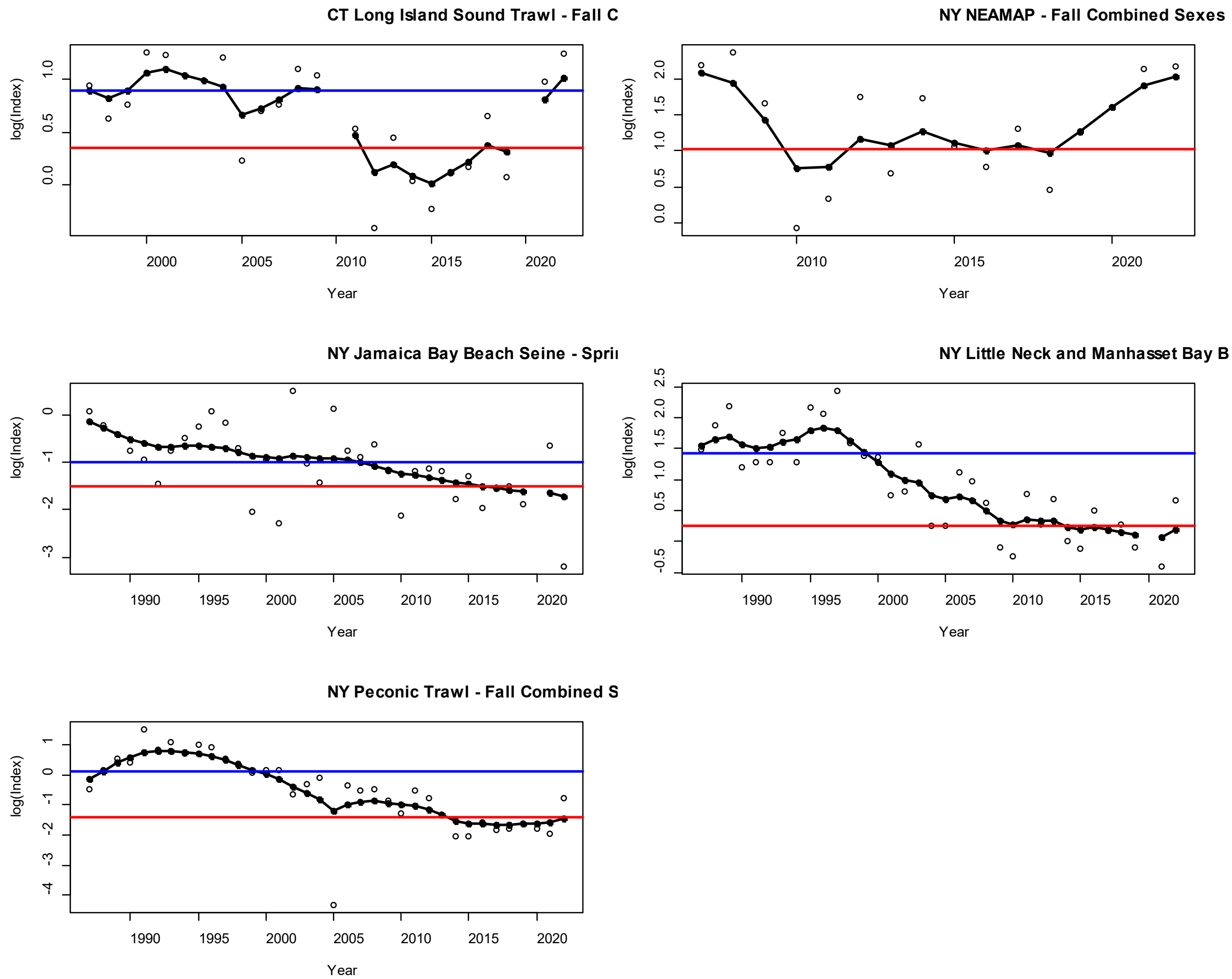


Figure 27. ARIMA model fits to horseshoe crab indices in the New York Region. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.

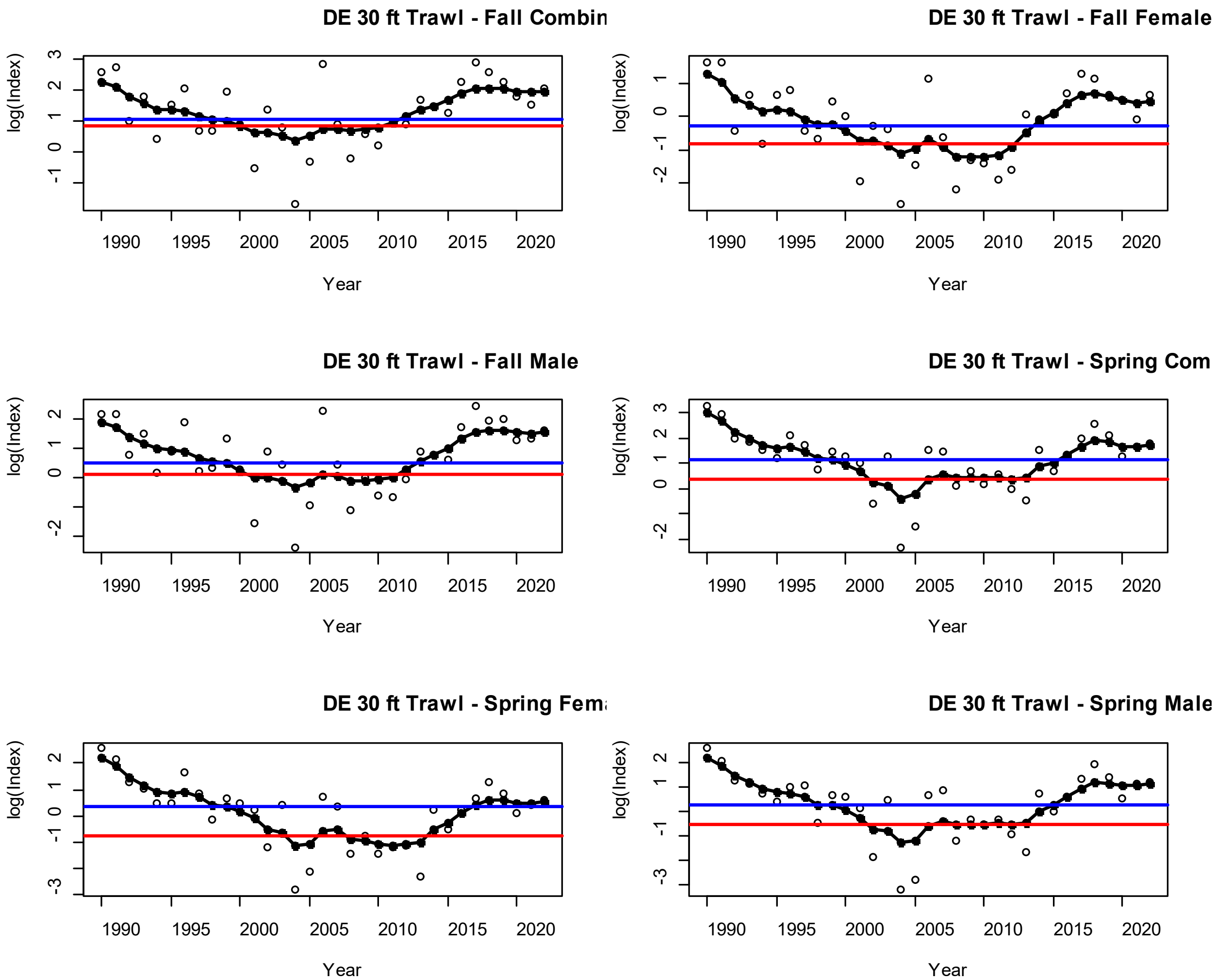


Figure 28. ARIMA model fits to horseshoe crab indices from the Delaware Trawl Survey in the Delaware Bay Region. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.

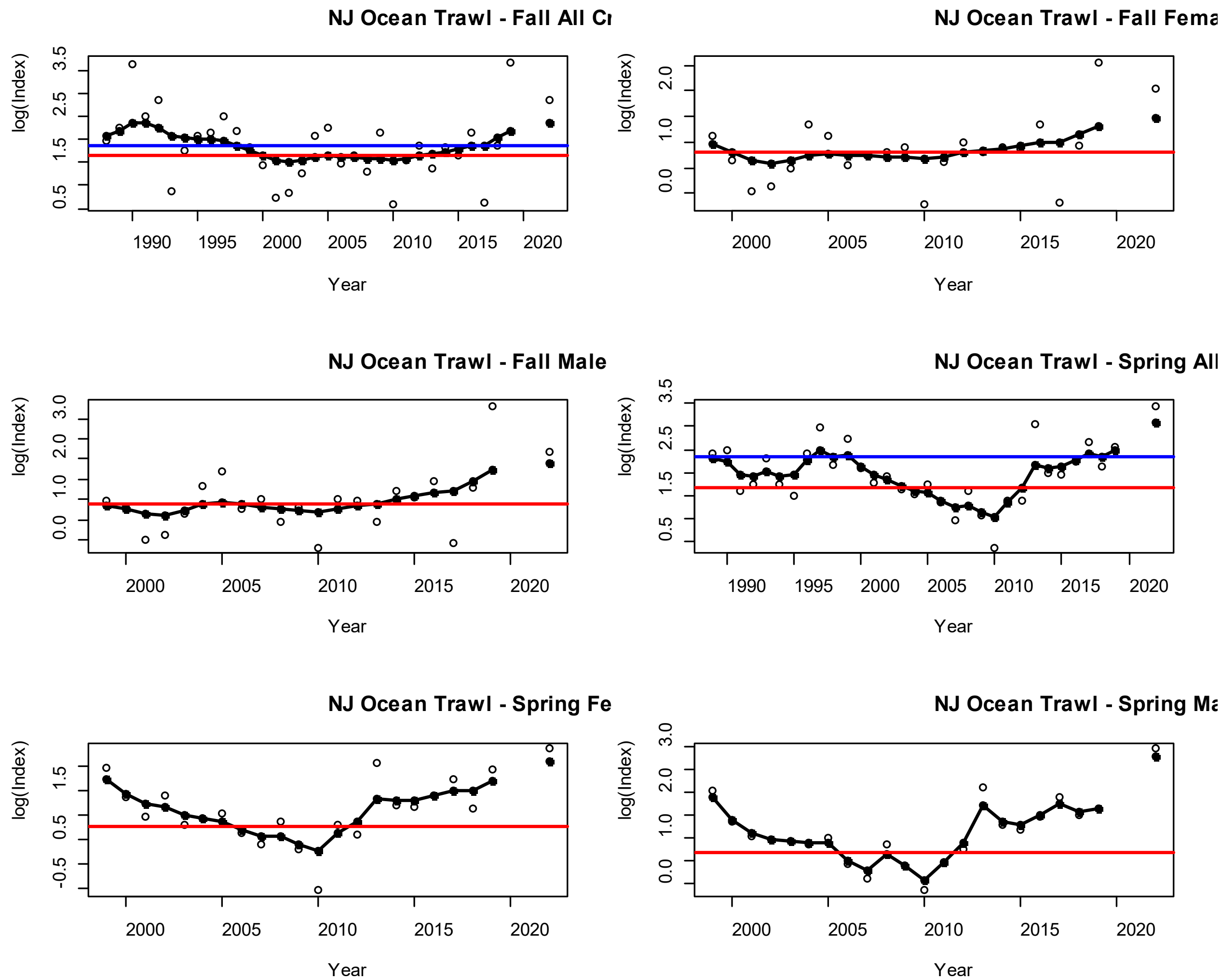


Figure 29. ARIMA model fits to horseshoe crab indices from the New Jersey Ocean Trawl Survey in the Delaware Bay Region. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.

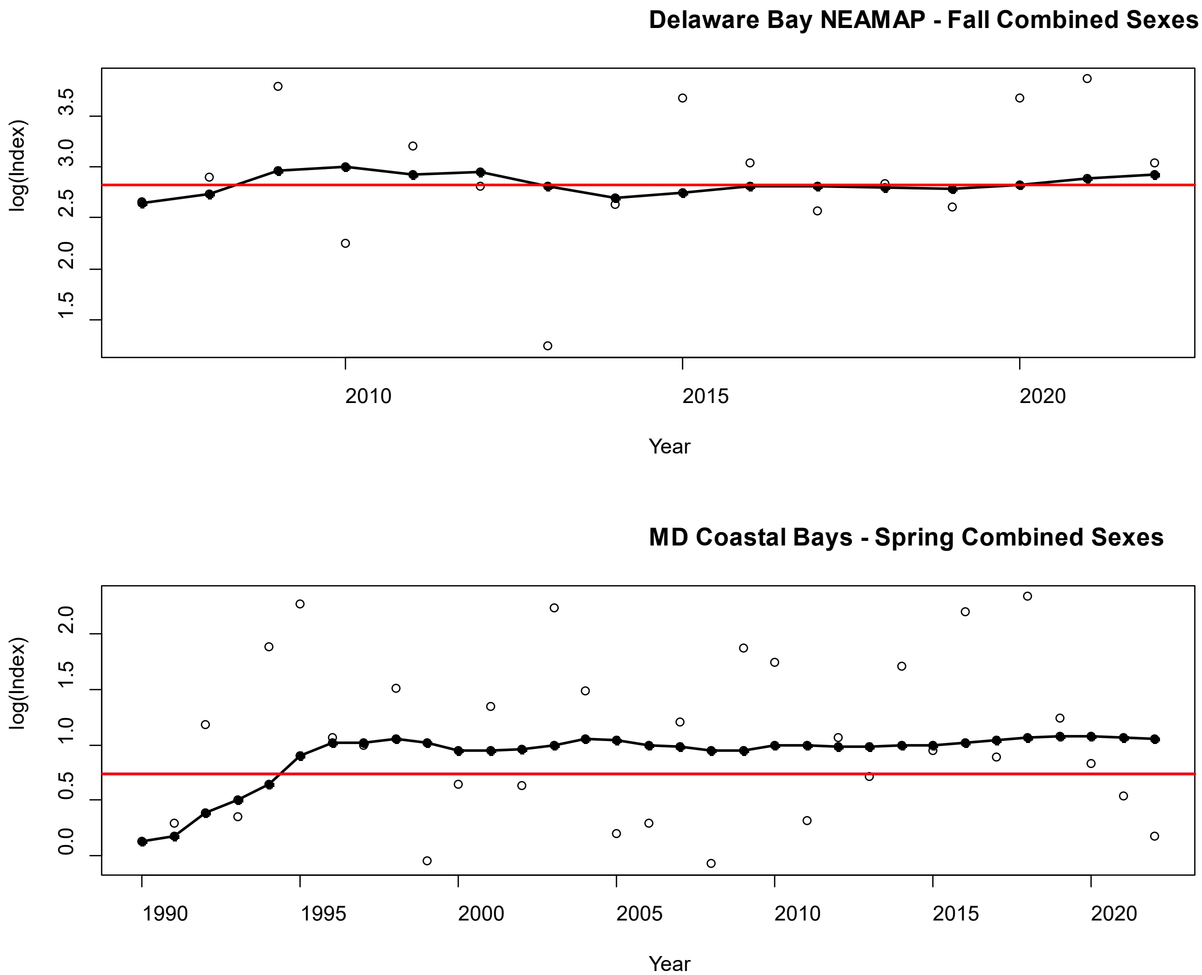


Figure 30. ARIMA model fits to horseshoe crab indices from Delaware Bay NEAMAP and Maryland Coast Bays Surveys in the Delaware Bay Region. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point. For the Maryland Coastal Bays survey,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

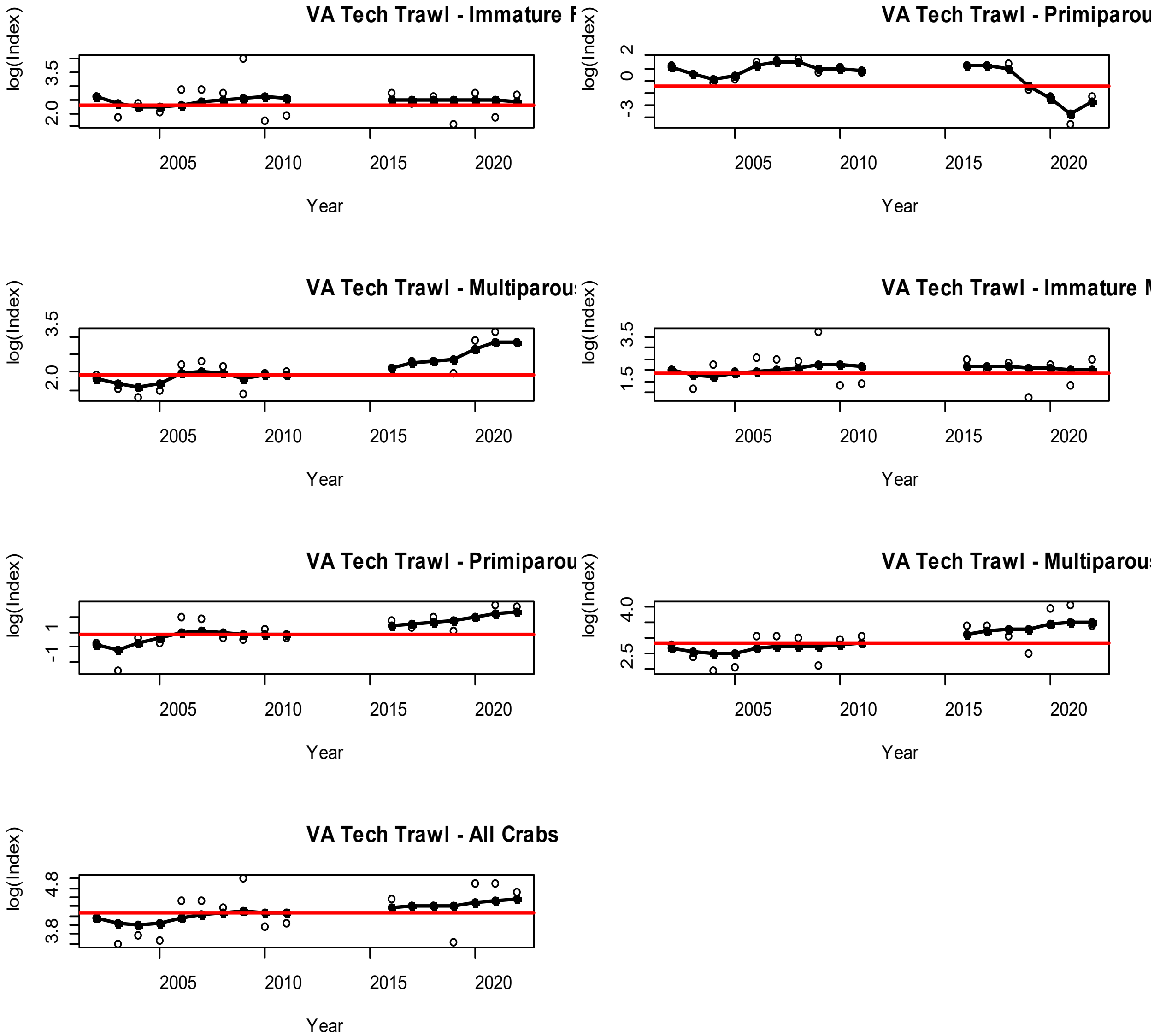


Figure 31. ARIMA model fits to horseshoe crab indices from the Virginia Tech Trawl Survey in the Delaware Bay Region. The red horizontal line represents the Q_{25} reference point.

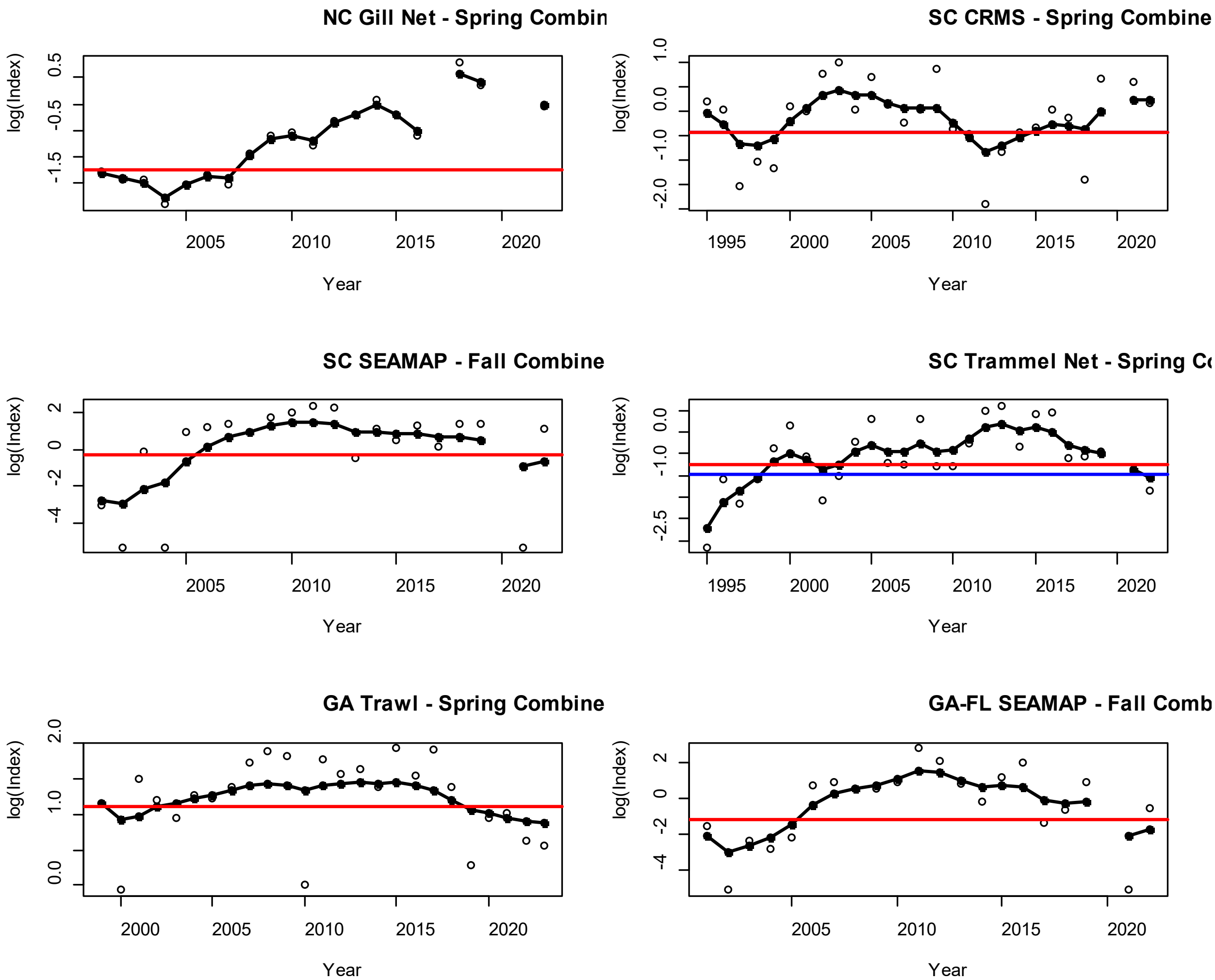


Figure 32. ARIMA model fits to horseshoe crab indices from the surveys in the Southeast Region. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.

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

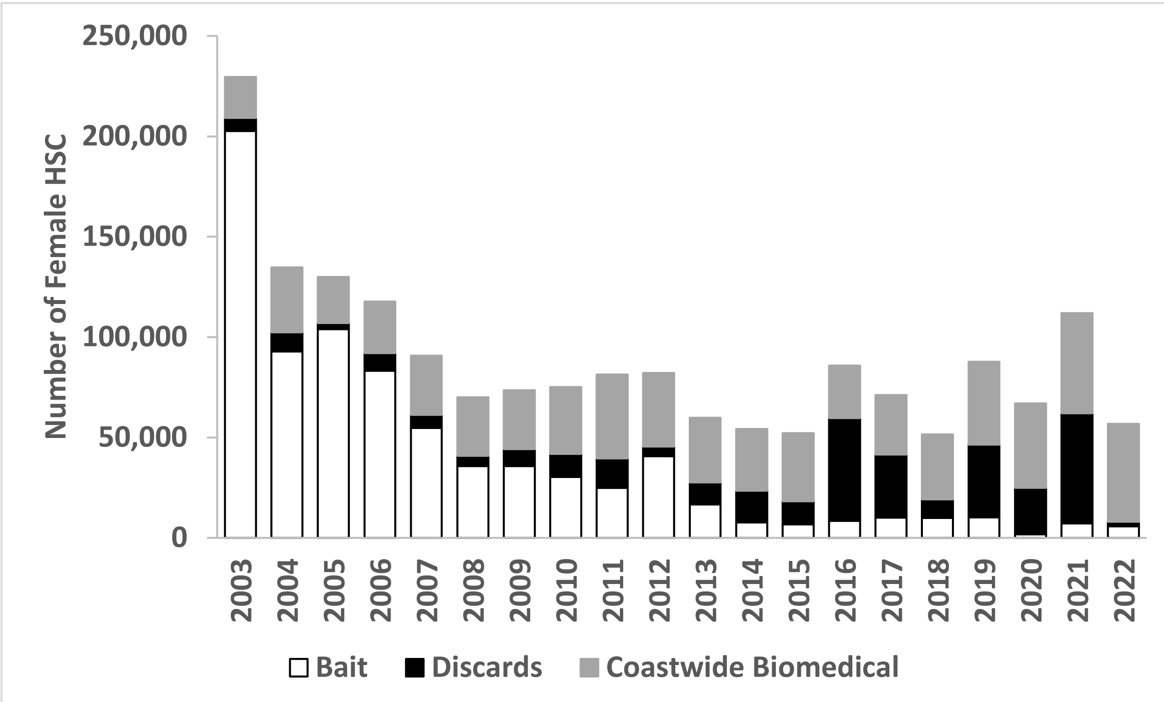


Figure A1. Total female horseshoe crab harvest by source in the Delaware Bay, 2003-2022, for use in the CMSA.

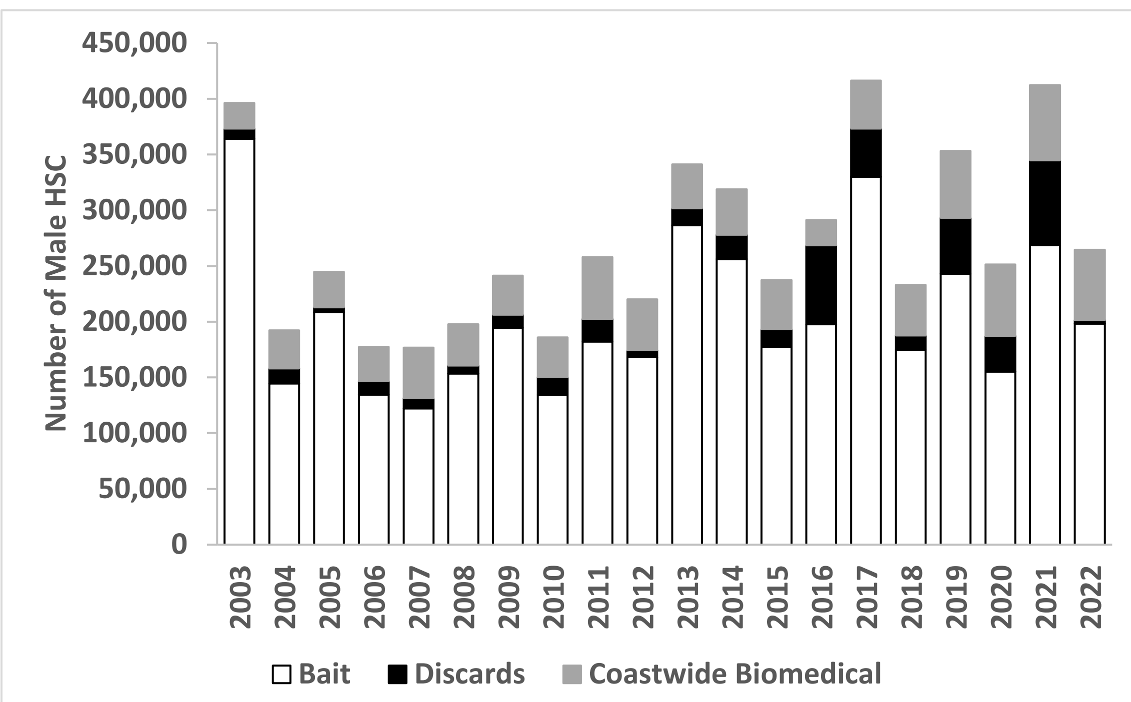


Figure A2. Total male horseshoe crab harvest by source in the Delaware Bay, 2003-2022, for use in the CSMA.

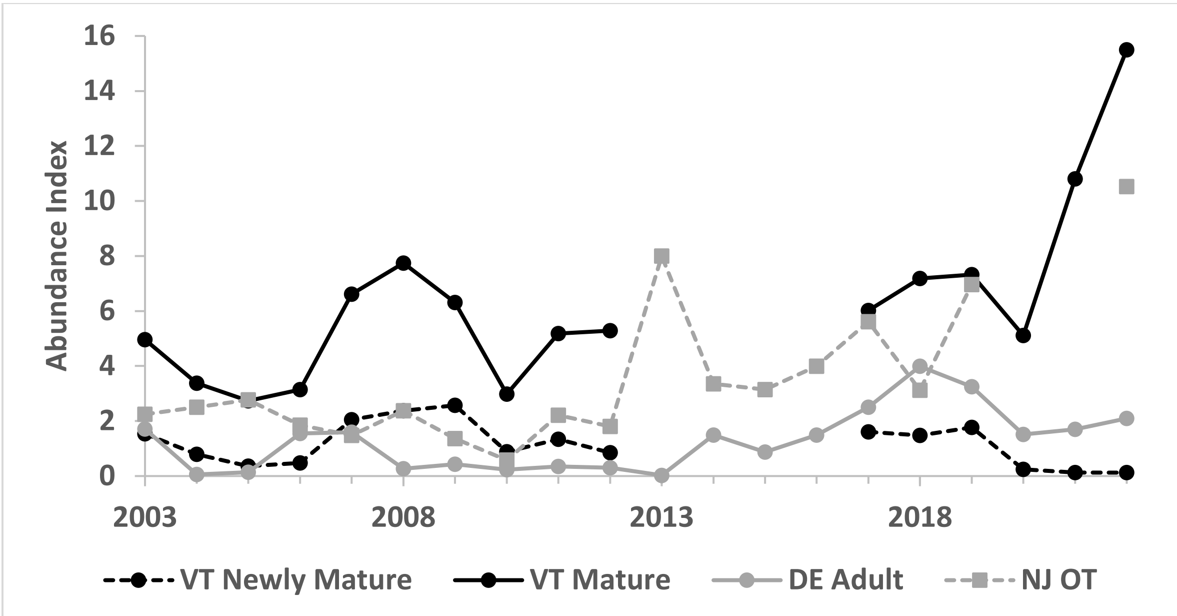


Figure A3. Female horseshoe crab abundance indices used in the CMSA. The Virginia Tech (VT) indices are in millions of newly mature and mature crabs while the Delaware Adult (DE Adult) and New Jersey Ocean Trawl (NJ OT) are in catch-per-tow.

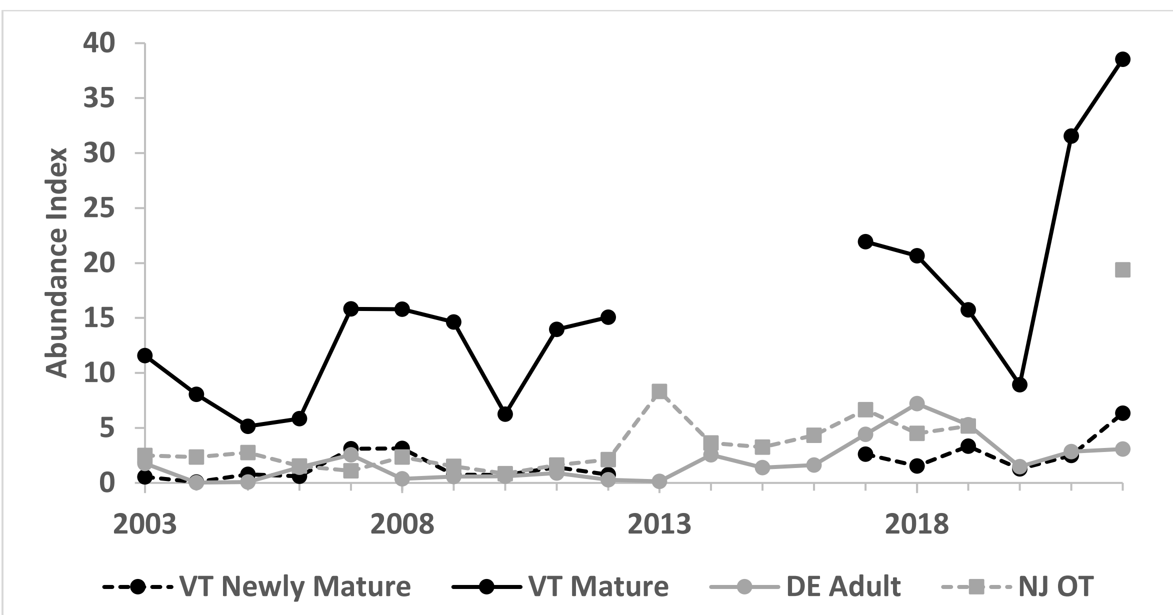


Figure A4. Male horseshoe crab abundance indices used in the CMSA. The Virginia Tech (VT) indices are in millions of newly mature and mature crabs while the Delaware Adult (DE Adult) and New Jersey Ocean Trawl (NJ OT) are in catch-per-tow.

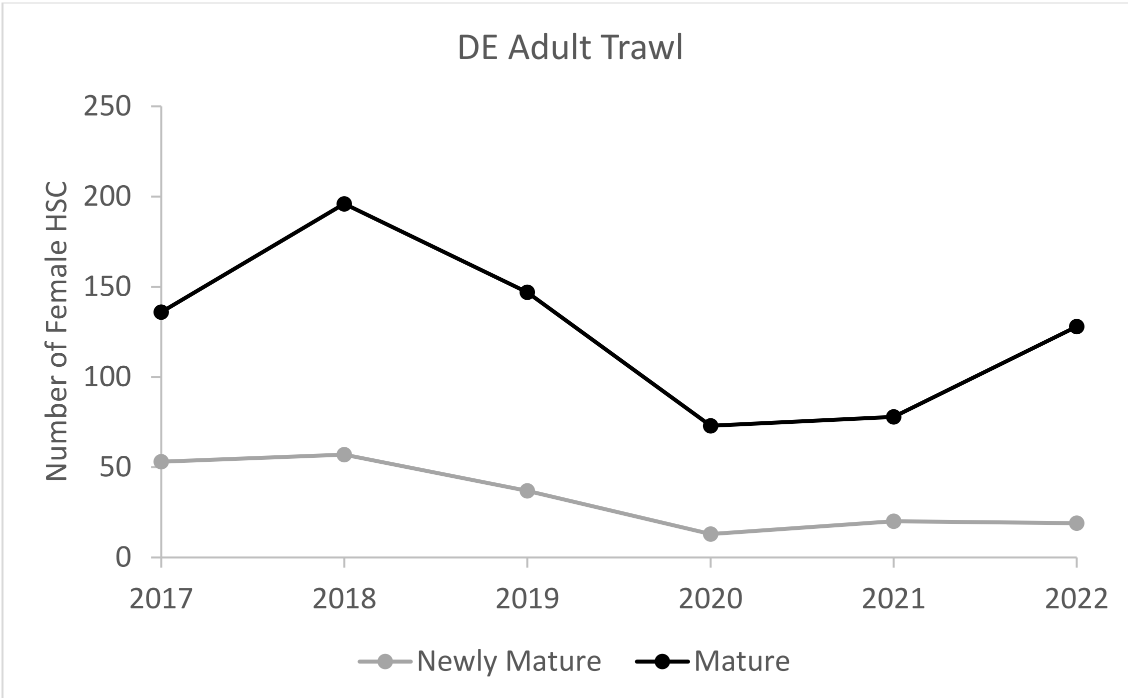


Figure A5. Mature and newly mature female horseshoe crabs caught in the Delaware Adult (30 foot) Trawl, 2017-2022.

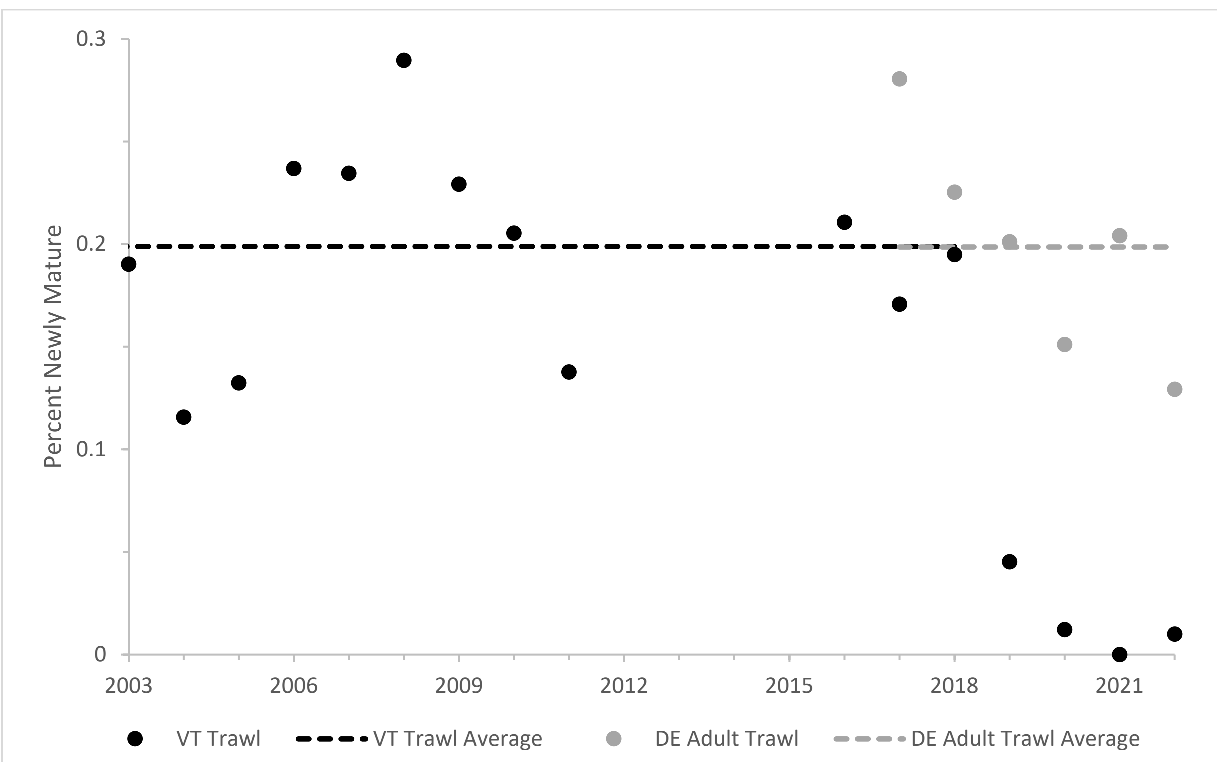


Figure A6. Percent of newly mature female horseshoe crabs in the Virginia Tech and Delaware Adult Trawls. The low years of newly mature female horseshoe crabs (2019-2022) were not included in the average for the Virginia Tech Trawl.

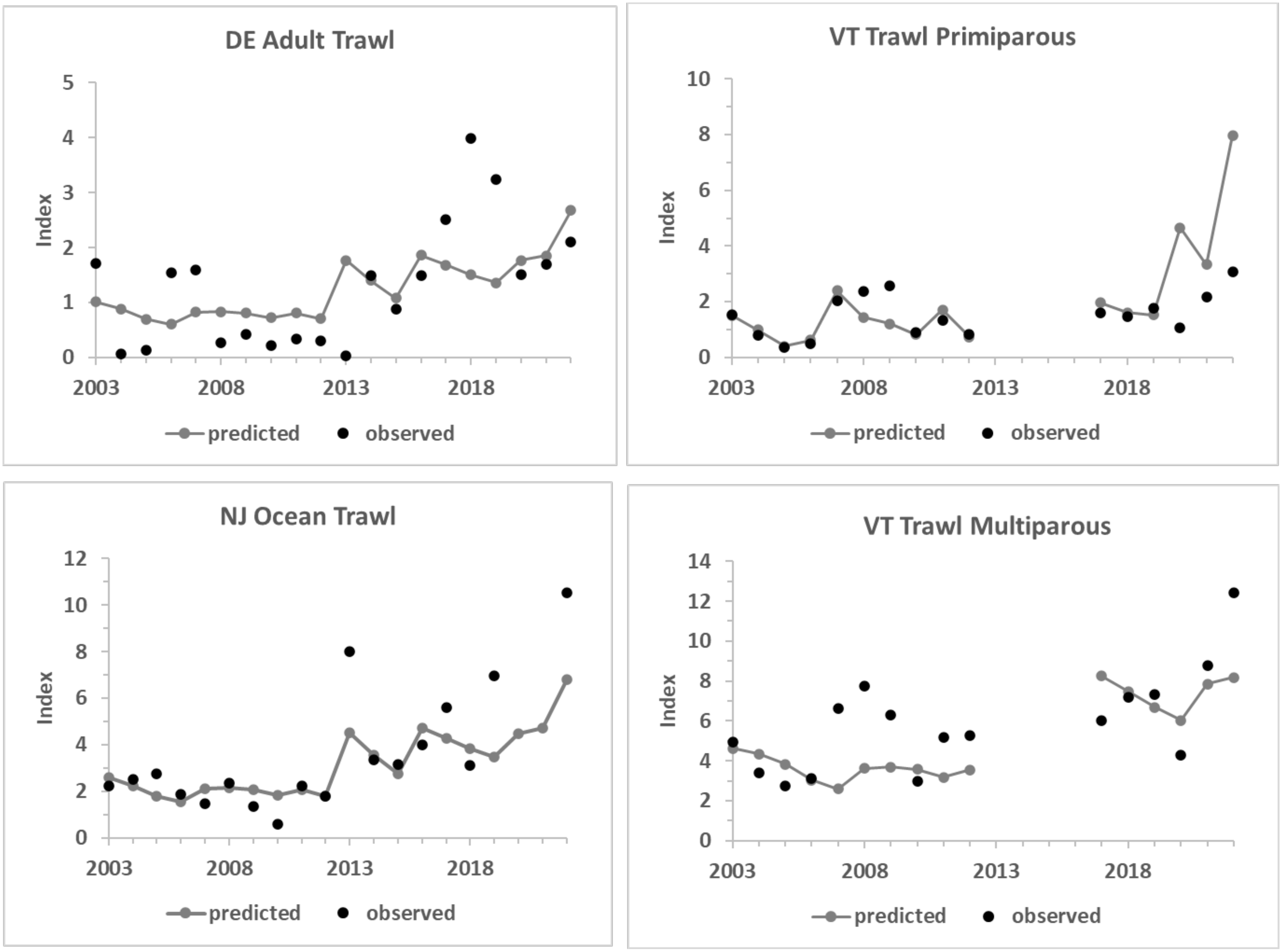


Figure A7. CMSA model fit to the indices of female horseshoe crab abundance.

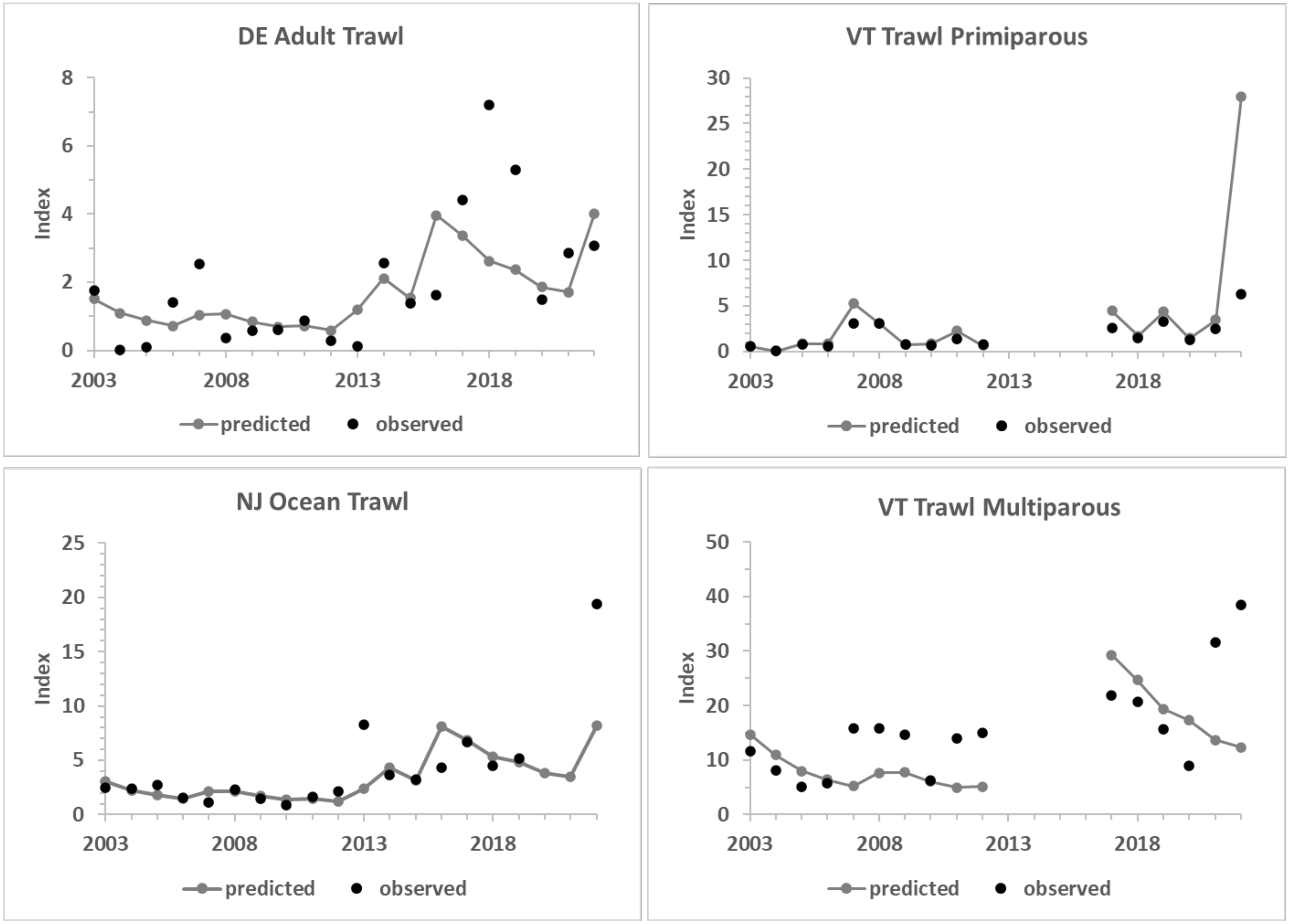


Figure A8. CMSA model fit to the indices of male horseshoe crab abundance.

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.

Atlantic States Marine Fisheries Commission

Technical Response to External Review of the 2022 ARM Framework Revision

Prepared by the
Adaptive Resource Management Subcommittee
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EXECUTIVE SUMMARY

The Adaptive Resource Management (ARM) Framework was developed in 2009 and implemented through Addendum VII in 2012 to set horseshoe crab harvest in the Delaware Bay at a level that does not limit the red knot stopover populations. In the decade since its implementation, more data on red knots and horseshoe crabs have been collected in the region, programming software advanced, and better population models were developed for the two species. Therefore, the ARM Framework was revised in 2022 by the ARM Subcommittee, a group that includes shorebird and horseshoe crab biologists and modelers. The ARM Revision was evaluated and endorsed by an independent panel of scientific experts through the Atlantic States Marine Fisheries Commission's (ASMFC) external peer review process.

While the ARM Revision represents significant advances in modeling and data use, the conversation around the revised ARM Framework quickly focused on the allowance of female horseshoe crab harvest when horseshoe crab population estimates are sufficiently high as to not limit red knot populations. The original ARM Framework had a technical flaw where it recommended 0 female horseshoe crab harvest when the adult female population was estimated to be less than 11.2 million, as it did from 2013-2022, or maximum female harvest (210,000 female horseshoe crabs) when the population was estimated to be greater than 11.2 million females, as it did in 2023. Rarely were the intermediate harvest levels selected by the model, as was shown through a simulation study. To correct this, the ARM Revision allowed a *gradual* increase of female harvest from 0-210,000 females as population estimates of female horseshoe crabs increased. The nuance of this change was lost in the discourse as stakeholders greatly opposed female harvest at any level, despite the original ARM Framework also recommending female harvest in recent years. In response to the concern over possible female harvest, Earthjustice, a non-profit public interest organization, hired experts to do their own technical review of the ARM Revision in 2022 and again in 2023 before the annual meeting of the Horseshoe Crab Management Board (Board) to set harvest specifications for the Delaware Bay region. During the October 2023 meeting, the Board tasked the ARM Subcommittee with responding to the 2023 technical review from Earthjustice.

The ARM Subcommittee seeks to always use the best scientific information available and welcomes scientific review and critique. As such, the Subcommittee has considered the comments provided by Earthjustice thoroughly. The following report outlines the ARM Subcommittee's responses to the six major criticisms listed by Dr. Kevin Shoemaker, a population ecologist at the University of Nevada, Reno, hired by Earthjustice as an external peer reviewer. Briefly, the ARM Subcommittee maintains that the red knot and horseshoe crab population models used in the ARM Framework currently represent the best use of the available data. Red knot survival rates and horseshoe crab population trends from the ARM Revision are consistent with other published values or data sources in the Delaware Bay region. This includes horseshoe crab egg density data, which were not provided to the ARM Subcommittee, but were subsequently published in the literature and show a similar trend to the horseshoe crab relative abundance indices. Additionally, the ARM Subcommittee responds to the comments in Dr. Shoemaker's report regarding the overparameterization or goodness of fit for the integrated population model for red knots and assert that this criticism misrepresents the work in the ARM Revision.

The ARM Subcommittee reiterates that an important benefit of the adaptive management process is the ability to make decisions even with imperfect knowledge of an ecological system. The overall goal of the ARM was to produce a decision-making framework informed by science and stakeholder values, given the available knowledge about the Delaware Bay ecosystem and horseshoe and red knot populations. At the time of the original ARM Framework, this knowledge was limited. However, the re-evaluation of the data, values, and knowledge on a regular basis is essential to the adaptive management process and is built into the ARM Framework. The 2022 ARM Revision represented a learning event where population models were re-designed to accommodate the advancement of data and knowledge since 2009. The peer reviews from Earthjustice fail to provide any real recommendations for improvement to the ARM Framework or provide other means for helping managers make an informed harvest decision beyond a mandate for zero female harvest at any population level. If the values of all stakeholders have changed (i.e., no female harvest under any circumstances), that change could be considered in a new approach in the future by the ARM Subcommittee. As it stands, the current ARM Framework represents the objectives previously established through stakeholder engagement: to manage harvest of horseshoe crabs in the Delaware Bay to maximize harvest but also to maintain ecosystem integrity, provide adequate stopover habitat for migrating shorebirds, and ensure that the abundance of horseshoe crabs is not limiting the red knot stopover population or slowing recovery.

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INTRODUCTION

The Atlantic States Marine Fisheries Commission (ASMFC) has been managing the harvest of horseshoe crabs in the Delaware Bay region using an Adaptive Resource Management (ARM) Framework since 2012. The ARM Framework uses linked population dynamics models between horseshoe crabs and red knots to determine a harvest level of male and female horseshoe crabs such that the fishery has the opportunity to benefit from the harvest of horseshoe crabs and the population growth of red knots is not limited by that harvest. The original ARM Framework recommended an annual harvest of 500,000 male and 0 female horseshoe crabs from 2013 – 2022. These harvest recommendations have likely contributed to in an increase of both male and female horseshoe crab abundance over the last decade.

The original ARM Framework was theoretical in nature because the underlying population dynamics models for both species were based heavily on literature values of life history parameters and not specific to Delaware Bay. Since its inception, more Delaware Bay-specific data have been collected and the ARM Framework was revised in 2021 and adopted for management use in 2022 (ASMFC 2022). ASMFC 2022, henceforth referred to as "the ARM Revision," documents the many advantages of the revised ARM Framework including the use of more Delaware Bay-specific data, modern modeling software, and more advanced models for horseshoe crabs and red knots. Although shorebird advocates supported the original ARM Framework for managing horseshoe crab harvest, they have expressed strong disagreement with the use of the ARM Revision for making horseshoe crab harvest recommendations primarily because of the female horseshoe crab harvest strategy. This disagreement spurred intense review and scrutiny of the ARM Revision by Earthjustice and the outside experts they hired to critique the data and modeling. The first public comment by Earthjustice was submitted to ASMFC in September 2022 and contained critiques by Dr. Kevin Shoemaker (University of Nevada, Reno) and Dr. Romuald Lipcius (Virginia Institute of Marine Science). The second public comment was submitted in September 2023 and contained additional critique by Dr. Shoemaker. During the October 2023 meeting, the Board tasked the ARM Subcommittee, which includes red knot and horseshoe crab biologists and modelers, with responding to the 2023 critique by Dr. Shoemaker.

The ARM Revision (ASMFC 2022) did modify the female horseshoe crab harvest strategy from that of the original ARM Framework (ASMFC 2009a, 2012). The original ARM Framework had some technical flaws in the algorithm that optimized horseshoe crab harvest which resulted in an "all or nothing" harvest strategy for female horseshoe crabs. A simulation study showed that the original ARM Framework would recommend either 0 female harvest, or the maximum female harvest (210,000) if the female horseshoe crab population reached a threshold of 11.2 million individuals. Intermediate harvest levels would rarely, if ever, be recommended. The "all or nothing" harvest flaw in the original ARM Framework was observed when 0 female harvest was recommended from 2013 – 2022 and then in 2023, it recommended maximum harvest (210,000 female horseshoe crabs) because female horseshoe crab population estimates exceeded the threshold of 11.2 million. Conversely, the ARM Revision allows female harvest to gradually increase with increasing female horseshoe crab abundance. Despite detailed explanation for this difference between the two ARM Framework versions, shorebird advocates have strongly objected to the possibility of any female harvest, regardless of the population level of female horseshoe crabs and despite the fact that the original ARM Framework also allowed for female harvest.

With the publication of the ARM Revision and the discourse around the change in female harvest recommendations, Earthjustice solicited an external peer review of the technical work. The following represents the ARM Subcommittee's response to six major criticisms outlined by Dr. Shoemaker in his 2023 peer review. Each criticism is followed by a few bulleted summary points of the response and then a more detailed technical response to the criticism. While the ARM Subcommittee was not tasked with responding to the 2022 critiques, some responses to the major criticisms not included in the 2023 report have been provided in an appendix as supplemental information.

Criticism 1: Estimates of red knot survival used in the ARM appear to be artificially inflated, resulting in falsely optimistic estimates of population resilience.

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

Technical Response: Dr. Shoemaker asserts that red knot annual survival probability is more likely closer to 0.8 than the 0.9 used in the revised ARM Framework, corresponding to an expected lifespan of about 5 years. There is not strong evidence for this lower annual survival probability for *rufa* red knot. In fact, previous studies of *rufa* red knot in Delaware Bay (McGowan et al. 2011) and Florida (Schwarzer et al. 2012) also estimated annual survival probability at approximately 0.9. In a separate published analysis, only using data collected by the state of Delaware, Tucker et al. (2022) estimated red knot annual survival probability at 0.89, and at 0.91 for ruddy turnstones, a species with similar body size and a similar annual life cycle. Additionally, observations of birds more than 5 years old are common in the mark-recapture data set (approximately 20% of birds), with a maximum of 17 years between physical recaptures. These observations are a conservative minimum estimate of lifespan. Further, it is worth noting that almost all vertebrate species with delayed maturation life cycles, like red knots, that do not recruit to the breeding population until their third year, exhibit high adult survival rates. This is especially true when annual reproductive output is low, as it is with red knots, which lay only four eggs in a single nest per year.

Outside of the Delaware Bay system, high survival and long lifespans are also reported for red knots and other shorebirds of similar size and annual cycle. For example, Piersma et al. (2016) report that annual apparent survival for red knots in Western Australia were well above 90% in most years of their study. In another example, Boyd and Piersma (2001) reported that they recaptured 155 birds in their sample >14 years after initial capture and 2 over 24 years after initial capture. There are published studies that report survival rates at 80% or lower, but to assert that the estimated survival rates used in the ARM based on the mark-recapture data are outliers or excessively high is erroneous.

In his report, Dr. Shoemaker claims that the survival estimates in the ARM are biased by individual misidentification, or flag misreads. Before analyzing the data, the ARM Subcommittee conducted a thorough QA/QC, including filtering records to only lime and dark green flags that were first deployed by New Jersey or Delaware, removing records of 5 duplicate flags (n = 36), flags apparently resighted before they were deployed (n = 711), and flags that were never deployed (n = 1). Removal of these records represents only 0.35% of the total resightings. Members of the ARM Subcommittee have worked extensively on the issue of flag misreads, including conducting a thorough simulation study investigating the situations in which misreads might bias survival estimates and the implications of that bias (Tucker et al. 2019). The key points from that work are: 1) misreads disproportionately affect survival estimates from the first years of the study, causing apparent negative trends in survival over time, and 2) there is an important tradeoff to consider between potential bias due to misreads and loss of precision if data filtering is applied. In that paper, the authors suggest a data filtering step of removing all observations of flags that were only seen once in a year as a way to potentially mitigate misidentification errors. However, there are nuances to consider when determining whether this is necessary, because this data filtering will inevitably remove some number of valid observations, and the authors identify thresholds that depend on study length and error rate. For a 10-year study, removing single observations becomes beneficial if the error rate is >5%; below that rate the bias is minimal relative to the detrimental effects of removing valid observations. In the Delaware Bay mark-recapture dataset, the misread error rate is between 0.38% (712 impossible observations/187,587 total) and 4.5% (8,448 single observations). Additionally, the characteristic apparent negative trend in survival over time that would indicate bias due to misreads is not observed. To examine this further, the distribution of the number of resightings in a year for every flag (Figure 1) was plotted, with and without removing single observations. The shape of the resulting histogram indicates that removing these records results in fewer flags being seen once in a year than would be expected, i.e., that the data filtering removes a large number of valid records (> 3,000). The integrated population model uses the mark-recapture data to estimate survival as well as parameters related to stopover site use within each year. There were concerns that removing single observations would bias estimation of within-year parameters, and because the error was below the thresholds identified by Tucker et al. (2019) and the characteristic negative trend in survival was not observed, single observations were kept in the data set for the analysis.

The ARM Revision (ASMFC 2022) contains a thorough discussion of this topic on pages 63-64, in which several hypotheses for the disagreement in annual survival probability estimates from the older studies was described. Dr. Shoemaker points to lower estimates of survival from studies from the early 2000s, when red knot annual survival probability was estimated to be close to 0.8. It is likely that older estimates were negatively biased to some extent due to short study periods, low detection probably, and unmodeled temporary emigration from the system. It is also possible that during that time, when horseshoe crab populations were lower, red knot survival probability was truly lower. Alternatively, because permanent emigration from the system cannot be distinguished from mortality in older mark-recapture studies, a higher rate of permanent emigration (i.e., birds abandoning Delaware Bay for other spring stopover sites) would appear as lower survival probability. It is possible that there is a threshold of horseshoe crab abundance below which red knot survival probability might be expected to drop dramatically. If such a threshold exists, it was not observed over the time series included in the model (2005-2018).

It has also been proposed that southern-wintering birds (with longer migrations) have lower annual survival probabilities than northern-wintering birds. Declines in the number of red knots overwintering in Argentina (Niles et al. 2009) suggest a decline in the southern-wintering subpopulation and therefore it is possible that in more recent years a greater proportion of the Delaware Bay stopover population are northern-wintering birds. As discussed in the report, this is a key area for future research.

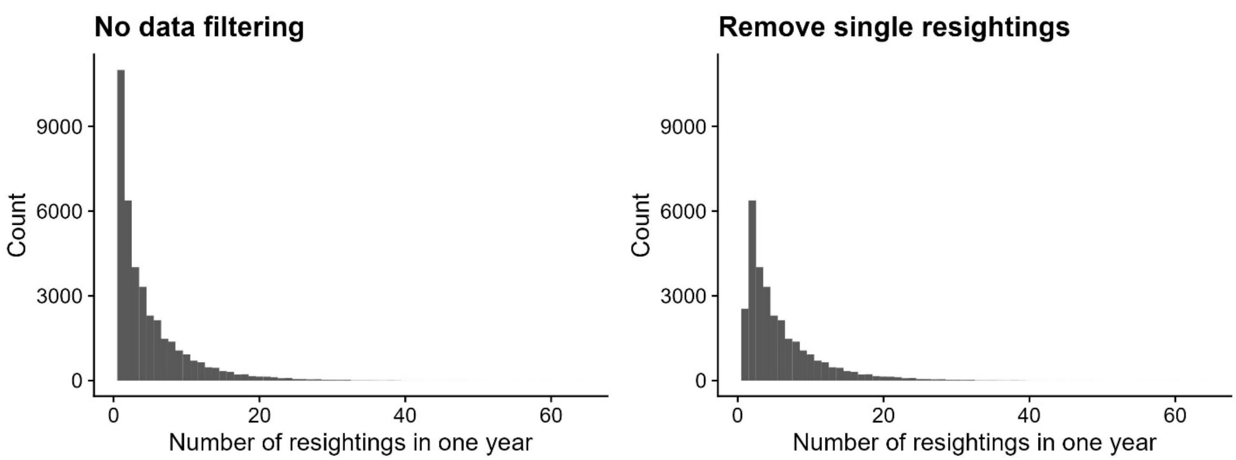

Figure 1. Histogram of the number of resightings per year for all lime and dark green flags deployed by New Jersey or Delaware from 2005 – 2018. The left panel is plotted without any data filtering. In the right panel, all flags that were seen only once (and not physically captured) were removed.

Criticism 2: Trawl-based indices of horseshoe crab abundance are inadequate for modeling the biotic interaction between red knots and horseshoe crabs.

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

- Trawl surveys are the standard for bottom dwelling organisms and for evaluating the abundance of many species.

Technical Response: Dr. Shoemaker argues that the trawl surveys used to monitor horseshoe crab abundance and serve as the basis of the catch multiple survey analysis (CMSA) are "…imperfect snapshots of the abundance of horseshoe crabs occupying Delaware Bay, obscured by differing survey methodologies and poorly understood aspects of horseshoe crab ecology, including seasonal and daily activities, habitat preferences, and degree of clustering on the seafloor." The ARM Subcommittee agrees that the trawl surveys are imperfect; catchability differs in each survey and possibly differs both within and between years. Such is the nature of fishery-independent surveys, and these same arguments also apply to indices of abundance for red knots and horseshoe crab egg density estimates. However, the use of the trawl surveys to index horseshoe crab abundance has gone through multiple peer reviews (e.g., ASMFC 2009b, ASMFC 2019, ASMFC 2022, Anstead et al. 2023) and found to be a scientifically sound measure of horseshoe crab abundance.

Dr. Shoemaker faults the trawl-based indices of abundance used by the ARM Subcommittee for not considering environmental covariates that could influence the catch of horseshoe crabs, and he obtained the raw data to recalculate the indices using generalized linear models (GLM) and generalized additive models (GAM). The ARM Subcommittee does not disagree with this approach to standardizing abundance indices based on environmental covariates, and this sort of analysis was conducted as part of the 2019 stock assessment (ASMFC 2019) but it did not improve the indices of abundance (e.g., decrease errors, reduce large annual fluctuations). The peer review panel for the ARM Revision (2022 ASMFC) recommended using a model-based index for the Delaware Trawl Survey because it is a fixed station survey; consequently, the ARM Subcommittee applied this approach prior to using this survey in the CMSA. The Virginia Tech Trawl Survey has a well-designed sampling scheme that stratifies sampling based on habitat; thus, habitat features that could influence catchability are already incorporated into the abundance estimates from this survey. Finally, and as stated earlier, a GLM did not improve the precision of the New Jersey Ocean Trawl Survey (ASMFC 2019) and the ARM Subcommittee continued using a simpler calculation of the abundance estimate (the delta-mean catch-per-unit-effort).

Like trawl surveys for any aquatic species, there is considerable variation in the catches of horseshoe crabs among individual trawl samples resulting in high inter-annual variation in abundance indices. Dr. Shoemaker concludes there is a lack of statistically significant correlation coefficients among the trawl surveys, and there is a fatal flaw in using those data to infer abundance. The ARM Subcommittee disagrees with this analysis and can demonstrate that there is in fact a significant correlation between trawl surveys and with the CMSA estimates of abundance (see response to Criticism 3). There is observation error associated with each survey (e.g., being in the right place at the right time) and it is not uncommon for a relatively high catch in one survey to correspond with a relatively low catch in another for the same survey year, so it is not surprising that there could be some "non-significant" correlations or correlation coefficients that one may consider low. However, each trawl survey could very well show a statistically significant trend. It is the consensus among surveys about the trend that is important, not how closely individual observations from the respective surveys track one another. The ARM Subcommittee acknowledges that each survey does not perfectly track the population, which is why the CMSA uses multiple surveys. In addition, it is very possible, from a statistical sense, that two time series of abundance data could not show a statistically significant correlation, but could still both show a statistically significant trend (Figure 2).

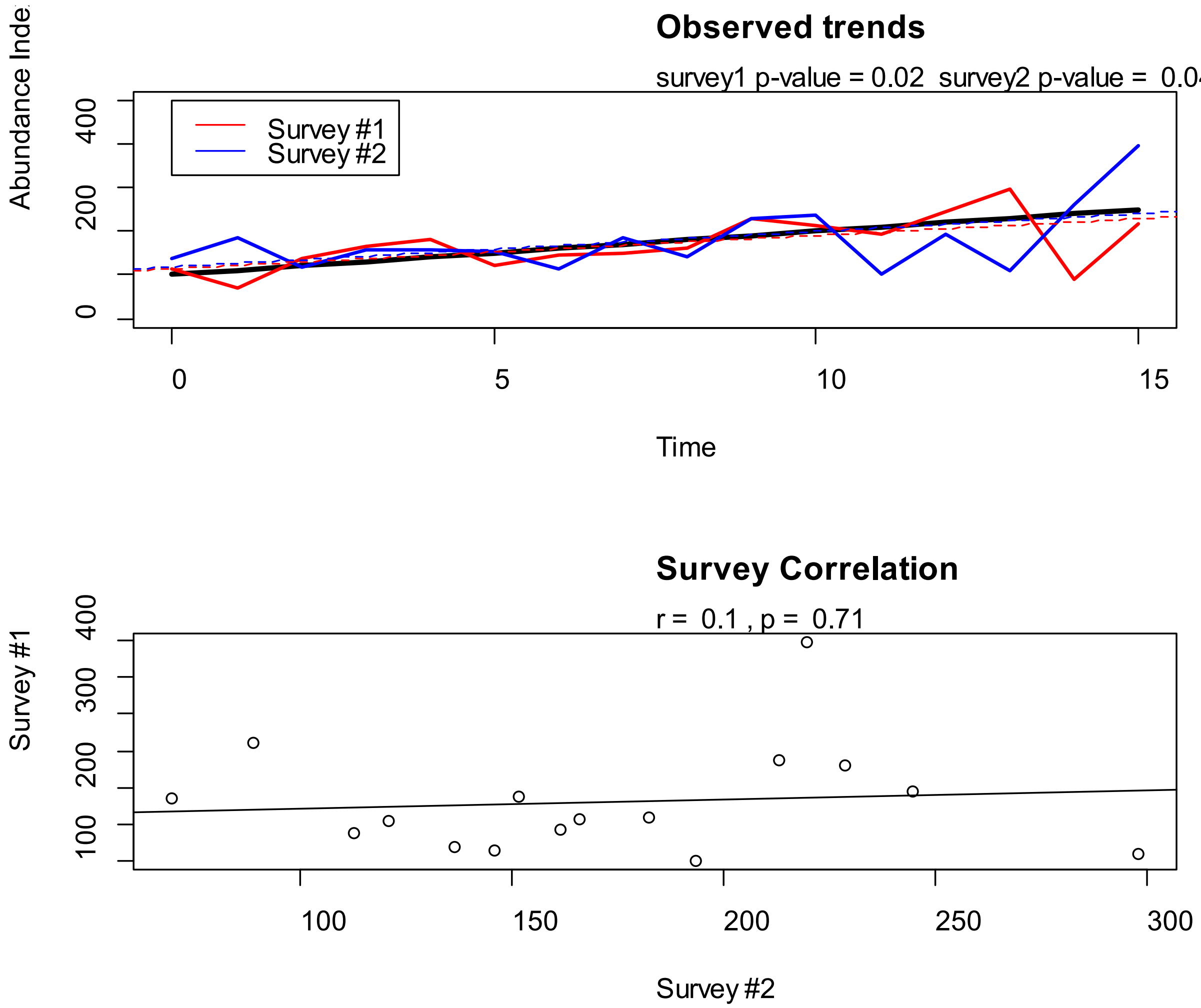

Figure 2. An example of simulated data to show that two surveys can both show an increasing trend but to be statistically uncorrelated with each other. The top graph shows the true change in hypothetical abundance (black line) and two randomly generated independent surveys of abundance each with a CV = 0.3. Dashed red and blue lines indicate linear regression lines for the two surveys. Both of these randomly generated surveys show statistically significantly increasing trends (p-values < 0.05), yet the correlation between the two is low (r = 0.10) and non-significant (p = 0.71).

Dr. Shoemaker also conducted his own capture-recapture analysis to determine the relationship between trawl-based indices of horseshoe crab abundance, horseshoe crab egg density, and red knot survival. Contrary to the results of the ARM Subcommittee, Dr. Shoemaker did not find any positive relationships between horseshoe crab abundance and red knot survival. Although additional analysis of these data is welcome, the ARM Subcommittee questions the value of such a comparison due to the many differences in how the data were analyzed. Dr. Shoemaker's analysis only used information about whether a bird was seen at least once in a year in a standalone Cormack-Jolly-Seber model, whereas the ARM Revision uses both within-year and among-year observations in an open robust design model that is embedded within an integrated population model. These differences in modeling approaches make it difficult to draw meaningful conclusions regarding differences in results. The analysis done by the ARM Subcommittee did find a positive relationship between horseshoe crab abundance and red knot survival, providing the demographic link between population models used in the ARM Framework.

Criticism 3: Red knot survival is strongly sensitive to horseshoe crab egg density, indicating that persistent degradation of the horseshoe crab egg resource could have dire consequences for the red knot population.

- During the development of the ARM Revision, horseshoe crab egg density data were requested, but were not provided to the modeling team. Therefore, these data could not be considered as an input to the models.
- Trends in horseshoe crab egg density (extracted from Smith et al. 2022 following the publication of the ARM Revision) are correlated with other data inputs for the years included in the ARM models and thus the inclusion of egg density data in the models is unlikely to result in any meaningful difference from the current ARM Framework in terms of harvest recommendations.
- Smith et al. (2022) showed a general increasing trend in horseshoe crab egg density in recent years similar to that of horseshoe crab abundance, consistent with findings from the ARM Revision.

Technical Response: The debate over the inclusion or exclusion of egg density data has been ongoing since the ARM Framework was initiated in 2007. The ARM Subcommittee does not deny that eggs are the true link between horseshoe crabs and red knots. However, the reasons for excluding egg density data from the ARM model, which range from sampling design to data availability, have been extensively discussed since the inception of the original ARM Framework, in both published versions of the ARM Framework (ASMFC 2009a, 2022) and in response to a minority report on the ARM Revision (ASMFC 2022). Ultimately, egg density data could not be considered in the ARM Revision because they were not provided to the ARM Subcommittee when requested. When egg density data were published (Smith et al. 2022), the trends appeared to be increasing during the years modeled, consistent with trends of the trawl-based indices used in the model.

Egg density data are highly variable, both spatially and temporally within a spawning season, and discrepancies in egg density results have been noted depending on who processed samples and how they were processed. To incorporate egg density data into the ARM would require development of two linked models, in which the relationship between horseshoe crab abundance and observed egg density is quantified in one, and the relationship between egg density and red knot survival/recruitment is quantified in the other. Such analysis and data exploration were not conducted during the ARM Revision primarily because the egg density data were not provided. The ARM Subcommittee is not opposed to using the egg density data as another index of horseshoe crab abundance once a reliably quantifiable relationship can be established. However, the first time the ARM Subcommittee saw the recent egg density results was in 2021 in the form of a draft manuscript (later published as Smith et al. 2022) as part of a minority report by Dr. Larry Niles. If the owners of the egg density data had been willing to provide the raw data, those data would have been considered in the revision of the ARM Framework. Instead, the ARM Subcommittee accounted for egg availability to shorebirds by including the timing of horseshoe crab spawning in the red knot integrated population model and made a research recommendation to examine the relationship between egg density estimates and horseshoe crab abundance estimates.

In Dr. Shoemaker's report, he finds that surface egg densities are uncorrelated or negatively correlated with the CMSA results and other indices of abundance used in the ARM Framework. In this analysis, he uses data from 1990-2022 although the CMSA and ARM Framework use data beginning in 2003. The CMSA model starts in the early 2000s to coincide with the start of many of required data sets used in the analysis (e.g., Virginia Tech Trawl, biomedical harvest, estimated dead discards from other fisheries). If the correlation analysis is abbreviated to include only the years used in CMSA modeling, all time series are positively correlated (Figure 3) for female horseshoe crabs (Dr. Shoemaker's analysis does not specify if his correlation analysis is for males, females, or both). In fact, the egg density time series from Smith et al. (2022) is positively and significantly correlated with the CMSA estimates of female horseshoe crabs. Therefore, it is likely that if the egg density time series were included in the ARM Framework as another index of horseshoe crab abundance, the CMSA results would not be much different from the current results.

Additionally, Dr. Shoemaker analyzed the egg density data from Smith et al. (2022) and accounted for differences in survey methodology through time. The results of his reanalysis showed no trend in egg density although Smith et al. (2022) showed a general increasing trend in recent years similar to that of horseshoe crab abundance from the CMSA (Figure 4). Dr. Shoemaker also conducted an analysis that shows the effect of egg density on red knot survival. However, this survival analysis is not documented in great detail and only includes data from the New Jersey side of the Delaware Bay. Thus, it is questionable whether this analysis is representative of the red knot population as a whole. If these analyses by Dr. Shoemaker are correct, it still begs the question of how to incorporate this into the ARM Framework. In Dr. Shoemaker's report, red knot survival is positively correlated with egg density but egg density has not changed over time; however, female horseshoe crab abundance has increased. Therefore, while egg density and female horseshoe crab abundance must ultimately be linked, this relationship is not evident in the data. The lack of an empirical relationship ultimately complicates any effort to quantify a model linking horseshoe crab abundance to red knot survival through egg density. Dr. Shoemaker falls short of proposing a way to do this. Regardless, for the time series of the CMSA model, egg density is positively correlated with the other time series of horseshoe crab abundance used. Because egg density data are not readily available to the ARM Subcommittee (either for the model development in 2021 or possibly on an annual basis that would be required for their inclusion), the data only cover New Jersey beaches, and their use and sampling design have been questioned over the years, the trawl surveys remain the best available data for horseshoe crab abundance in the ARM Framework.

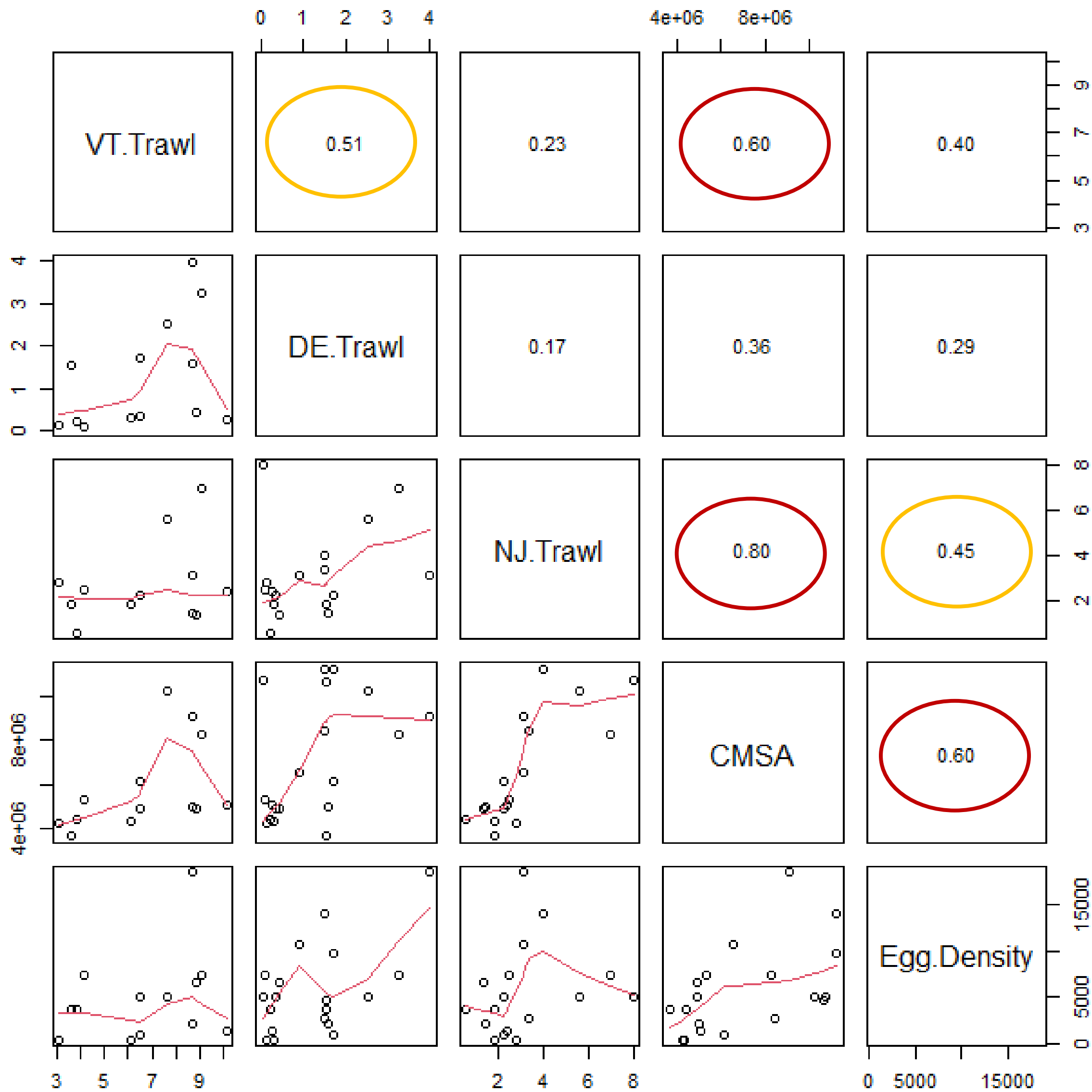

Figure 3. Scatterplot matrices (lower diagonals) and spearman correlation tests (upper diagonals) for female horseshoe crab abundance indices derived from the CMSA model (used as an estimate of horseshoe crab abundance in the ARM Framework), three trawl-based surveys conducted in the Delaware Bay area from 2003 to 2021 (female indices), and New Jersey surface egg densities from Smith et al. (2022). All time series are positively correlated and those correlation coefficients circled in red are significantly correlated at the P<0.05 level. Correlation coefficients circled in yellow are significant at the P<0.10 level.

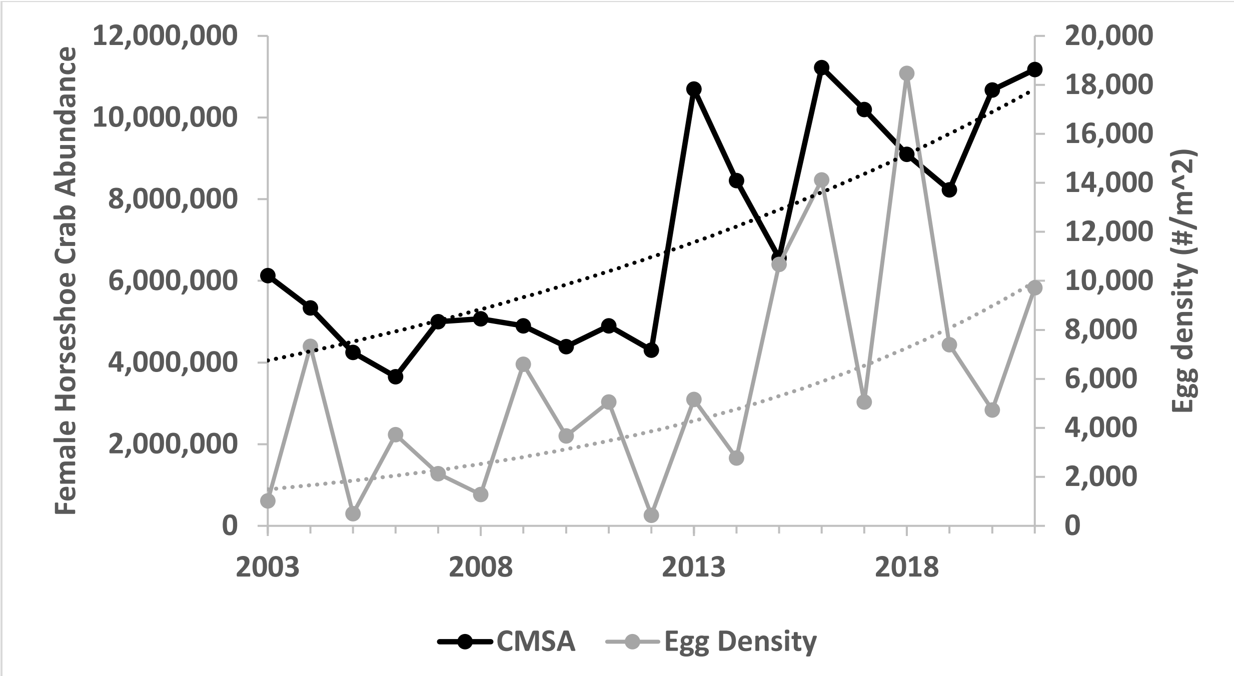

Figure 4. Increasing trends of female horseshoe crab abundance from the catch survey model and egg density time series, 2003-2021. Egg density data were digitized from Figure 2 in Smith et al. (2022).

Criticism 4: The ARM exaggerates the evidence for an increasing trend in the number of female horseshoe crabs in the Delaware Bay.

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

Technical Response: Dr. Shoemaker suggests the ARM Subcommittee exaggerates the evidence for an increasing trend in horseshoe crab abundance through time. A long time to maturity for horseshoe crabs (9-10 years) suggests that recovery from overfishing would take some time to become evident in fishery-independent surveys. With reductions in harvest in the Delaware Bay region in the early 2000s, it makes sense that any increase in abundance would not be seen until approximately 10 years later (~2010). This is what was observed in the three trawl surveys used to index abundance. When a simple linear regression model is fit to each one of the trawl surveys beginning in 2010, all of them show statistically significant increasing trends (Figure 5). Dr. Shoemaker argues that "…trawl-based indices of horseshoe crab abundance are a noisy and unreliable indicator of annual fluctuations in the horseshoe crab population, and are likely an inadequate metric for quantifying the biotic interactions between red knots and horseshoe crabs in the Delaware Bay." The ARM Subcommittee emphatically disagrees with this statement given the life history of horseshoe crabs, the amount of time since bait harvest has been curtailed, and the agreement of the three trawl surveys for an increasing trend in abundance. Harvest management appears to have worked to increase abundance. A rebuttal to this point is also given in Criticism 2.

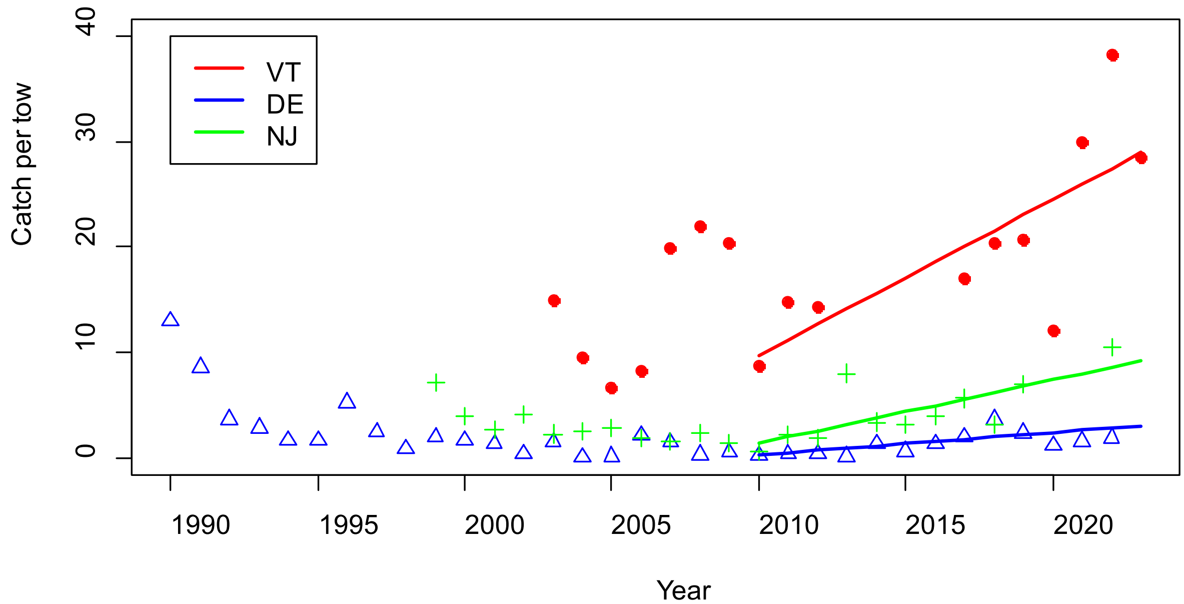

Figure 5. Time series of catch-per-tow of female horseshoe crabs from the three trawl surveys used to index abundance. Simple linear regression models for each survey since 2010 all show statistically significant ($p < 0.05$) increasing trends in abundance.

Dr. Shoemaker again faults the indices of abundance used by the ARM Subcommittee for not being standardized according to environmental covariates in a GLM approach, and he specifically demonstrates his standardization on the New Jersey Ocean Trawl data. However, during an initial review of his report by New Jersey and Delaware staff, it was recognized that he subset the data incorrectly, using the wrong time periods including sample periods when the crabs are not fully available to the survey, resulting in data and an index of abundance that are not used the by ARM Subcommittee. Dr. Shoemaker included the January samples, when the overwintering crabs may remain farther offshore than the survey's sample area, accounting for the significantly decreased catches during this period. He also included the June samples, when most of the adult crabs have migrated into bays and estuaries to spawn, again making them unavailable to the survey. The inclusion of these two sampling periods has an inappropriately dampening effect on the resulting indices which cannot be corrected through a GLM standardization and will not provide an accurate index of relative abundance. Again, a GLM standardization was attempted with the New Jersey Ocean Trawl data during the 2019 benchmark stock assessment (ASMFC 2019), but it was found to not provide any improvement over a simple delta-mean index. Standardization of the trawl survey catches by a GLM or GAM is still something worth exploring in future assessments as additional years of data may provide the necessary information to better evaluate the true effects of covariates on catches.

Beyond the issue of the erroneous data standardization of the New Jersey Ocean Trawl Survey data by Dr. Shoemaker, he made a questionable analytical choice leading to the conclusion that female horseshoe crab abundance has not increased. Dr. Shoemaker used both the "raw" and "adjusted" catch-per-tow data from the entire time series of the three trawl surveys in a linear regression analysis to determine if there was a trend in abundance through time (Figure 6). The Delaware Bay crab population is known to have declined to a minimum level by the early 2000s (prompting harvest restrictions), thus, a linear model fit through the entire time series (1990 to present) of all surveys is nonsensical. The near zero slope of the linear model is driven by the high CPUE from the Delaware Trawl Survey at the very beginning of the time series (1990 – 1992). That horseshoe crabs declined in the 1990s and early 2000s is undisputed. All surveys show a low point around 2010, with an increase afterwards. The pattern of the combined surveys looks like a "U" – decreasing and then increasing. A linear model fit to such a pattern will show a non-significant slope (i.e., trend) over the entire time period. It is unclear whether Dr. Shoemaker investigated the resulting residual pattern, as that would have confirmed the inappropriateness of using a simple linear trend model. Perhaps this analysis is indicative of Dr. Shoemaker's unfamiliarity with the changes in horseshoe crab harvest management through time, but it nevertheless perpetuates the unfounded belief that the horseshoe crab population has not responded positively to harvest restrictions. As previously stated in the rebuttal to Criticism 2, all surveys have shown an increasing trend since 2010 (Figure 5). Alternatively, a segmented regression model could be fit to the time series of data to demonstrate how abundance trends have changed through time. When this is done, both the Delaware and New Jersey Ocean Trawl Surveys show declining abundance followed by an increase after 2010 (Figure 7). Given the lengthy time to maturity of horseshoe crab, it has long been understood that it would take about a decade to begin seeing an increase in abundance following the initiation of harvest restrictions.

Shorebird stakeholders' views of the trawl surveys have evolved through time. In a 2009 publication questioning if harvest restrictions have worked to increase horseshoe crab abundance in the Delaware Bay region, Niles et al. (2009) included a graph of the Delaware Trawl Survey showing a declining trend in catch-per-effort as evidence that horseshoe crab abundance has declined. In Earthjustice's September 2022 comments to the Board, they argue that the "…original decision to rely exclusively on the Virginia Tech Trawl Survey reflected explicit stakeholder input," and that other trawl surveys are "not purpose-designed" and "disfavored" by stakeholders. Finally, in 2023, according to Dr. Shoemaker, "trawl-based indices of horseshoe crab abundance are a noisy and unreliable indicator of annual fluctuations in the horseshoe crab population…". If the view that the trawl surveys only capture random noise is accepted, and thus the increasing trend in the surveys since 2010 cannot be trusted, one should also question if the horseshoe crab population actually ever declined.

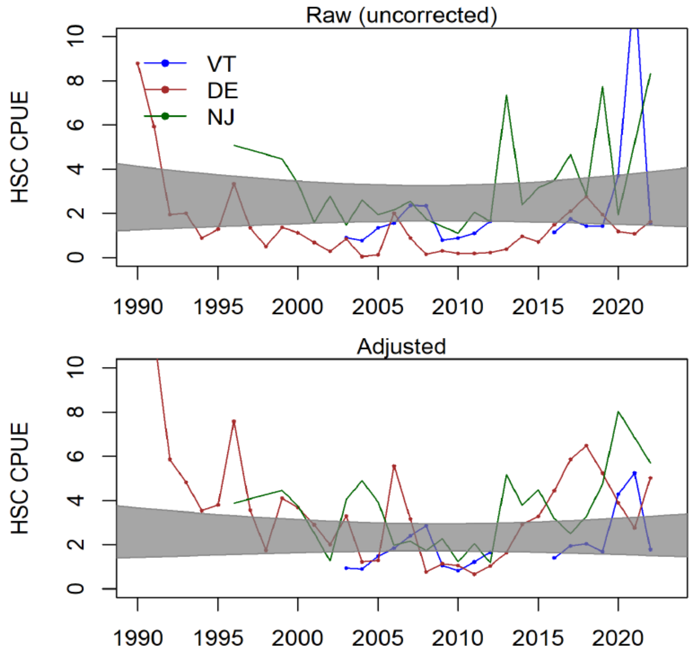

Figure 6. This graphic is taken from the 2023 Dr. Shoemaker report (Figure 12). The intent was to show there is no significant trend in female horseshoe crab abundance through time for the combined trawl surveys using a linear regression model over the entire time series (1990 – 2022). The reason for the lack of a significant trend, either increasing or decreasing (gray shaded area) is because the time series exhibits a "U" shaped pattern – decreasing until around 2010, and increasing afterwards.

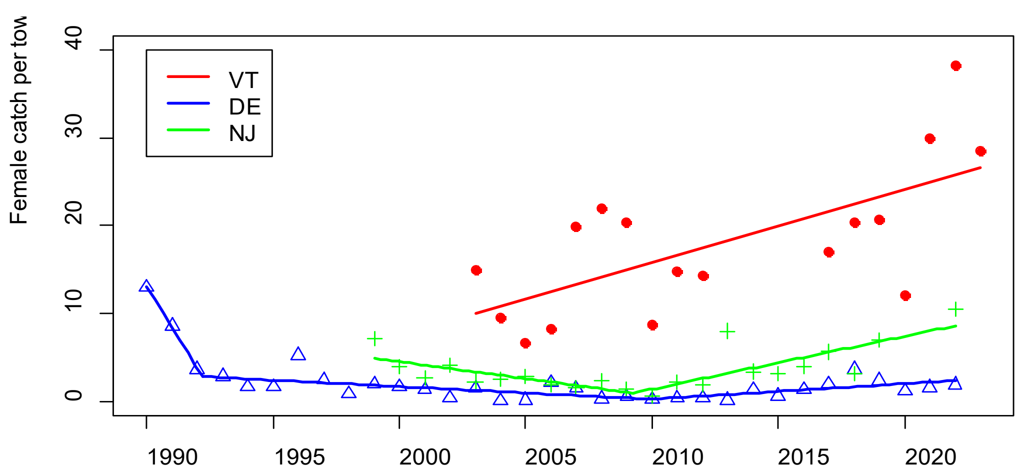

Figure 7. Trends in female horseshoe crab catch-per-tow from the three trawl surveys in the Delaware Bay region. Lines for the Delaware and New Jersey Trawls represent segmented regression models fit to those data. The results of the segmented regression analysis show that the slope of the trend for both the Delaware and New Jersey Trawls changed from being negative to being positive around 2010. The trend line for the Virginia Tech Trawl Survey is simply a linear model over the entire time series because the Virginia Tech Trawl Survey did not extend back in time as far as the other surveys.

Dr. Shoemaker also reanalyzed egg density data from New Jersey to further argue that horseshoe crab abundance has not increased. These data were published by Smith et al. (2022) and showed a variable but increasing trend in egg densities over the last two decades (Figure 4). However, upon reanalysis, Dr. Shoemaker contradicts Smith et al.'s (2022) conclusion for an increasing trend, suggesting that it was an artifact of differing sampling methodologies through time. There is not much the ARM Subcommittee can say concerning trends in egg density data beyond what is published by Smith et al. (2022) because those data were not supplied to the ARM Subcommittee when requested during the ARM Revision. The acknowledgement by Dr. Shoemaker of the changing methodology in egg density data does corroborate one of the reasons the ARM Subcommittee has been reluctant to make use of egg density data since the development of the original ARM Framework in 2007. If the owners of the egg density data would follow the established ASMFC data acquisition processes by sharing the data when requested at the beginning of a stock assessment, the ARM Subcommittee would certainly evaluate the utility and inclusion of such data in the ARM modeling process just like any other data source.

Criticism 5: The integrated population model used for estimating red knot population parameters is overparameterized and likely to yield spurious results.

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

<u>Technical Response:</u> The critique of the state-space model ignores the fact that this model is not analyzed independently, but as a sub-model within an integrated analysis. This viewpoint is apparent in several places in Dr. Shoemaker's critique, as he writes about using the two data sources (i.e., red knot count data and mark-recapture data) to "train" the two sub-model components as if they were separate endeavors where information from one has no influence on the model parameters in the other. Integrated population models combine the likelihoods of two or more sub-models, allowing researchers to estimate demographic parameters from multiple models and data sources simultaneously (Schaub and Abadi 2011). In the ARM Framework, the admittedly limited count data are integrated with 100,000s of mark resight observations from Delaware Bay. A third component, a Markov population model, provides a strong structural prior that links estimates from multiple sub-models based on an understanding of the life history of the species. One key benefit of this approach is the ability to estimate parameters that would not be estimable with any one model or data source alone. In the case of the ARM Framework, the estimation of the red knot recruitment rate is informed by both the analysis of the count data (state-space sub-model) and the mark-recapture data (open robust design sub-model).

By ignoring the structural linkage that shares information between model sub-components, Dr. Shoemaker set up a misleading basis to make unsubstantiated claims about model overparameterization and to falsely demonstrate spurious results produced by the ARM model. Regarding overparameterization, he referred to the familiar rule-of-thumb of 30 data points per model parameter as sample size guidance for robust estimation. While this guidance is useful in traditional applications where data are used to inform the parameters of a single model, its relevance for integrated modeling – where information is shared across multiple model components – is unclear. His assessment that 18-28 parameters were estimated from 14 data points is a serious mischaracterization of the model and requires overlooking the fact that information from mark-resight data also informs the state-space model. In the ARM Framework, the number of parameters estimated from the count data alone is three: one initial population size and two counting errors. The recruitment parameters (three parameters: mean, variance, and effect of horseshoe crab abundance) are estimated jointly using information from all three components of the integrated population model. The availability parameters are specified with highly informative priors, which were developed externally to the model. In the ARM Subcommittee's view, the availability parameters should be more appropriately thought of as data informing the model, not estimates on which inference was based.

Dr. Shoemaker used a simulation exercise to purportedly demonstrate production of spurious results by the model. By replacing the peak counts with white noise in the simulation runs, he anticipated that the simulated abundance at the end of the time series should match the initial abundance on average. Instead, he was surprised to discover negative trends in simulated abundance and that final abundances produced by the model were most often lower than initial abundance. He did not know the cause of this outcome, and he speculated on a variety of reasons having to do with simulation methods, starting values, etc. The cause is simple to explain, but it requires acknowledgement that the information sources are linked to each other through the Markov population model. By providing a stream of pattern-less peak count data to the model, Dr. Shoemaker effectively contaminated information about recruitment, leaving survival rate as the only reliably informed parameter. Therefore, a population simulated with no recruitment and survival probability <1 will most often decline. Though he failed to understand the cause of the observed simulation behavior, and he cautioned against using his results to infer a systemic bias in the model, he nevertheless concluded that the model is unstable and has a strong tendency to produce spurious results.

The critique of the state-space sub-model also contains an assertion that overparameterized models are necessarily biased. While overparameterization can result in poor generalization to new datasets, it does not guarantee biased results. In fact, bias could also arise if models are under-parameterized and fail to capture system complexity. The relationship between bias and overparameterization is not as straightforward as is portrayed in Dr. Shoemaker's report.

The ARM Subcommittee readily acknowledges that the red knot count data are a much weaker data set than the mark-recapture data, but they were the only count data collected consistently over the all of the years of the monitoring program, so the ARM Subcommittee made the best use of them to better understand the system. As described in ASMFC 2022 (page 80), this model could be greatly improved by including auxiliary information such as survey-specific covariates (e.g., observer ID, tide state, weather conditions), integration of simultaneous ground count data, or future implementation of digital photography or double-observer methods. One of the challenges of working with historical monitoring data is the inability to influence study design or data collection processes. There were no auxiliary data that were consistently collected (or, at least, made available to the ARM Subcommittee) for aerial surveys that would allow counting error to be better estimated. Similarly, the ARM Subcommittee knows that concurrent ground counts were conducted in at least some years, but those data were not provided. The ARM Subcommittee made the best use of the available data, and conducted these analyses within the management decision context. Sometimes in decision support roles, scientists have to develop the best analysis to support decisions even when data are imperfect (McGowan et al. 2020). All modeling exercises require assumptions and constraints, and those included in this model represent the best understanding of the system at this time; the ARM Subcommittee hopes and intends for this model to be updated as more information and more data become available. It should be noted that all previous attempts to model red knot populations in this system and assess the linkages between knots and horseshoe crabs in this management context required significant assumptions, and the ARM Subcommittee believes that their approach in the ARM Revision alleviates or improves many of those assumptions. Previously, all attempts to model productivity and recruitment in this population relied upon estimates from Europe and basic assumptions about life history (i.e., setting juvenile survival as a percentage of adult survival, see McGowan et al. 2011) and this approach uses data from this flyway in a complex but much improved model to estimate those parameters.

Criticism 6: The integrated population model exhibits poor fit to the available data.

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

Technical Response: There are no unified goodness of fit tests for integrated population models, so the commonly-accepted approach is to assess model fit independently for each sub-model. Posterior predictive checks (PPCs) are the standard type of goodness of fit tests for Bayesian models. The PPC for the state space model indicated adequate fit (P = 0.44 where P = 0.5 indicates no evidence of either over- or under-dispersion, and P near 0 or 1 suggests poor model fit), but the PPC for some components of the open robust design model indicated lack of fit to the data.

This critique contains shaky logic. First, Dr. Shoemaker asserts that PPCs are a good method for checking model fit and criticizes the lack of fit of the open robust design model. Indeed, Dr. Shoemaker used a PPC in his analysis of banding data to conclude that his model had “reasonable fit.” Next, he states that PPCs are not a reliable indicator of goodness of fit to cast doubt on the ARM Subcommittee’s statement that the state space model “passed” the test. By Dr. Shoemaker’s logic, PPCs are only to be trusted when they indicate lack of fit. Dr. Shoemaker’s inconsistent logic with respect to checking goodness of fit casts doubt on the integrity of the analysis. Putting that aside, the apparent lack of fit for the open robust design model will be discussed. The open robust design model consists of three likelihoods, and PPCs indicated lack of fit for likelihood L3 (P = 0.9), which describes the process of reencountering individuals within years. This lack of fit could arise due to unmodeled heterogeneity in true arrival and persistence probabilities as a result of pooling encounters into three-day sampling periods. If aggregations occur over a time period that is short relative to the expected length of stay, the expected bias is minimal (Lindberg and Rexstad 2002; O'Brien et al. 2005). Average stopover duration for red knot at this site has been estimated to be 12 days (Gillings et al. 2009); 3 days should be a short enough window to avoid biased estimates of arrival and persistence but could introduce heterogeneity and overdispersion. The likelihood that contains the apparent annual survival probability is likelihood L1, which describes the process of encountering marked birds across years. PPCs for this likelihood did not indicate lack of fit (P = 0.31).

CONCLUSIONS

Continuous scientific review and critique is welcome as that is how science advances. There will always be room for improvement in any modeling effort in the management of natural resources. This is part of the double-loop learning in an adaptive management effort whereby model design and management are periodically reevaluated (Fabricius and Cundill 2014; Williams and Brown 2018). In this specific case, however, advocacy is infused into the scientific debate. The 2022 ARM Revision represented some great advancements in the understanding of the population dynamics of horseshoe crabs and red knots, and their interactions during the double-loop of the adaptive management process. It is curious that these advancements have stirred so much controversy because the technical criticisms of the ARM Revision could have equally applied to the original ARM Framework. In fact, the original framework merited specific criticism because it relied on life history parameters informed by literature values taken from outside the Delaware Bay or based on expert opinion. The ARM Subcommittee questions if the true problem is not with the process or technical modeling, but rather with the final result and harvest recommendation.

An important benefit of the adaptive management process is the ability to make decisions even under imperfect knowledge of an ecological system (Williams et al. 2002). The overall goal of the ARM Framework was to produce a decision tool informed by science and stakeholder values, given the available knowledge about the Delaware Bay ecosystem and horseshoe and red knot population dynamics. In the original ARM Framework, knowledge about some system components, for instance red knot population dynamics, was quite limited. The ARM Revision represented a double-loop learning event, in adaptive management terms, and population models were re-designed to accommodate 1) the large volumes of high-quality data collected on both species since the original ARM's inception, and 2) changes to both populations over that period. In the view of the ARM Subcommittee, the effect of a change to an ecological model must be judged according to its effect on both the properties of the overall decision framework, and the ability of the ARM Framework to incorporate new monitoring data to improve understanding of the system. One important goal in the development of the ARM Revision was to design population models for horseshoe and red knot that would allow for rapid and efficient learning given the monitoring efforts in place for each species (Williams 2011). This critical feature of the ARM Framework—the ability to learn from monitoring—is not addressed by Dr. Shoemaker or Earthjustice; and yet it was a major consideration by the ARM Subcommittee. The design of ecological models for use with adaptive management should also be guided by the decision objectives (Fuller et. al. 2020), a point not addressed by Earthjustice.

Much of the 2022 and 2023 criticism by Dr. Shoemaker (as well as the comments by Earthjustice) stem from the belief that there must be a strong relationship between horseshoe crab abundance, horseshoe crab egg density on the beaches, and red knot survival. They claim that because the ARM Subcommittee did not find this "strong" relationship when examining the empirical data from the Delaware Bay region, the ARM Revision must therefore be fraught with error. It is apparent that Dr. Shoemaker reviewed the ARM Subcommittee's work with an unwillingness to entertain the idea of anything but a "strong" relationship. A specific example of this is his statement in his 2022 report where he postulated that the collection of additional data may show that the relationship between horseshoe crab abundance and red knots survival could disappear or become negative. He states, "This outcome would pose an existential problem for the ARM Framework, decoupling the two-species Framework and rendering the red knot model unusable in the context of management." Of course, the "no relationship" outcome would be expected if horseshoe crabs become sufficiently abundant to not limit red knot survival, but that knowledge does not challenge the scientific validity and usefulness of an adaptive management framework for decision making. Such comments demonstrate a reluctance to learn within an adaptive management framework and a desire to cling to previous beliefs in spite of scientific advances.

There is no doubt that Dr. Shoemaker is a very knowledgeable quantitative ecologist. However, his critiques are unhelpful in advancing a two-species adaptive management effort. His criticisms focus on specific components of the overall ARM Framework, and why each may be wrong, but nowhere does he provide any recommendations for how to assemble the pieces into a unifying framework to make management decisions. For example, he makes strong arguments for using egg density to predict red knot survival but provides no recommendations for how to link egg density to female horseshoe crab abundance, which is directly affected by harvest management. He also makes a large issue about uncertainty in the horseshoe crab population projections but fails to recognize how uncertainty is handled in the optimization (approximate dynamic programming) or make any recommendations on alternative methods to conduct an optimization given the uncertainty.

The ARM Framework is designed to continuously improve the underlying models through double-loop learning, and the ARM Subcommittee welcomes constructive input on how to do so. Unfortunately, the critiques by Dr. Shoemaker (and Earthjustice) fail to make any real recommendations for improvement or provide any other means for helping managers make an informed harvest decision beyond consideration of the values of a single stakeholder group. If the values of all stakeholders have changed (i.e., no female harvest under any circumstances), that change could be considered in a new approach in the future by the ARM Subcommittee. As it stands, the current ARM Framework represents the values previously established through stakeholder engagement: to manage harvest of horseshoe crabs in the Delaware Bay to maximize harvest but also to maintain ecosystem integrity, provide adequate stopover habitat for migrating shorebirds, and ensure that the abundance of horseshoe crabs is not limiting the red knot stopover population or slowing recovery.

SUPPLEMENTAL RESPONSES TO THE 2022 EXTERNAL PEER REVIEWS

The Management Board specifically tasked the ARM Subcommittee with responding to the 2023 critique by Dr. Shoemaker, and the responses above fulfill that task. However, the ARM Subcommittee felt it appropriate to address a few additional items presented in the 2022 public comment by Earthjustice that included critiques by Dr. Shoemaker and Dr. Romuald Lipcius, as well as the supplemental section to the 2023 critique by Dr. Shoemaker. These items are not in any particular order.

Criticism 7: The estimate of mean horseshoe crab recruitment and propagation of error within the horseshoe crab population dynamics model is inappropriate.

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

Technical Response: The revised ARM Framework uses the same mathematical model to estimate the abundance of horseshoe crabs (the CMSA) and to project the horseshoe crab population into the future while accounting for annual removals of individuals due to bait harvest, dead discards from other fisheries, and mortality associated with biomedical facilities. In his 2022 critique, Dr. Shoemaker expresses his opinion that uncertainty in model parameters was not propagated through time in an appropriate manner. This criticism does have some merit and his proposed methodology is worth the ARM Subcommittee considering in future revisions of the ARM Framework. Dr. Shoemaker contends the current horseshoe crab projection model greatly underestimates uncertainty and its effects on predicted future abundance. Although Dr. Shoemaker's proposed methodology may be more appropriate, the ARM Subcommittee believes these concerns are overstated as there is still much uncertainty in the projected population – female horseshoe crab abundance can range between 5 – 15 million under a no harvest scenario.

Another parameter Dr. Shoemaker criticized was the estimate of mean horseshoe crab recruitment because of the gap in the Virginia Tech data from 2013 - 2016. The ARM Subcommittee agrees that CMSA estimates of recruitment during these years are poor; therefore, the average of them was used when calculating the overall mean recruitment level. One could argue that recruitment estimates during the Virginia Tech gap years should simply be thrown out. However, doing so ignores the obvious above-average recruitment during those years that must have occurred to increase the multiparous population to the degree that was observed in the following years. The treatment of the missing years of recruitment data balanced the nonsensical estimates of the CMSA with the biological reality that recruitment during these years had to have been relatively high. All other things being equal, changing the mean female horseshoe crab recruitment from 1.67 to 1.26 million, as suggested by Dr.

Shoemaker, would result in an unexploited population size at equilibrium of 6.4 million (95% CI: 3.4 – 14.5 million) compared to 8.5 million (95% CI: 4.5 – 19.2 million) in the current parameterization of mean recruitment. If Dr. Shoemaker were correct in his estimate of mean recruitment, the latest population estimates from the Virginia Tech Trawl Survey swept area estimate and CMSA are well above this equilibrium level and the population will likely decline even in the absence of any harvest. It is also interesting to note that Smith et al. (2006) estimated the female population size via a mark-recapture study at 6.25 million in 2003, shortly after the period of high horseshoe crab harvest. This is another line of evidence that the mean recruitment parameter used in the ARM Framework (1.67 million) is more appropriate than the one proposed by Dr. Shoemaker (1.26 million) given the observed increases in female abundance since the population was estimated by Smith et al. (2006).

Dr. Shoemaker shows his female horseshoe crab population projection from his reformulated Bayesian CMSA model that includes his parameterization for recruitment and method for propagating uncertainty. It is interesting that given all his criticism of the ARM model, his model produces nearly identical results with respect to an equilibrium number of primiparous and multiparous females (Figure 8) and associated uncertainty. If anything, his equilibrium population size may be slightly higher than what the revised ARM Framework predicts and the uncertainty on each seems equivalent.

Dr. Shoemaker did not comment on the harvest policy functions, which are the mathematical equations that actually tell the ARM Subcommittee how many horseshoe crabs to harvest given the abundance of horseshoe crabs and red knots. He also did not comment on the Approximate Dynamic Programming (ADP) process by which the harvest policy functions were derived. When solving for the optimal harvest policy functions, ADP incorporated the full range of uncertainty in population projections for both horseshoe crabs and red knots, and within the ADP process, the optimal harvest policy functions would be more conservative with greater uncertainty. Thus, any recommendation of harvest coming from the revised ARM Framework explicitly incorporates uncertainty in population projections.

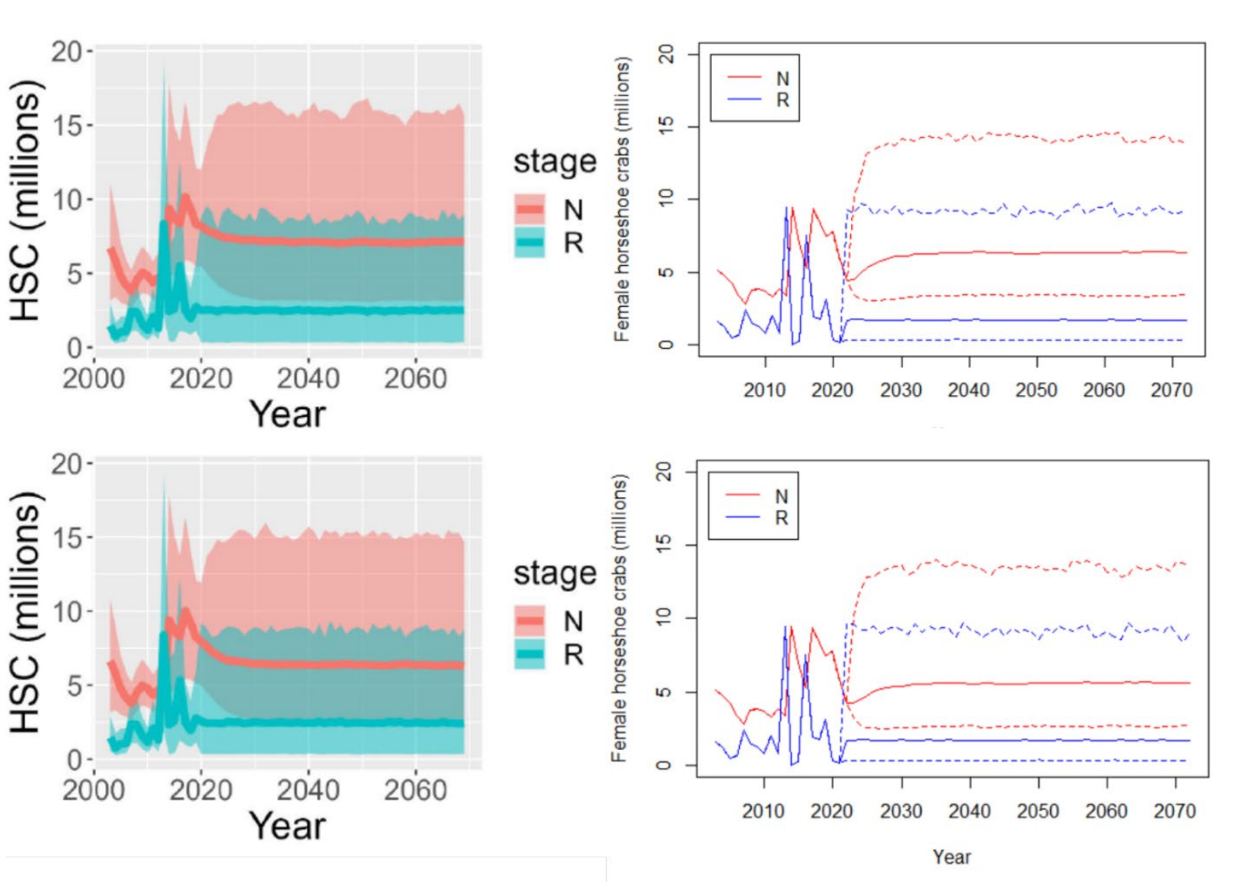

Figure 8. Comparison of the projection model of female horseshoe crabs by Dr. Shoemaker in Earthjustice's September 2022 comments (left graphs) with that from the revised ARM Framework (right graphs). The early part of the projected time series (2021 and prior) represent population estimates from the CMSA – both the version in the revised ARM Framework and Dr. Shoemaker's Bayesian version in Earthjustice's September 2022 comments.

Criticism 8: That the ARM model would not predict a decline in red knots under a total collapse of the horseshoe crab population is evidence that the model is fatally flawed.

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

<u>Technical Response:</u> In his 2022 critique, Dr. Shoemaker states, "…the apparent inability of the ARM model to predict a decline in red knot abundance under a total horseshoe crab population collapse…undermines the apparent purpose of the model." This judgment can be seen echoed throughout the materials submitted by Earthjustice in 2022 and 2023, where the narrative is peppered with claims of predicted red knot population increases even at complete depletion of horseshoe crabs from Delaware Bay. The critics' implication is this: if the model is unreliable at

the population level of zero horseshoe crabs, how can it be trusted for harvest management at any population level of crab? This is an unfortunate and prejudicial coloring of the model because Dr. Shoemaker was wrong in his 2022 judgment. He not only failed to correct the false assertion in his analysis, but he also amplified it (p. 22) in his later critique.

In Dr. Shoemaker's 2022 critique, he acknowledged that he relied on a "back of the envelope" calculation to arrive at his conclusion because he lacked access to the model data and code at the time. Were he to obtain access to the materials, he fairly asked, "[w]hat would happen to the red knot population projections if female horseshoe crab abundance were set to zero?" For his 2023 evaluation, Dr. Shoemaker was provided access to the data and code, yet he failed to address his own question. He would have observed that the data used to establish the relationship between female horseshoe crab abundance and red knot survival was the logarithm of female horseshoe crab abundance (ASMFC 2022) and not female abundance as it comes straight from the CMSA estimates. Consequently, the model predicts that red knot survival declines to 0 as female horseshoe crab abundance decreases, and a population increase in red knots under this condition is mathematically impossible.

Misunderstanding and mischaracterization of the model aside, prediction by any model for a scenario well outside of the data bounds of model development is a dangerous exercise. A complete loss of horseshoe crabs through harvest is an extreme and unlikely hypothetical scenario that was not considered by the ARM Subcommittee. Such a collapse would require a harvest level greatly exceeding any previously observed harvest level, let alone any harvest level that is within the range of possible values given the current fishery management plan stipulations. The critics should give the ARM Subcommittee and Board some benefit of the doubt: if the horseshoe crab population should fall below any historically observed levels, and outside the bounds of model development, the ARM Subcommittee is sure all would agree that horseshoe crab harvest should be drastically reduced or ceased. This demonstrates an attempt to sensationalize an extremely rare possibility and paint scientific management of the species as reckless.

Criticism 9: Demographic data indicate a declining horseshoe crab population.

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

<u>Technical Response:</u> In 2022, Dr. Lipcius argues demographic data are inconsistent with an increase in the horseshoe crab population such as the apparent decline in mean size of individual horseshoe crabs. It is true that mean size has decreased and the ARM Subcommittee agrees that in a typical finfish fishery a declining trend in mean size-at-age is indicative of overfishing (i.e., faster growing fish recruit to the fishing gear at younger ages and a fishery

then selects against fast growing fish). However, horseshoe crabs are not finfish, they have a terminal molt, and stop growing after maturity is reached. One cannot apply the general rule-of-thumb that average size deceases with excessive exploitation to a species like horseshoe crabs, which stop growing once mature and are targeted by a commercial fishery at the mature stage. Fishing pressure for males, and especially females, greatly declined since the 1990s, yet it appears from the Virginia Tech Trawl Survey data on prosomal widths that the decrease in size occurred after 2008 (Wong et al. 2023), and after the fishery was curtailed in the mid-2000s. Alternative hypotheses for the reduction in size is density-dependent growth as the population rebuilt, or an ecosystem wide loss of productivity over the last 20 years resulting in fewer resources available for horseshoe crab growth. The ARM Subcommittee agrees that additional research is needed to explain the declining size of horseshoe crabs, but it is doubtful that it is tied to fishing mortality given how limited the harvest has been relative to the size of the population.

Dr. Lipcius makes an argument that with the decrease in mean size of mature female horseshoe crabs, individual fecundity would also decrease and total reproductive output has not increased. This hypothesis seems unlikely because horseshoe crab abundance would not have increased if natural mortality has not changed and there had there not been an increase in total egg deposition and hatch. Smith et al. (2022) shows a general increase in egg density in recent years, which also refutes this hypothesis.

Dr. Lipcius also argues that the recent low numbers of newly mature (primiparous) females in the Virginia Tech Trawl Survey indicate recent harvest is problematic. Intuitively, one would expect an increase in recruitment following the prohibition of female harvest. However, many factors influence year class strength of horseshoe crabs and there is a 9 to 10-year delay between when new crabs are spawned and when primiparous crabs are assessed. There could be density-dependent effects (nest disturbance by subsequently spawning females) at play, and inter-annual variation in survival over the 9 to 10-year period between the egg and primiparous stage could mask any differences in year class strength. Some very high years of newly mature males also occurred prior to the prohibition of female harvest (Wong et al. 2023). The observed variation in newly mature animals suggests year class strength is influenced by much more than female spawner abundance alone. Also, harvest pressure targets mature individuals and Virginia Tech Trawl Survey data shows a significant increase in mature individuals through time, especially in the last three years. There could not have been an increase in multiparous individuals without a preceding increase in primiparous individuals. Finally, we do not observe the same decline in primiparous males as observed in primiparous females. If harvest pressure caused a decline in female recruitment, as suggested by Dr. Lipcius, why would it not also cause the same decline in male recruitment? The recent years of low primiparous female abundance observations is something the ARM Subcommittee and Delaware Bay Ecosystem Technical Committee are discussing.

Criticism 10: There is an incorrect specification of "pi" parameter in the red knot integrated population model.

- This is a criticism that does warrant further consideration by the ARM Subcommittee.

Technical Response: Dr. Shoemaker asserts that there is a missing parameter that should be included in the derivation of π_{jt} (the probability of being present in Delaware Bay in occasion t of year j) to represent the fraction of the population using Delaware Bay in the previous year. This seems to be a valid criticism, but requires further scrutiny to understand whether this parameter is derived incorrectly and, if so, what the implications might be. The ARM Subcommittee is exploring solutions.

Criticism 11: There is an over-representation of Mispillion Harbor in red knot resighting data.

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

Technical Response: More resighting data is collected in Mispillion Harbor than any other site in Delaware Bay. However, red knots move around the Bay during the stopover period and are often resighted in more than one location within a year. The open robust design sub-model makes use of those repeated observations instead of collapsing all information about each bird into a single 0 or 1, as Dr. Shoemaker did to fit his Cormack-Jolly-Seber model. Given this, it is unclear how Dr. Shoemaker decided that a given bird belonged to the "Mispillion" or "Not Mispillion" group, given that many birds are seen both within and outside of Mispillion Harbor in a given year. The proportion of birds seen only in Mispillion ranges from 0.12 to 0.54 (0). The proportion of birds never seen in Mispillion ranges from 0.17 to 0.69. Given this variation and lack of systematic bias towards birds only being resighted in Mispillion Harbor, we do not believe there is reason to think that the large number of observations from this site result in biased inference.

Table 1. The proportion of individual birds resighted at Mispillion Harbor only, at other sites only, or at both Mispillion and other sites in each year.

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

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