Atlantic States Marine Fisheries Commission

Horseshoe Crab Management Board

October 16, 2023
2:00 – 4:00 p.m.
Hybrid Meeting

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. Clark)*	2:00 p.m.
2. Board Consent • Approval of Agenda • Approval of Proceedings from May 2023	2:00 p.m.
3. Public Comment	2:05 p.m.
4. Consider Results of Stakeholder Survey on Delaware Bay Management Objectives *(C. Starks)* **Possible Action**	2:15 p.m.
5. Set 2024 Delaware Bay Bait Harvest Specifications **Final Action** • Review Horseshoe Crab and Red Knot Abundance Estimates and Model Results from the Adaptive Resource Management Framework *(J. Sweka)* • Set 2024 Specifications *(C. Starks)*	3:15 p.m.
6. Consider Approval of Fishery Management Plan Review and State Compliance for 2022 Fishing Year *(C. Starks)* **Action**	3:45 p.m.
7. Report on Status of Synthetic Endotoxin Testing Reagents *(C. Starks)*	3:50 p.m.
8. Review and Populate Advisory Panel Membership *(T. Berger)* **Action**	3:55 p.m.
9. Other Business/Adjourn	4:00 p.m.

The meeting will be held at Beaufort Hotel (2440 Lennoxville Road, Beaufort, North Carolina; 252.728.3000) and via webinar; click here for details

MEETING OVERVIEW

Horseshoe Crab Management Board Meeting
October 16, 2023
2:00 – 4:00 p.m.
Hybrid Meeting

Chair: John Clark (DE) Assumed Chairmanship: 1/22	Horseshoe Crab Technical Committee Chair: Vacant	
Vice Chair: Justin Davis (CT)	Horseshoe Crab Advisory Panel Chair: Brett Hoffmeister (MA)	Law Enforcement Committee Representative: Nick Couch (DE)
Delaware Bay Ecosystem Technical Committee Chair: Wendy Walsh (FWS)	Adaptive Resource Management Subcommittee Chair: John Sweka (FWS)	Previous Board Meeting: May 3, 2023
Voting Members: MA, RI, CT, NY, NJ, DE, MD, DC, PRFC, VA, NC, SC, GA, FL, NMFS, USFWS (16 votes)		

2. Board Consent

- Approval of Agenda
- Approval of Proceedings from May 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 Results of Stakeholder Survey on Delaware Bay Management Objectives (2:15-3:15 p.m.) Possible Action
Background • In May 2023 the Board formed a work group to develop a survey that will be distributed to stakeholders to guide the Board in evaluating management objectives for the Delaware Bay horseshoe crab bait fishery, and whether to consider future changes to management. • The survey targeted stakeholders from the Delaware Bay region including bait harvesters and dealers, fishermen who use horseshoe crab as bait, biomedical fishery and industry participants, and environmental groups. • The survey was sent to recipients on August 22 and the survey window was closed on September 25. • Survey responses were analyzed and compiled in a report of the results (**Briefing Materials**).
Presentations • Delaware Bay Stakeholder Survey Results by C. Starks

Board actions for consideration at this meeting

- Consider management response to survey results

5. Set 2024 Delaware Bay Harvest Specifications (3:15-3:45) Final Action

Background

- In September 2023, the Delaware Bay Ecosystem TC (DBETC) and Adaptive Resource Management (ARM) Subcommittee met to review results of the horseshoe crab and red knot population abundance surveys in the Delaware Bay region (**Briefing Materials**).
- The ARM model was run using three fishery-independent surveys for horseshoe crabs, various sources of horseshoe crab removals, and the estimated population of red knots to provide a recommendation for harvest specifications for Delaware Bay states in 2024 (**Briefing Materials**).

Presentations

- Horseshoe Crab and Red Knot Abundance Estimates and 2023 ARM Model Results by J. Sweka

Board actions for consideration at this meeting

- Consider ARM harvest recommendations and set 2024 specifications for states in the Delaware Bay region

6. Consider Approval of Fishery Management Plan Review and State Compliance for the 2022 Fishing Year (3:45-3:55 p.m.) Action

Background

- State Compliance Reports were due July 1, 2022.
- The Plan Review Team reviewed each state report and compiled the annual FMP Review (**Briefing Materials**).
- South Carolina, Georgia, and Florida have requested and meet the requirements of *de minimis* status.

Presentations

- FMP Review of the 2022 Fishing Year by C. Starks

Board actions for consideration at this meeting

- Accept FMP Review and State Compliance Reports for the 2022 Fishing Year.
- Approve *de minimis* requests.

7. Report on Status of Synthetic Endotoxin Testing Reagents (3:55-4:00 p.m.)

Background

- In May, The Board requested information on the efficacy of the synthetic alternatives to LAL, the endotoxin testing reagent derived from horseshoe crab blood.
- Recently, an expert committee of the US Pharmacopeia (USP) proposed a new standard, Chapter <86>, that provides additional techniques for bacterial endotoxin testing using non-animal derived reagents. The new chapter includes methods for using several reagents, including recombinant Factor C (rFC) and recombinant cascade reagents (rCR), and provides information for manufacturers of new and existing biopharmaceuticals on how to incorporate them into their quality testing.
- The USP developed a fact sheet to answer frequently asked questions on this topic (**Briefing Materials**).

• The official open comment period on the proposed standard will run from Nov. 1, 2023 through Jan. 31, 2024.
Presentations • Report on Status of Synthetic Endotoxin Testing Reagents by C. Starks

8. Other Business/Adjourn

Horseshoe Crab

Activity level: Medium

Committee Overlap Score: Low

Committee Task List

- TC – July 1st: Annual compliance reports due
- ARM & DBETC – Fall: Annual ARM model to set Delaware Bay specifications, review red knot and VT trawl survey results
- Stock Assessment Subcommittee – Winter, Spring, Summer: Assessment analyses and report

TC Members: Katie Rodrigue (RI), Jeff Brunson (SC), Derek Perry (MA), Deb Pacileo (CT), Catherine Fede (NY), Samantha Macquesten (NJ), Jordan Zimmerman (DE), Steve Doctor (MD), Ingrid Braun (PRFC), Ethan Simpson (VA), Jeffrey Dobbs (NC), Eddie Leonard (GA), Claire Crowley (FL), Chris Wright (NMFS), Joanna Burger (Rutgers), Kristen Anstead (ASMFC), Caitlin Starks (ASMFC)

Delaware Bay Ecosystem TC Members: Wendy Walsh (USFWS, Chair), Samantha MacQuesten (NJ), Katherine Christie (DE), Jordan Zimmerman (DE), Steve Doctor (MD), Ethan Simpson (VA), Jim Fraser (VA Tech), Eric Hallerman (VA Tech), Yan Jiao (VA Tech), Kristen Anstead (ASMFC), Caitlin Starks (ASMFC)

ARM Subcommittee Members: John Sweka (USFWS, Chair), Linda Barry (NJ), Henrietta Bellman (DE), Jason Boucher (DE), Steve Doctor (MD), Wendy Walsh (USFWS), Conor McGowan (USGS/Auburn), David Smith (USGS), Jim Lyons (USGS, ARM Vice Chair), Jim Nichols (USGS), Kristen Anstead (ASMFC), Caitlin Starks (ASMFC)

Stock Assessment Subcommittee Members: Katie Rodrigue (RI, Chair), John Sweka (USFWS), Derek Perry (MA), Linda Barry (NJ), Margaret Conroy (DE), Jeffrey Dobbs (NC), Daniel Sasson (SC), Kristen Anstead (ASMFC)

DRAFT PROCEEDINGS OF THE

ATLANTIC STATES MARINE FISHERIES COMMISSION

HORSESHOE CRAB MANAGEMENT BOARD

The Westin Crystal City
Arlington, Virginia
Hybrid Meeting

May 3, 2023

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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INDEX OF MOTIONS

1. **Move to approve Agenda** by consent (Page 1).

2. **Move to approve Proceedings of November 10, 2022** by consent (Page 1).

3. **Move to accept the draft BMP document as final and publish it on the ASMFC website** (Page 10). Motion by Dan McKiernan; second by Mel Bell. Motion approved by consent (Page 11).

4. **Move to pursue option 1 from the memo dated April 17, 2023 with the intent to include a wide range of stakeholders in a survey formulated by a workgroup of board members** (Page 18). Motion by Shanna Madsen; second by Rick Jacobson. Motion carried by consent (Page 19).

5. **Motion to adjourn** by consent (Page 20).

ATTENDANCE

Board Members

Dan McKiernan, MA (AA)
Raymond Kane, MA (GA)
Rep. Sarah Peake, MA (LA)
Jason McNamee, RI (AA)
Eric Reid, RI, proxy for Sen. Sosnowski (LA)
David Borden, RI (GA)
Justin Davis, CT (AA)
Rob LaFrance, CT, proxy for B. Hyatt (GA)
Jesse Hornstein, NY, proxy for B. Seggos (AA)
Emerson Hasbrouck, NY (GA)
Jeff Brust, NJ, proxy for J. Cimino (AA)
Adam Nowalsky, NJ, proxy for Sen. Gopal (LA)
John Clark, DE (AA)
Roy Miller, DE (GA)
Craig Pugh, DE, proxy for Rep. Carson (LA)
Mike Luisi, MD, proxy for L. Fegley (AA) (Acting)
Dave Sikorski, MD, proxy for Del. Stein (LA)
Russell Dize, MD (GA)
Shanna Madsen, VA, proxy for J. Green (AA)
Chris Batsavage, NC, proxy for K. Rawls (AA)
Mel Bell, SC (AA)
Malcolm Rhodes, SC (GA)
Chris McDonough, SC, proxy for Sen. Cromer (LA)
Spud Woodward, GA (GA)
Carolyn Belcher, GA, proxy for Rep. T. Rhodes (LA)
Erika Burgess, FL, proxy for J. McCawley (AA)
Gary Jennings, FL (GA)
Marty Gary, PRFC
Chris Wright, NMFS
Rick Jacobson, US FWS

(AA = Administrative Appointee; GA = Governor Appointee; LA = Legislative Appointee)

Ex-Officio Members

Brett Hoffmeister, Advisory Panel Chair
John Sweka, ARM Subcommittee Chair
Nicholas Couch, Law Enforcement Representative

Staff

Robert Beal
Toni Kerns
Madeline Musante
Tina Berger
Tracey Bauer
Emilie Franke
Chris Jacobs
Jeff Kipp
Adam Lee
Caitlin Starks

Guests

Max Appelman, NMFS
Pat Augustine, Coram, NY
Russell Babb, NJ DEP
Meredith Bartron, US FWS
Alan Bianchi, NC DENR
Nora Blair, Charles River Labs
Jeff Brunson, SC DNR
Melissa Chaplin, US FWS
Haley Clinton, NC DENR
Margaret Conroy, DE DFW
James Cooper
Deborah Cramer
Ben Dyar, SC DNR
Chiara Eisner, NPR
Jacob Espittia, FL FWC
Julie Evans
Catherine Fede, NYS DEC
Angela Giuliano, MD DNR
Shirley Goffigon, Fuji Film
Shari Heller
Berlynna Heres, FL FWC
Jay Hermsen, NOAA
Alexandria Hoffman, DE DFW
Brett Hoffmeister, AP Chair
Blaik Keppler, SC DNR
Wilson Laney
Christina Lecker, Fuji Film
Ben Levitan, Earth Justice
Samantha MacQuesten, NJ DEP
Nichola Meserve, MA DMF

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

Guests (continued)

Steve Meyers
Allison Murphy, NOAA
Deborah Murray, SELCVA
John Pappalarado, Cape Cod Fishermen
Michael Pierdinock
Tracy Pugh, MA DMR
Zoe Read, WHYY
Allen Reneau, Fuji Film
Paul Risi, City Univ, NY
Daniel Sasson, SC DNR
Chris Scott, NYS DEC
McLean Seward, NC DENR
Jennifer Slovinski, Fuji Film
Brian Sparrow, Fuji Film
David Stormer, DE DFW
Yoshihiro Takasuga, Fuji Film
Wendy Walsh, US FWS
Megan Ware, ME DMR
Craig Weedon, MD DNR
Kristoffer Whitney, RIT
Angel Willey, MD DNR
Jordan Zimmerman, DE DFW
Renee Zobel, NH F&G

The Horseshoe Crab Management Board of the Atlantic States Marine Fisheries Commission convened in the Jefferson Ballroom of the Westin Crystal City Hotel, Arlington, Virginia, a hybrid meeting, in-person and webinar; Wednesday, May 3, 2023, and was called to order at 1:10 p.m. by Chair John Clark.

CALL TO ORDER

CHAIR JOHN CLARK: Welcome everybody; I'll be chairing the meeting. I'm John Clark from the state of Delaware.

APPROVAL OF AGENDA

CHAIR CLARK: Let's get right into this. Our first item is Approval of the Agenda. Does anybody have any questions or concerns about the agenda, any additions? Seeing none; the agenda is approved by unanimous consent.

APPROVAL OF PROCEEDINGS

CHAIR CLARK: The second question is the Approval of the Proceedings from the November, 2022 meeting. Does anybody have any comments about the proceedings? Seeing none; those are approved by unanimous consent.

PUBLIC COMMENT

CHAIR CLARK: Now we move on to Item 3, which is Public Comment. Do we have anybody signed up for public comment? Okay, is there anybody in the room that would like to make a comment about an item that is not on the agenda? Seeing none; we will move on then. Excuse me, we have an online, and Ben Levitan would like to make a comment about an item that is not on the agenda.

CHAIR CLARK: Okay, you are free to speak, Mr. Levitan.

MR. BEN LEVITAN: This is Ben Levitan from Earth Justice, and I'm speaking on behalf of New Jersey Audubon and Defenders of Wildlife. In a letter that we submitted into the supplemental materials for this meeting, we conveyed our appreciation for the Board's decision last fall to acknowledge significant public concern about red knots, and maintain a zero female bait harvest for Delaware Bay origin horseshoe crabs.

We also ask the Board to resolve an obstacle to future public participation. Specifically, going forward the public won't know in a given year whether the Board intends to maintain the zero female bait harvest, or adopt the recommendation of the new ARM model, which is expected to consistently recommend a substantial female harvest.

We're asking the Board to resolve this uncertainty by committing to provide advanced notice if it will consider authorizing a bait harvest of female horseshoe crabs. For example, the Board could commit to notifying the public no later than its summer meeting if at the annual meeting in the fall, the Board will consider authorizing a female harvest for the following fishing year.

If the Board provides that notice, concerned members of the public can submit comments and demonstrate their continued opposition to a female harvest, and if the Board doesn't provide that notice, the public will have assurance that a female bait harvest is not a live issue for the next fishing year. Without this sort of process in place, the public may feel compelled to organize against a female harvest every year, which would just waste time and resources for both the public and the Commission. But with a process like the one I just described; the Board could safeguard public participation by enabling the public to make informed choices about when to engage in the Board's decision making. Thank you.

CHAIR CLARK: Thank you, Mr. Levitan, and I believe with one of our agenda items we will at least partially address your concerns there. That was it for public comment.

CONSIDER THE WORK GROUP REPORT ON BIOMEDICAL BEST MANAGEMENT PRACTICES

CHAIR CLARK: We will now move on to Agenda Item 4, which is to Consider the Work Group Report on

Biomedical Best Management Practices, and this is an action item. Take it away, Caitlin.

MS. CAITLIN STARKS: I'll just give a presentation on the Work Group's recommendations on the Biomedical Best Management Practices. To start off with some background. As a reminder, at the August, 2022 meeting the Board agreed to form a Work Group to review the Best Management Practices for handling biomedical catch, and suggest options for updating and implementing the BMPs.

This was based on a recommendation from the Plan Development Team that no action was needed related to the Biomedical Mortality Threshold that's in the FMP, but that the Board could continue to annually review estimated biomedical mortality levels, and also form a work group to address and improve upon the Biomedical Best Management Practices.

The Work Group members are listed on the slide here, and they included state and industry representatives, who are technical experts in horseshoe crab biology at biomedical blood collection processes. The Work Group was tasked with looking at the original BMPs, which were developed in 2011, and included recommendations for best management practices for each of the steps in the biomedical process, from the point of capture to the point of release.

These BMPs are recommended but are not required by the Commission's FMP. The FMP does include some requirements that relate to biomedical collections, including the states. States are required to issue a special permit or other specific authorization for harvest for biomedical purposes, and that horseshoe crabs taken for biomedical purposes must be returned to the same state or federal waters from which they were collected.

Then additionally, the FMP requires states to report the number of biomedical horseshoes crab collected, the number bled, the number of observed mortalities, and the number of horseshoe crabs that are released alive on an annual basis. This 2023 Work Group met five times this winter and spring, and they reviewed the BMPs from 2011. The product of these meetings, which was included in your Board materials, is an updated draft BMP document.

This updated version includes additional context and background information on the biomedical industry and fishery, the purpose of the BMPs, the relevant FMP requirements and a modified list of BMPs that were recommended by the Work Group, as well as additional research recommendations. The Work Group also recommended changes to the flow chart that shows the steps in the biomedical process. On this screen is the old chart from the 2011 document, and then this is the modified chart that is recommended by the Work Group. The changes here are getting at trying to more accurately describe the process, and include the process of in-water holding of horseshoe crab between the point of capture and being transported to the facility, which was not previously recognized in the BMPs from 2011. Just to walk through this. We start at the point of collection of the horseshoe crab, and then there is the possibility that they might be held in water for a short period of time before being transported to the facility, where their blood would be collected.

At the facility they are held and inspected for bleeding, so there are some crabs that are accepted, and they would get their blood collected, and then other crabs that are rejected for reasons such as looking damaged or unhealthy would go back into holding until they can be released. All of the crabs that are bled also go into holding, and then all of the crabs together are released alive to the state or federal waters where they were collected.

All right, I'm not going to go through the recommended changes that the Work Group proposed to the BMPs themselves. I want to start by saying that the recommended changes were mostly to reorganize and streamline the BMP document. The main changes that are in the document are that the overarching BMPs that apply across the process were moved up to the top, since these are pretty important for general handling practices.

Similarly, some of the BMPs were recognized or moved to different sections, to better align with the biomedical process. As mentioned, the Work Group also added a section related to in-water holding BMPs. In general, though most of the 2011 BMPs were maintained in this document, sometimes two BMPs that were covering similar issues were combined to reduce redundancy. There were some cases where edits were made to reduce specific details like temperature ranges, in order to make the BMPs more applicable across the states or regions.

This means there is not as much detail in these BMPs as some folks might have been looking for, but the Work Group agreed that because of the range of different environmental conditions and regulations across the states, it would be difficult to specify some of these aspects in the BMPs, because what is best in one state may not be best in another state.

In the next set of slides, I'm going to go over each section of the BMPs, and highlight some of the more major changes. The first section of BMPs covers the overarching practices that apply to the whole process. In the first bullet, language was added about avoiding anoxic conditions, which was not previously addressed.

Then in the next bullet, which is avoid prolonged exposure of gills to fresh water. This was moved into this section from a different section, to make it clear that this should be avoided at all points in the process. The last two highlighted bullets were also moved up to this section from other sections.

The first of those was modified from the previous version. The 2011 version read, return to the water as soon as possible. If not being returned to the area of capture, ensure that conditions, salinity, water temperature et cetera are similar to those found at the harvest site, and the revision, which is highlighted here states, return horseshoe crabs taken for biomedical purposes to the same state or federal waters from which they were collected. This change was intended to be consistent with the language in the FMP requirement. One bullet was removed from this section, because the Work Group thought it was redundant, which was generate written procedures for all handlers of horseshoe crabs, covering all steps in the process from collection to release. There is another bullet in this section about written agreements, with outlying practices and expectations.

The next section covers the collection of biomedical horseshoe crabs. The first change is in the first bullet, which now reads, minimize tow times for targeted horseshoe crab trawl tows. The Work Group recommended removing specific tow times, which were previously defined as 20 to 30 minutes, because the Work Group felt that there was not sufficient data or information to substantiate this number.

In the second bullet on proper care and handling of horseshoe crabs while sorting and placing into bins, the Work Group recommended changes to highlight certain practices to minimize injury to crabs, so we have, avoid dropping/tossing horseshoe crabs, et cetera. Then in the fourth bullet on night collections, language was added to say, when permitted by state regulation.

This recognizes that some states do not allow collection of horseshoe crab at night. More details were added to the next bullet about not collecting or returning soft shelled or undersized horseshoe crabs, in addition to those that appear unhealthy. The last bullet was moved from a later section to this one, because the Work Group wanted to recognize that crabs that have been marked as being bled already in the last year, should be returned as soon as possible, rather than be collected and brought into a biomedical facility at all.

This whole section on in-water holding is a new addition that the Work Group recommended. In their discussions the Work Group recognized that this practice does not occur everywhere, and that there are not yet a lot of technical studies to provide guidance that could be included in the BMPs. But they did want to add the section, and provide some general guidance.

The recommendations here are to include minimized holding time, avoid overcrowding, monitor water conditions, temperature dissolved oxygen salinity, and minimize exposure to stressful conditions, as well as follow state guidelines on holding conditions where applicable. In the transport to facility section there was a minor change to add that transport containers should also be protected from heat as well as sunlight.

Then there were a few BMPs from the 2011 Work Group that the Work Group recommended be removed from this section. The first of those was a BMP that said, to maintain temperature between approximately ambient water temperature at the time of collection and 10 degrees Fahrenheit below ambient water temperature.

The Work Group discussed this at length, and they ultimately decided that the range of normal temperatures and environmental conditions and the range of states that have biomedical collections are variable, and they wanted to have BMPs that could apply across the board. They couldn't determine a temperature range that would be the same for all areas. They also recommended removing the BMP to maintain good ventilation while stacked in bins. This is because the Work Group thought there could be room for confusion with this BMP, because on one hand the horseshoe crabs need oxygen, but on the other, too much airflow could dry out the gills, and that would negatively affect respiration. To address this issue, the Work Group added language to the overarching section about avoiding anoxic conditions. In the Holding at Facility/Blood Collection section, the changes were pretty minor.

The word ideally was added to the first bullet. That recognizes that sometimes unforeseen circumstances can cause the holding time to exceed 24 hours, but the goal is to always hold the crabs for less time. Then in the third to last bullet, the Work Group suggested this edit so that it now reads, cease blood collection once blood flow rate slows, instead of the previous wording, which was bleed until the rate slows down, so that excessive bleeding is prevented.

This change was really intended to make it clear that blood collection should stop immediately at the point that the blood flow slows down. Then these are the last two sections of the BMPs. Under post blood collection holding in our last bullet, the Work Group recommended changing it from keeping crabs in the dark to keeping them in low light areas.

This is because they didn't want to give the impression that the best practice is to keep them in complete darkness. A few of the BMPs that were in this section were also moved up to the overarching section. Then lastly, there were no changes recommended for the Return to Sea section. In addition to the BMPs that were recommended, the Work Group came up with a list of research recommendations that they believe would enhance our understanding of the impacts of the biomedical process on horseshoe crabs.

They recommended studying survival rates over time, when kept in water holding ponds or pens. They recommended studying the impacts of biomedical collection processes on spawning of horseshoe crabs, comparing mortality rates across different collection methods, and estimating horseshoe crab discard mortality associated with trawling collection.

They also recommended summarizing the findings of current literature on horseshoe crab mortality associated with blood collection, and comparing those across experiments that more closely reflect the BMPs versus those that do not reflect the BMPs. They also recommend quantifying mortality rates of horseshoe crabs post blood collection, applying the BMPs in other standard biomedical industry practices, and studying conditions that minimize movement and injury of horseshoe crabs during biomedical processes such as light and density.

During their meetings there were a few other issues that the Work Group discussed, which didn't really fit into this BMP document, but the Work Group thought they were worth raising to the Board. First, the Work Group recommends that the management board task the Technical Committee with reevaluating the calculation or the coastwide biomedical mortality estimates that are presented in Commission documents.

The Work Group discussed the possibility that with our current calculation process, which adds the observed mortalities to a 15 percent estimated mortality of bled crabs. This could result in double counting of some horseshoe crab mortalities, so they would like to see this looked into, to clarify that. The Work Group also recommends the Commission's FMP be modified to use language that accurately reflect the practices used by the biomedical industry. One example here is the use of the word collection rather than harvest in the context of biomedical, because of the requirement that those crabs be released alive. Another example is the use of the word shipping in the FMP versus transport, which the Work Group thought could be misleading about the distance or time it takes to move crabs.

Then lastly, the Work Group discussed that while there are five biomedical operations along the Atlantic Coast that are licensed by the U.S. and Drug Administration, there are some other operations along the coast that are not licensed by the FDA, but are still permitted by the states to collect blood from horseshoe crabs for other purposes such as health or medical research.

They just thought it would be good to get a better understanding of these operations, so the Work Group recommends that each state provide a report back to the Board on those activities and the permitting and reporting requirements associated with them. Thanks for hanging in there through a lot of information. This is my last slide. Today, the action before the Board is to consider approving the recommended changes to the BMPs that were proposed by the Work Group. With that I can take any questions.

CHAIR CLARK: Thank you very much, Caitlin. Before we get to questions, in my cake-addled state, I rudely did not introduce that presentation. An excellent presentation was given by Caitlin Starks, who is the FMP Coordinator for Horseshoe Crab, and I'm also joined by Kristen Anstead, who as you know is our expert on all things ARM related or modeling for Horseshoe Crab. Sorry about that, too much cake. Now, on to questions. Who has questions about this? First, I have Rob LaFrance. Go ahead, Rob.

MR. ROBERT LAFRANCE: Thank you, Caitlin, for a great presentation. I guess my question now is, what is the next step? In other words, do we take this document, and does it go for public review like we would with other amendments or addenda, or is this it?

MS. STARKS: Thanks for that question. I think that is a little bit up to the Board. The 2011 BMP document did not go out for public review. It was simply this process where a Work Group was formed, they recommended BMPs, brought those back to the Board. The Board approved that list of BMPs, and it was posted on the Commission's website. Again, these are recommendations that the Commission is posting, but it is not something that is required by our FMP. If there is an intent for that to be different, then I would need guidance from that.

MR. LAFRANCE: From my own point of view, just in response to that, I would love to see this actually, because there was a fair number of people commenting on this, you know slightly differential. I think there was a lot of information provided about future research. My sense is, both of those things would be worth another go around, if you will, with some of the public who are interested, very interested in the species.

I think you're making headway, but I think there are some still, I would describe them as perhaps slightly not quite coordinated elements of what was written by this Horseshoe Coalition letter, as well as what was put together by the Working Group. My sense is it would be helpful, I think, from both people's understanding of the horseshoe crab issue, to do a little bit more outreach to the public, and perhaps spend a little time allowing people to comment on all elements of what you put together, which I think has been some really good work. Thank you.

CHAIR CLARK: Next, we have Chris Wright online.

MR. CHRIS WRIGHT: Yes, I have a couple of questions. In the one slide you added, or the group added on the word observe. Who is going to be doing the observation? Is that going to be the state law enforcement folks? That was not clarified in the edit.

MS. STARKS: Yes, thanks for that question. The Work Group did discuss that it made sense to them that it should be up to the states to decide who was doing these types of audits or observations, since they have different processes within facilities and state's regulations. They did not clarify who would be responsible for those.

MR. WRIGHT: Okay, and then the second question, that helps me, the second question was that a lot of times they tag the bled crabs, but as far as my recollection is. But for those rejected crabs, do they also tag those so we can get the mortality rate on those that are actually released?

MS. STARKS: I do not believe so.

MR. WRIGHT: They're just tagging those bled crabs.

MS. STARKS: That is my understanding.

MR. WRIGHT: I'm just wondering, because I know they were talking about recommendations regarding, you know mortality rates for those released crabs, but if we tag a proportion of those, we might be able to get some information if we tag those also, if they are already in the facility. Anyway, those are my two questions. Thank you.

CHAIR CLARK: The next question is from Dan McKiernan. Dan will pass. Any other questions? I see Justin and then Jeff. Go ahead, Justin.

DR. JUSTIN DAVIS: I guess I'll return back to Rob's earlier comment about public comment. I think I agree with Rob that there might be some benefit in sending this out for public comment. I can't see any harm in that, given that we're not up against, as I understand it, some sort of deadline to complete this.

We're probably not likely to take a look at it again anytime soon, since it's been quite a while since we updated these. But I do think, if you are interested in hearing opinions about that around the table, then we would have to think about, what do we do with that public comment? What would be the next step?

Would that public comment go back to the Working Group? And then they would have to decide if they want to make any changes to the document in response to that comment. I think that would have to be worked through. But I guess I'm just interested in hearing opinions around the table, and expect to hear something from Toni here on that.

CHAIR CLARK: Toni, do you want to take that?

MS. TONI KERNS: Just quickly in follow up, Justin, just as the Board comments on that to understand the intention. These currently are recommendations; they are not requirements of the FMP. Typically, we don't go out for public comment on things that are recommendations. Would it be the intention of the Board to ask the states to make this a requirement in some way, shape or form?

I don't know if that would be in order to get the permit this would be a requirement of the companies or not. Just as you are commenting on that, to try to have a better understanding, because what are we asking of the public on these recommendations?

CHAIR CLARK: Thanks, Toni, thank you, Justin, and next we have Jeff Brust and then Ray Kane.

MR. JEFFREY BRUST: I guess before I get to my question, I just wanted to respond to Justin. I don't really see any issue taking it to public comment, other than how you finished with, what would we do with that? To Toni's point, they are just recommendations. I appreciate that clarification, because that was going to be one of my questions.

What would we do with that public comment? I would hope that we can keep these as recommendations. I agree with a lot of the things that are in this document. I think there is enough variability across the coast and across the different collection facilities, that there is a one-size-fits-all that makes these requirements.

I would hope that we could give each facility the flexibility to work within these recommendations to use what fits their operation most appropriately. Notwithstanding that certain states can take any one of these recommendations and make them regulatory in their own state. But I don't think we're ready to make these essentially compliance criteria for all operations equally at the same time. I guess that's my response to your question.

I guess I just had one other question, maybe to Caitlin or to Kristen. There is a bullet in there that said, review current literature on biomedical collection practices, especially those that are following the BMPs to reevaluate the mortality rate. Is there any new research, or are we just going back to the studies that have already been reviewed back in what, one and a half, two decades ago? I would be just curious to know if there is anything new, or we've just got the same list that we've had for a while now. Thank you.

MS. STARKS: I believe there is one newer study that was not used, but this is something that we would be looking at through the Horseshoe Crab Assessment Update process. Regardless of what happens coming out of this meeting, it is something that would be looked at throughout that process as well.

As you remember in the 2019 benchmark, they reevaluated that estimated mortality number by doing a metadata review of all the research that is out there. But I think the thing to focus on for what the Work Group is recommending is really honing in on the experiments that followed the BMP versus those that did not. Because I think right now the 15 percent, there is a perception that this is based on all of the studies and not necessarily just those that follow the practices that are actually used.

CHAIR CLARK: Did you have follow-up, Jeff?

MR. BRUST: I thought about it, but no, I think I'm good.

CHAIR CLARK: Next, we have Ray Kane.

MR. RAYMOND W. KANE: I've never studied the physiology of a horseshoe crab, but it has come to my attention by both captains of otter trawlers and deep pickers. Is there a better way, a more appropriate way of marking a horseshoe crab that has had blood drawn, as opposed to painting a stripe on it? Because according to these harvesters that paint fades rapidly. I was wondering if there was a more appropriate way of marking the crab.

MS. STARKS: I don't think I have an answer for the most appropriate way to mark. I know that the facilities do use different methods, and the methods that they use are because they think that they are working well. I'm not sure I can answer that question for you.

CHAIR CLARK: Next, we have Roy Miller, and then Chris McDonough.

MR. ROY W. MILLER: This question is for either you, Mr. Chair, or for Caitlin. Can you refresh my memory what happens, or what you are allowed to do with a crab that succumbs as a result of the bleeding process? Can it be entered into the bait market, or are these bait market and bled crabs kept entirely separately at all times?

MS. STARKS: Thanks for the question, Roy. I can answer that. To be as clear as possible, there are crabs that are collected under a bait permit, and there are crabs that are collected under a biomedical permit. The biomedically collected crabs under a biomedical permit, may not be entered into the bait market, even if they die during the process.

The bait crabs, there are a few instances where states allow those crabs to first be bled by the biomedical facilities, in order to kind of kill two birds with one stone, in effect, and then go back to the bait market. But those crabs are always counted against the bait quota, and they are always assumed to have the 100 percent mortality rate applied to them that would apply to a bait crab.

MR. MILLER: Do you know what happens to the crabs that succumb, what their eventual distribution is?

MS. STARKS: I do not. I assume that they are put back into the environment, but I am not sure.

CHAIR CLARK: Next up we have Chris McDonough.

MR. CHRIS McDONOUGH: Yes, Caitlin, I'm just curious. On the new section in the recommendations, the in-water holding. You guys have under monitoring water conditions, you guys aren't really recommending any minimum environmental standards, and I'm assuming that is covered under the last bullet, follow state guidelines on holding conditions, because then it would depend on the location and the state.

MS. STARKS: Yes, that is correct. There are differences in the in-water conditions that these crabs are being held in. Just generally from my understanding through these Work Group discussions, there are some cases where they are held in a harbor, and some cases where they're held in a coastal bay. Those are two very different environments, and the Work Group did not have numbers to put on these things like temperature dissolved oxygen for that reason.

CHAIR CLARK: Are there any other questions? Rob Lafrance.

MR. LAFRANCE: I just wanted to follow up on Roy Miller's question having to do with those crabs that are taken in the bait market, versus those crabs that are actually utilized for biomedical purposes. When I was reading the material, I did not get a sense of what the volume of that is. I am very interested to know what percentage overall is actually being done that way. I mean there was discussion of like the 15 percent versus 100 percent. But if you could help me understand that better that would be a big help from my perspective.

MS. STARKS: Yes, I can try to clarify. A portion of the bait crabs, the total bait crabs that are taken on an annual basis, and this is again only occurring I think in one state or two. Those states have quotas for those bait crabs, and if they choose to allow some of those crabs to go to the biomedical facility first, they still are counted under their bait quota. Does that clarify it?

MR. LAFRANCE: It does, and this may be a silly question, but I want to understand. Those bait crabs, when they are going to the facility. Do they have to be treated under the same processes that would be otherwise required for those crabs that will be returned to the ocean or not?

MS. STARKS: Again, these are not requirements in the BMPs in the first place, so I would say no they are not required to be treated in a certain way. But the Work Group did discuss that these BMPs are targeted at the crabs that are intended to be released alive. If there are facilities that are doing dual use, which is bleeding of bait crabs before they go back to the bait market, then I think it is up to them how to handle those. But my understanding is that they typically follow the same processes that they use for the biomedical crabs.

MR. LAFRANCE: Thank you, that is very helpful. My concern is, if they are not, how would you know the difference when they are at the facility, right? You bring one in, it came that it's going to be tagged ultimately to be used as bait, and another one that is going to be returned to the ocean. How do you know if you are actually looking at that whether they were actually complying with that, so it's a concern?

MS. STARKS: If I could just follow up on that. My understanding is that the crabs that are brought in from the bait market are batched together, and they are not intermingled with the biomedical crabs.

MR. LAFRANCE: But that's not included in the BMPs, correct?

MS. STARKS: Accurate, yes.

MR. LAFRANCE: Again, that is one small issue that I would like to see, why I would like to be able to go out to the public on some of these smaller things, recognizing that BMPs are not requirements. But they will be looked at, I believe, as documents that the Atlantic States Marine Fisheries Commission has looked at, and will be looked to as best management practices across the industry. That is why I would like to see them reviewed publicly.

CHAIR CLARK: Thank you, and I see we have a question from Craig Pugh.

MR. CRAIG PUGH: Yes, and Mr. Lafrance's comments. These BMPs seem to be quite micro managerial as the fishery conducts itself, as far as I can point to one example right now. The tow times of the dredge are generally dictated by depths and bottom structure, you know dictating the time. If you're going to regulate that and put it into like a regulatory program that would be certainly hard to enforce.

I think if you're going to look at this, we have to take a much, much deeper and harder look at these managerial micromanaging points that they've explained in here. I would take issue with some of those, maybe because I'm not so sure that most people in this room are aware of that type of fishing and what it takes to get that part of it done.

MR. LAFRANCE: If I might respond, Mr. Chair.

CHAIR CLARK: Go right ahead, Rob.

MR. LAFRANCE: Thank you for those comments, I wouldn't disagree. I guess part of what I'm trying to say is, I'm not just looking for one side to make comment. I would also be interested to hear from the industry on what their concerns may be or not be, in terms of I understand there were representatives there. But sometimes representatives don't represent the entire industry. Again, I'm looking at this more from a transparency perspective for what the Board does on a document that ultimately will be looked at as the Board's work thing.

CHAIR CLARK: Are there any other questions? I'm not seeing any hands. Anybody remotely? Chris Wright, you have another question?

MR. WRIGHT: No, sorry. I didn't put my hand down from prior.

CHAIR CLARK: All right then, we've had a discussion here, a good amount of questions. Our next step on this, this is an action item, so because these are just recommendations, are we moving to approve them or accept them, or what's the deal here?

MS. STARKS: Yes, so I think that the Board could choose to approve the modifications that were made by the Work Group or recommended by the Work Group. If that is the route that the Board were to go today, we would post that new document online in place of the old one. If there is a desire to do something different, other than approve these, then I would need some kind of guidance. Thanks.

CHAIR CLARK: Bob.

EXECUTIVE DIRECTOR ROBERT E. BEAL: Just a question or comment. If the Board approves these recommendations as Caitlin commented, they remain that. They are still recommendations. They are not binding on the states or on the industry, they are just recommended best management practices by the Atlantic States Marine Fisheries Commission, and we'll publish them on our website and those sorts of things. I just want to be clear; they don't become binding if the Board approves them today.

CHAIR CLARK: Just to clarify also, because I know Rob brought up the question of public hearings about it or doing some sort of outreach about this. Is approving it and putting it on the website, would that preclude doing any further outreach on this? Go right ahead, Bob.

EXECUTIVE DIRECTOR BEAL: Well, you know we don't really have a mechanism to do public hearings on a suite of recommendations, recommended best management practices. You know I'm not sure where the Board is on this, but if we wanted to open up a whatever, 30-day public comment opportunity or something like that, that could be done. But again, back to maybe Justin's question of then what. What are you going to do with that feedback that you get? You could do that, I'm just not sure where we go with that.

CHAIR CLARK: Thanks, Bob. Just to maybe summarize. The Board can either approve, these will be posted as the recommendations put on the website, maybe a press release done about it, or if as you mentioned there. If the Board preferred to have like a 30-day comment period, or something to that effect, the Board could move to do something like that at this point, or that would work. We have a couple options here. Does anybody want to put forward a motion? Dan McKiernan.

MR. DANIEL McKIERNAN: Yes, I would move that we accept the draft document as final, and publish it on the ASMFC website.

CHAIR CLARK: Do we have a second? I see Mel Bell. Okay, we have a seconded motion. Once it's on the board if anybody would like to make a comment, speak to it. Of course, after you, Dan.

MR. McKIERNAN: I can speak to it, it's a pretty simple motion. Just to assure everyone that we have in Massachusetts, I'll speak for my own agency, you know a close oversite and a close working relationship with the companies involved with this. We have permit conditions on their permits that we place that are largely based on this, but in some cases are more restrictive. We will continue to work these issues, not only with the processing firms or the biomedical firms, but also with the harvesters, because there has been a shift in the harvesting makeup, or the makeup of the harvest is where more and more of our crabs are being harvested by otter trawlers, you know more than three miles from shore in some pretty productive areas. We are evolving our management strategies to accommodate that. This is a good document. You know the team put their heads together. We do recognize that there are differences among the companies, but in the locations relative to temperature and the like in salinity. I'm comfortable with the document, but it doesn't mean that we're not going more restrictive on some of the conditions.

CHAIR CLARK: Thanks, Dan. Mel, as the seconder, did you have any comments you would like to add?

MR. BELL: No, other than I think you had a good group of folks here, in terms of their experience level and they were the folks that gave this a lot of thought and input, so you got some good recommendations. I will say as Dan mentioned, we do permit this fishery, and we already have things in place that are more restrictive or more detailed than some of these. I think I'm satisfied with them.

CHAIR CLARK: Thanks, Mel, anybody have any comments? I see Rob Lafrance. Go right ahead, Rob.

MR. LAFRANCE: I was very satisfied with a notion of a 30-day comment period, allowing for people to comment. I'm not looking for digestion of that. I mean my sense is if people have a concern, they could write it in and we would record it. I don't know whether that needs to be added to this, but if it were something that was just left open, where staff could review and just send to this Board any comments that came in from the public.

I do not believe that we're going to get into the minutia of trying to deal with it. But I do think it would be helpful for all of us to understand if there are concerns. I guess I'm looking to what Bob had recommended, and wondering if we can just ask that be posted on the web, and if people want to comment they are given 30 days. I'm not looking for anything else.

MS. KERNS: Rob, I guess a question back would be, if we do post them for comment but you are approving them today, what are we doing with those comments?

MR. LAFRANCE: I think that is for the next go around, right? I mean at some point in time people are going to say they either liked them or they didn't like them and why they did or they didn't. But you're adopting them today based upon the work of the Working Group. I guess all I'm saying is, it's almost like taking an exception to a decision. You are able to put on the record why it is you didn't like it.

MS. STARKS: If I could just respond to that quickly. I think that the Work Group, first of all, did discuss that these BMPs are meant to evolve over time. The original Work Group that put them together in 2011 wrote that into the document, and this Work Group maintains that and does expect that there could be future changes to the BMPs. If we're posting it online and folks want to send in comments, we will definitely record those and keep them in our records, and send them to the Board. Next time the Board wants to revise or review these BMPs, it would just need to initiate a new process.

MR. LAFRANCE: Well, that satisfies me, so thank you.

CHAIR CLARK: Any further discussion of the motion? Seeing none; is there any need for the Board to caucus on this motion? Yes, okay why don't we take two minutes to caucus. Okay, before we call the question, we did have another comment from Chris Wright, and Chris, you are reminded to please mute yourself after you make your comment, thanks.

MR. WRIGHT: I have a question just clarifying on the motion. Is this just on the BMP document, or are we going to discuss the recommendations later that the group had?

CHAIR CLARK: This is just on the BMP document.

MR. WRIGHT: All right, are we going to have a discussion on the recommendations then?

CHAIR CLARK: Are you referring to the next agenda item? Sure, we could discuss those after we take the vote.

MR. WRIGHT: All right, thank you.

CHAIR CLARK: Okay, we've had time to caucus. I guess before we do a vote, is there any opposition to the motion? Okay, seeing none; I think we can have the motion approved by consent. Before we move on from the subject then, as Chris just brought up. He wanted to speak to the recommendations, right? Okay, I guess at this point then, since Chris, you brought it up. Would you like to make a comment?

MR. WRIGHT: Yes, I would like to just have a little discussion on the recommendations. The one recommendation that I was interested in, and we might be able to take action on now is the other non-FDA organizations that are part of the industry that are still bleeding, but we're not tracking those. I'm a little bit confused. Are we just not tracking those in the state reporting? If not, I think we might be able to get that resolved today, because in my mind we should be tracking those folks also.

MS. STARKS: I can try to respond. The conversation that happened at the Work Group level was that some of the Work Group members believe that there are other operations that are not one of the five FDA licensed biomedical facilities that do collect and bleed horseshoe crabs.

It is unclear what those facilities are and what their permitting requirements are, and that's why this came up. I do think we would need input from the states to understand if there are crabs that are being collected and bled that are not being reported by the Commission, we would need to understand that.

MR. WRIGHT: Great, and so can we at least ask the states to either report on that informally or put them in their state reports? I don't know which way the process is for that. But I would like to get an idea about that too, because I didn't know that there were other operations that were bleeding crabs, and I don't know if they are under state permit or what have you. I've been on the Horseshoe Crab Board for quite a while, and that's the first I've heard of it.

MS. STARKS: I think talking with Toni, it seems like it would be a good idea to send a questionnaire out to the Board by e-mail after this meeting, to try to get at some of these questions.

MR. WRIGHT: Yes, that sounds fair.

CHAIR CLARK: Thanks, Chris, any further comment about the recommendations? I'm not seeing any hands.

MS. STARKS: I guess I want to ask for guidance on this first recommendation about tasking the Technical Committee with reevaluating the mortality estimates. Is it something the Board would like the

TC to work on more immediately? If so, we can have that conversation.

CHAIR CLARK: Yes, Shanna.

MS. SHANNA MADSEN: Maybe this is just a clarification. I thought that when Jeff asked his question regarding this, it was clear that the biomedical mortality would be looked at when you do the stock assessment update, which is coming up.

MS. STARKS: Thank you. These are two separate issues. I know it's a little nuanced, but there is the 15 percent estimate of bled crabs that are assumed to die. That is what we are referring to with the stock assessment, where they would review all the literature related to that. Then this question is more specifically about when we calculate the number of total biomedical mortality in our Commission documents, are we double counting any mortalities? Right now, when I get reports to me from the states, that includes the number of mortalities. They have a column usually of observed mortalities, where the crabs are at some point, but from collection to release observed to die. Then we also have a 15 percent applied to any crabs that are bled. The question is getting at whether there is any double counting there.

CHAIR CLARK: Do you need further input on that, Caitlin, or Shanna, do you have a follow up?

MS. MADSEN: Well, I think Caitlin's question now I understand, is when we might want to do that. Is there something that we can roll into the stock assessment update? Like, is it necessary that we tackle that right now? I feel like we're tasking you guys with a lot of stuff, and we're talking about potentially tasking with you more things at our next decision point. I'm trying to figure out what works best.

MS. STARKS: I do believe that this is something that the Stock Assessment Subcommittee could tackle. When we do the stock assessment, we will want to validate the data on biomedical mortalities, and so I think this would fall into that.

CHAIR CLARK: That makes sense. Okay, so a new task has been added then. Okay, now is that the end of the discussion of this item, or is there anything else that anybody wants to bring up about the BMP? Oh, Mr. Beal.

EXECUTIVE DIRECT BEAL: Just back to the 30-day comment period. I'm not clear if that was a consensus of the Board. Rob brought it up. Are we doing that or not? You know if the Board wants to do it, we can do it. If there is consensus that we don't need to revisit these or have additional public comment right now. We could do it; you know obviously public comment at a later date before we update BMPs the next time. It just wasn't clear on the record of whether we're doing it now or not.

CHAIR CLARK: Well, that makes two of us, Bob. Let's see, I've got a couple of hands here. Mike Luisi and then Jeff Brust.

MR. MICHAEL LUISI: I'll just say that in my experience, I think that is more frustrating for an individual who wants to make comment to something like this, to make that comment with no expectation that the Board is going to consider making any changes at this time, as kind of what was discussed with Caitlin's idea about when this is revisited again, perhaps we could fold in some of the information we hear from the public.

I think that even if you don't open a public comment period for 30 days, you're going to get comment based on the actions that were taken as a result of the press release that goes out, that states that the Board approved these best management practices. If you're engaged in this discussion, you are going to go online.

You are going to read the BMPs, and someone is going to get an e-mail about it, probably Caitlin and John, as well as all the shark collection permits that you'll be getting soon. But that is just my take. I think you are going to hear what you're going to hear. I don't know that 30-day comment period with no action on top of that is necessary at this time. Thanks, John.

CHAIR CLARK: Jeff and then Rob Lafrance.

MR. BRUST: I think I agree completely with what Mike just said. I don't understand why we need to put a time certain on the review period. We're going to get comments. We get comments on all our other completed actions as well. It will be on the web; people can comment on it.

At some point, yes, I think that those comments should come back to the Board. You know it's been 10 years since we looked at these the last time, 12 years, maybe. Perhaps if we get a substantial number of comments, the Board hears about that and reconsider when the next update comes. But again, I don't see any need to put a time certain review period on this.

CHAIR CLARK: Thanks, Jeff, and Caitlin, you have a response.

MS. STARKS: Yes, I just kind of want to add on to something that Jeff said. Our typical process with receiving comments, outside of a specific comment period, is that if those comments come into our comment's inbox or to staff directly, we save those and we put them in the materials for the next Board meeting. Those comments would come back to you in the following meeting after they're received, and we can certainly compile them all and save them in our records for the next time the BMPs come up as well.

CHAIR CLARK: Rob, you had a comment?

MR. LAFRANCE: Yes, I did not know that was the process, so in many ways I guess I was trying to maybe simplify it, so you would only keep those for 30 days. But I mean again, to the extent that there are comments, and I think the comments are not only on the BMPs, but they are on some of your other research recommendations. I think we will get comments, and as a member of the Board I would love to see them. Since they are going to be in the next materials, I am satisfied by that as well.

CHAIR CLARK: Mel Bell, you had a comment?

MR. BELL: Yes, I was just going to say, I mean Rob is right, we'll get comments and we will see the comments, and Mike is absolutely right. My fear is having a process set up where you are actually asking for comments on something that you've already made a decision on. That wouldn't sit well with me if I was commenting. I think we've got it set up properly.

CHAIR CLARK: Was the idea that we would have that in the press release would say, if you have comments send them to the comment box? No? I'm full of good ideas. The comments will come in regardless, got it.

Are there any further comments on this subject? All right, seeing none; we are going to move on to Item Number 5, which is to Review Potential Processes and Resources Required for Evaluating Management Objectives for the Delaware Bay Bait Fishery. Caitlin, you have another presentation on this.

REVIEW POTENTIAL PROCESSES AND RESOURCES REQUIRED FOR EVALUATING MANAGEMENT OBJECTIVES FOR THE DELAWARE BAY BAIT FISHERY

MS. STARKS: Yes, you have to listen to me again. All right, so I am going to go through this pretty briefly. This is in your materials. There was a memo on this. This is just to summarize what's in that memo, to provide the Board with some ideas for thinking about evaluation of the management objectives for the Delaware Bay Horseshoe Crab bait fishery. In November, 2022, the Board adopted the revised ARM Framework with Addendum VIII, and it set specifications for 2023 for Delaware Bay bait harvest.

That was set at 475,000 males and 0 females. At this time the Board discussed forming a Work Group to evaluate the current goals and objectives for the management of the Delaware Bay horseshoe crab fishery. That is why we're bringing this back today. What we did as staff was come up with a couple of options for ways that the Board could go about evaluating these management objectives.

I'm just going to run through those really quick. The first one is a stakeholder survey, the second is a

Board/Work Group process, and the third is a more in-depth process that would look like an Ecosystem Management Objectives Work Shop, similar to the one that was done for menhaden. The stakeholder survey idea concept is that this would be our lower end of resource requirement intensity. For personnel we would be looking at ASMFC staff, along with 5 or 6 Board members to develop the survey.

We expect this would take about 4 to 6 months to put the survey together, send it out to a specific set of stakeholders, and receive those responses, and then analyze them and bring the results back to the Board. Major budget items, this is not expected to cost much, unless we want to do an in-person Work Group meeting, so that is the main thing there. Then the next suggestion is a Board/Work Group process, and this would be a more medium level resource requirement. Our personnel needs would be again, ASMFC staff, and then we would look for Board members to serve on the Work Group, as well as some Advisory Panel members and Technical Committee and stakeholder representatives to advise the Work Group, not necessarily to participate on it, but to actually bring some information to that group to help them.

We are imagining this process taking from 6 to 9 months, in which we would set up that Work Group, form the Work Group. Have a couple of meetings with the Work Group, and maybe either at or between those meetings have some consultations with the stakeholders that I mentioned, to try to help develop recommendations for potential management objectives, or changes to the management objectives for the Delaware Bay.

That group would then be responsible for producing a report that would include those recommendations and information, and bring that back to the Board. For this we would plan on having in-person Work Group meetings, in order to have a more effective conversation. That would be the major budget item.

Then the last suggestion is this type of Ecosystem Management Objectives Workshop. This is expected to be a pretty big lift, and some higher resource requirements, in terms of staff and money. For personnel we would need ASMFC staff as well as Board members and Advisory Panel members and some technical and stakeholder representatives to attend the workshop or workshops, as well as either a Workshop Chair or a hired facilitator to run that.

For this we would expect a longer timeline somewhere from 9 to 12 months. That takes a lot of planning to put something together like this. On the front end we would need more time to set up that workshop, and then the workshop would occur and we would use that to develop a report that would come back to the Board with some potential recommendations for management objectives or changes to those. As you could guess, our major budget items here would be actually having that in-person workshop with stakeholders and a facilitator.

The next steps for the Board today are to discuss what your intentions are with evaluating the Delaware Bay Management Objectives. I think it would be helpful to hear today what questions you are specifically hoping to answer through any of these processes, and maybe once we have some discussion on that we can consider if you would like to move forward with one of these or multiple of these processes today or put this on hold for now and come back to it later. With that I can take any questions.

CHAIR CLARK: Thank you, Caitlin, and as the Board remembers, the impetus for this item was the brilliant new ARM Model, which we approved in Addendum VIII. Of course, it did show that female horseshoe crabs could be harvested again, and in fact even the old ARM Model would have allowed that. The Board at the time, because of the huge amount of public consternation about that, decided male-only harvest.

We decided to move ahead with this item, to see what we want to do in the future, because of course if there is no desire for female harvest that is a whole different way to manage those species. With that, why don't we get some discussion going. The first hand I saw up was Mike, and then I've got Shanna.

MR. LUISI: I guess this is a question for either you or maybe Caitlin, perhaps even Bob or Toni. You know the way I saw the three options laid out; they were focused on resources. I just wonder if you have all given some thought about the cost benefit, the tradeoff between spending more and getting more, or spending less and having it drawn out over a longer period of time with more steps and layers, as to which one is, at the end of the day, going to be something that is most useful. What is the better bang for the buck, you know as far as taking next steps?

CHAIR CLARK: Do you want to respond to that, Toni?

MS. KERNS: I'll try, I guess. One of the things that I've been thinking about is for the Delaware states. One of the things that we talked about, I think two meetings ago, was you guys going home and talking to your fishermen, to find out if they want to harvest females or not. If the answer is no, then do we need to even do any of these things, and the Delaware Bay states could make a recommendation to the Board that you don't want to harvest females anymore.

We could do an addendum to do so, and then provide the ARM Model to address that new direction. That is how we have also thought about it, but this is what the Board had asked us to provide, so there is that thought back to you, in terms of, I guess that would be less work maybe on both ends. Not that the outcome would be similar, but similar end point.

MR. LUISI: All right, thank you.

CHAIR CLARK: Shanna.

MS. MADSEN: Thank you Caitlin and Toni for working to put these options together. I know it's a pain to have to come back and have workgroups suggested to you, so I really appreciate it. The thing I kind of wanted to start off saying is, I was a part of the original EMO Workshop. I was staffing it at that time. I don't think that we're at that point just yet.

To Toni's point, I think that the very first thing that we need to consider doing is asking that tough question, because that question is really what forms the objective statement that we have for the ARM right now. The thing that I think that I would most likely want to recommend, and I don't know if we're going to do this by motion or just by Board consent, but I would like to see us start with Option 1, which is putting together a survey to ask that very direct question.

Do our constituents want us to harvest female horseshoe crabs? If the answer is no, then I think that really helps us outline what that objective statement is. I think it might still lead us to potentially going to Option 2, because we still really as a Board need to define what our objective statement is, to help you define as the Stock Assessment Subcommittee, the ARM Workgroup.

What exactly we're asking you for, because I remember being stuck in that back and forth of being a scientist, not exactly knowing what my managers wanted. I want to make sure that we're giving you the best and most clear information possible. From my standpoint, I think that we start with Option 1, put together some very pointed questions to our stakeholders, from the Delaware Bay states, and ask exactly what they are looking for. Then we come back and reevaluate, and see what our next steps are.

But I just did want to make clear that I do not think that we are at the level of Option 3 just yet, and I do not want to put my foot on that gas pedal right now, especially given the conversation that we've just had at our last meeting, with Dr. Drew looking at that stock assessment schedule, looking at how busy all of our staff are. Let's start simple, get some answers to questions, and move forward from there. Don't overcomplicate it yet.

CHAIR CLARK: Thanks, Shanna, good suggestion. I see Rick Jacobson.

MR. RICK JACOBSON: I want to thank the Chair and the staff of ASMFC for bringing forward these three options for the Board to consider. It is exactly the kind of thing we were looking for when we first put this charge together last fall, so again, thank you very much for that. I agree too with the previous speakers that we do have a fundamental question that we need to ask ourselves first. What is the public appetite for the harvest of female horseshoe crabs from Delaware Bay?

It is a critical question, and if the answer to that question is no, it greatly simplifies all of our work moving forward, and it will define what our next steps are. The second part is, however, if we take the alternate path, and the public does in fact support the harvest of horseshoe crabs, that we will need to explore the broader array of how public sentiment needs to be factored into the ARM. Whether it's Option 1 or it's some combination of Option 2, with a survey as called for in Option 1, I'm not altogether clear. But I don't think we're at the point of Option 3 at this point.

CHAIR CLARK: Do we have any other comments? Rob Lafrance.

MR. LAFRANCE: Yes, we've had some discussions around the table about this outside and prior to today's meeting. I think I speak with Bill Hyatt, who is my Governor's Appointee, and one of the things he wants to make certain is whatever we're doing we're doing it with ecological basis. I think in his preliminary evaluation of this, he thought the Ecosystem Management approach was a good one.

But in my conversations with other folks around the table about this, the notion that we understand whether or not we're going to move forward with a female harvest or not, is a key and important question. I think once we come to some semblance of that, I just don't want to see us not think about Option 3, in the event that we get there.

In other words, even if we have females off the table, what does that mean, I mean in terms of an ecological perspective? But in parsing it out, moving from one maybe to some semblance of two makes sense? From what I've heard thus far from a technical perspective, we're probably not ready for 3, but I don't think we can forget about 3.

CHAIR CLARK: I don't believe that starting with Option 1 would preclude us moving to either of the second or third option, and Caitlin and Kristen are both nodding in agreement to that. At this point, is there anybody else who would like to make a comment? Craig Pugh.

MR. PUGH: I'm in a bit of precarious situation here. I've become one of the old new guys in our commercial fishery in Delaware, so I still remember the collection and usage of female horseshoe crab. However, just during the closure of that we have a lot younger group of commercial fishermen now that don't really realize what benefit that is.

Do we use that as a benefit here is a question that kind of conflicts me, because I grew up with the usage of that. But knowing that most of my younger generation is not aware of that experience, and have become accustomed to what we have today, the female horseshoe crab appetite, I believe has waned off in our commercial industry.

That's as honest and as truthful as I can be. I would like, however, to somehow hold on to the ability or the language to some extent, in case things were to change. Do we have that option? The sustainability and feasibility of those fisheries if become available, do we continue with that option? In some fashion I would like to see that.

But I can tell you that the overall arching that even though our commercial fishery is such a small, miniscule part of our population, would not hold water in our legislature, damn sure. More than likely, even if we allowed it here today, it would probably more than likely, legislation would be passed to eliminate that option. But how do we do this? That is my question. Maybe that is the staffs? Can we still withhold some of this, even though knowing that the appetite at this point in time is not there?

CHAIR CLARK: Caitlin, did you have a response to that?

MS. STARKS: Yes, just in general, if the Board were to go down a path that the appetite is not there, you do not want to harvest females at this time, so you were to initiate an addendum and approve that addendum that says we're only going to harvest males. The Board could always do another addendum in the future if that appetite came back.

There is always the opportunity to modify a management program in that way. Then the situation that you're in right now seems to be that you have the option to harvest females, but there is not an appetite there, so you have used the specifications process to only harvest males in the Delaware Bay. Those are kind of two different alternatives, but both have the same answer, which is not harvesting females and potentially being able to harvest them in the future.

CHAIR CLARK: Do we have any other commentors online? We do not. Based on what we've discussed here, the view of the Board seems to be to move ahead with Option 1, trying to survey if the stakeholders. I agree with Craig. You know I know in our state that even though the ARM would allow female harvest, the Board of course did not allow female harvest. We are moving ahead with just a male-only harvest. But even just the possibility of female harvest has really brought out a lot of opposition to any horseshoe crab harvest. It's definitely going to be a fraught issue, but I think the survey would be a good place to start. Do we need a motion on that, or is the Board comfortable with just moving ahead with the survey by assent? Oh, Toni.

MS. KERNS: Not a motion, I just want to make it clear that it's not our intention to send this survey to the world. We intend to hit the major stakeholders. We would like the states to make sure that their industry members are a part of that survey, and we can work with you, the four Delaware Advisory states, to make sure either we get those e-mail addresses or you guys facilitate that. But I just want to make it clear that it is not the entire public that we are sending this out to.

MR. PUGH: That lengthy process would be, I think of some benefit to those stakeholders that we have. It would, I guess sort of it may dampen hopes, but it's information I think that could be extended out, and should kind of lower the seas. I would appreciate that and welcome that.

CHAIR CLARK: Justin Davis.

DR. DAVIS: Just to follow up on Toni's comments. Would it include a broad variety of stakeholders? I mean, how is it going to work though if you send it to somebody and they send it to somebody? I mean, you can set it up somehow so it can't be distributed broader than who you distribute it to?

MS. KERNS: It will be a single-source survey, where you can't share the link.

CHAIR CLARK: Sure thing, Justin, follow up.

DR. DAVIS: Who is going to make the determination about who it gets sent to?

MS. STARKS: The Work Group. This process, Process Number 1, does still involve a Work Group of the Board being formed to develop the survey and to discuss the participants in the survey.

MS. KERNS: Just follow up, Justin, we're not trying to exclude the public, but we have just done a management document where we received 34,000 comments, and we heard from the general public on their intentions. We still want to make sure we're capturing all the stakeholders here, but we're also not looking for that many comments to have to summarize in order to provide feedback to this Board.

CHAIR CLARK: Roy Miller.

MR. MILLER: Craig and I were just discussing who constitutes a stakeholder in this particular case. Does a non-harvester like an Audubon Society member, could they be considered a stakeholder?

MS. STARKS: Yes, I think the general stakeholder groups that we discussed are the fishery, the commercial fishery for bait harvest, the biomedical fishery as well that occurs in the Delaware Bay, and then environmental groups that are also involved with the Delaware Bay ecosystem, and have been involved through the process of the development of the ARM. Those are, I think, our three main general stakeholder groups.

CHAIR CLARK: We actually have ecotourism for horseshoe crab spawning now, so something else to think of. Dan.

MR. McKIERNAN: Good luck with this. I have two recommendations, one is I think you need to broaden the stakeholder consideration from the commercial side, and not just talk to harvesters, because then you might not talk to dealers, you might talk about the users of bait. If you don't have a horseshoe crab fishery in Delaware Bay, that puts more pressure on states that do. I just want that to be understood.

Even if you don't put people from Massachusetts on that list. But I would recommend, when you do this survey you hire a facilitator, and maybe bring some of the principals together, and see if people can stop talking past one another. I think there needs to be some mediation to get some common ground.

CHAIR CLARK: Thanks Dan, and Rick you had a comment?

MR. JACOBSON: Am I correct in assuming that the array of people that will be surveyed under Option 1 will be equally broad, if not more broad, than those who would be engaged under Option 2, and that that group would be as broad or more broad than those who would be engaged in Option 3?

I ask that question, because if we're thinking the array of stakeholders that would be engaged is at its broadest at Option 1, and a subsequent action, depending on what we learn from Option 1, may lead us to further engagement through Option 2 or Option 3, then we will not have missed anyone in that first step. That is Item 1.

Since we were so clear last fall about our intent to engage the public in how we might look at the ARM Model that was adopted, and perhaps even change some of the criteria elements within the model to reflect that. It seems to me we do need to take some formal action here, as a follow up to last fall's direction to the staff, but perhaps I'm wrong.

CHAIR CLARK: Rick, you're suggesting that we need a motion. We've heard that we could do this by assent, but I don't think it hurts to have a motion. We can just go ahead and do it as a motion. Would somebody like to make that motion? Go right ahead, Shanna.

MS. MADSEN: I'm going to do this one off the cuff here. I guess I would move to pursue Option 1 from the memo dated April 17, 2023, with the intent to capture a wide range of stakeholders in a survey formulated by a workgroup of Board members. I think it was just Board members, right Caitlin? Okay, good. Then, so that we're clear, because I want to make sure that I'm taking everyone's thoughts into account. This does not preclude the Board from later pursuing Options 2 or 3 following the survey.

CHAIR CLARK: That is a most impressive motion off the cuff there, Shanna, great. Do we have a second? Rick Jacobson is second. We'll wait until that motion is up there. Okay, is that looking like what you thought it would look like? Hey Ray, go ahead.

MR. KANE: Just a friendly to the maker and the seconder. With the intent to survey a wide range of stakeholders in a formulation by a workgroup of Board members, as opposed to the way it reads now.

CHAIR CLARK: Oh, instead of to capture, to survey, is that okay with you, Shanna?

MS. MADSEN: That's fine, and then at the end of this motion I did say, not to preclude the Board from later pursuing Options 2 or 3 in the memo, just to get that up there as well. We don't need it?

CHAIR CLARK: It's not necessary. We've got two surveys in there don't we? Everything is on the fly here. How about to include in the first place, instead of survey, in the first instance of survey change to include. How does that look? Okay, Rob Lafrance.

MR. LAFRANCE: I guess I just want to understand, I think some of the dialogue here for the Board was that we weren't going to preclude Options 2 and 3. I just don't understand why we can't put that up. I mean, is it just left unsaid because of the record? I mean my sense is this may be the first step of future steps.

CHAIR CLARK: Yes, I'm leaving that to Bob.

EXECUTIVE DIRECTOR BEAL: It's obviously part of the record here, and the intent of the Board to move forward with that, depending on the results of the survey. It's fair game and it's not precluded, but it doesn't need to be necessarily in this motion.

MR. LAFRANCE: Fair enough, I just wanted to get that clarified on the record, thank you.

CHAIR CLARK: Is there any further discussion of this motion? No seeing any, I don't believe there is a need to caucus. Is there any opposition to this motion? Seeing none; let's consider it approved by consent. That ends this item.

OTHER BUSINESS

CHAIR CLARK: Oh yes, we just have Other Business. Is there any other business to come before this Board? Because we do have other business, but it's not Horseshoe Crab Board business. Chris Wright, go right ahead.

MR. WRIGHT: I have a question. Are we going to get the Board members for the Work Group now or later?

CHAIR CLARK: We're going to do that later, Chris.

MR. WRIGHT: Okay, thank you.

CHAIR CLARK: Malcolm, you have your hand up, Malcolm Rhodes. You can go right ahead.

ALTERNATIVE TO LAL SPEAKER

DR. MALCOLM RHODES: Mr. Chairman, I was trying to get in on the first discussion, and I really wanted to thank Caitlin and her Working Group for that job on the BMP. In these days we're getting into more and more multiple resistant organisms to test for sterility is vitally important.

It's much easier to not catch a disease than have to treat it, and especially as we're getting into more resistant ones. I applaud that and what this industry has done. The one thing I was wondering, if at some point, and it may be a year from now, if we could get some experts in to discuss the recombinant/synthetic LAL efficacy versus, you know the one derived from the horseshoe crabs. More and more we see this being thrown out, and the U.S. Pharmacopeia has not allowed that for a lot of products, and especially for vaccines, because our current LAL made from horseshoe crab is the gold standard. It's hard to find any up-to-date information that I feel is acceptable, and I think it would help the Board, you know at some point, just to put a marker in, to have someone address the Board on that one issue.

CHAIR CLARK: Thank you, Malcolm, is there any response to that?

MS. STARKS: I'm not sure I'm entirely clear on the question, so I just want to ask a follow up. Is it your intent to have an external presenter come and provide information? Is that what you're asking for?

DR. RHODES: Whether it's external or internal who could do it. We've had, it may have been a decade ago, it may have been longer. The Board was addressed by someone discussing LAL and the recombinant alternatives to it. Whenever we get letters, or when you're reading the newspaper press clippings, you know, you are kind of inundated.

Well, use the synthetic, use the synthetic. I think it would be good for us to know if it is as effective, and where we are of this substance versus the recombinant alternatives. I don't know if that would come from someone in the industry, if someone in one of our groups has the expertise to go through the literature and find appropriate peer reviewed studies. But just to inform us fully about LAL. (Recording faded out)

CHAIR CLARK: Okay, thanks, Malcolm, and I think Caitlin and Bob were just discussing this, and I believe the idea was to get outside, so get an outside expert on that and definitely have that at a future Board meeting. Thank you. I see Dan has got his hand up.

MR. McKIERNAN: Yes, just a point of clarification. There is a lot of competition in that line of work. Could it be someone from an impartial party like the FDA? You know National Institute for Health, NIH, something? I hate to see some up-and-coming biomedical firm come in here and say, oh yeah, it's perfect. Do away with the wild harvest, we don't want that. It's the position of the government that it hasn't been approved on that scale, so why not the FDA?

CHAIR CLARK: Makes sense to me. I think it's something to explore all these options in the future.

MR. McKIERNAN: I appreciate Malcolm's point; I want to thank him for making that.

CHAIR CLARK: Right, it's great, obviously a very germane topic to what we've been discussing here today.

ADJOURNMENT

CHAIR CLARK: Is there anything else, any other hands out there? Not seeing any; do we have a motion to adjourn? Mike Luisi, seconded by Ray Kane. We are adjourned.

(Whereupon the meeting adjourned at 2:40 p.m. on Wednesday, May 3, 2023)

September 25, 2023

Horseshoe Crab Management Board
Atlantic States Marine Fisheries Commission
1050 N. Highland Street, Suite 200 A-N
Arlington, VA 22201
comments@asmfc.org

VIA ELECTRONIC MAIL

Re: Use of the Adaptive Resource Management Model to Recommend Horseshoe Crab Bait Harvest Quotas

Dear Members of the Horseshoe Crab Management Board:

New Jersey Audubon and Defenders of Wildlife urge the Horseshoe Crab Management Board ("Board") to maintain the prohibition on harvesting female Delaware Bay-origin horseshoe crabs for bait. These comments present extensive new technical analysis by Dr. Kevin Shoemaker demonstrating that the adaptive resource management ("ARM") model[1] does not accurately represent the impact of the horseshoe crab harvest on red knots or horseshoe crabs. As a result of the ARM model's flaws—many of which are intrinsic to its core structure and functionality—utilizing the model to inform management decisions will not safeguard against "limiting the red knot stopover population or slowing recovery"[2] or violating the Endangered Species Act ("ESA"). These comments also explain why the Board must not use the ongoing stakeholder survey to initiate a resumption of the female harvest.

The ARM model ostensibly represents the connection between horseshoe crabs and red knot shorebirds (*Calidris canutus rufa*). Each year, red knots fly from as far south as Tierra del Fuego to the Arctic Circle, where they breed—a round trip that can span 19,000 miles. At a critical point in their northbound migration, after depleting much of their energy, most red knots stop at Delaware Bay as horseshoe crabs emerge from the water to spawn on the beach. By feasting on a superabundance of horseshoe crab eggs, red knots can double their body weight in under two

[1] Unless otherwise stated, in these comments, the "ARM model" refers to the version approved by the Horseshoe Crab Management Board in 2022.
[2] ASMFC, *Revision to the Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Inclusive of Red Knot Conservation (Draft for Board Review)* 25 (2021) ("ARM Report") (providing the objective statement for the ARM Framework).

weeks.[3] With their energy restored, red knots have an improved likelihood of completing their migration and breeding successfully.[4]

In the late twentieth century, horseshoe crabs were severely overharvested. As their numbers fell, eggs on the beach grew scarcer, with devastating impacts on red knots. In 2015, the U.S. Fish and Wildlife Service ("USFWS") listed red knots as threatened under the ESA, citing "[r]educed food availability in Delaware Bay due to commercial harvest of the horseshoe crab . . . [as] a primary causal factor in red knot population declines in the 2000s."[5] The Atlantic States Marine Fisheries Commission ("ASMFC"), through its Horseshoe Crab Management Board, has regulated the harvest of horseshoe crabs for use as bait since 1998, but both red knots and horseshoe crabs remain perilously depleted compared to historical levels. Last year, the Board approved the use of a revised ARM model to process data about horseshoe crab and red knot demographics and recommend horseshoe crab bait harvest quotas.[6] The ARM framework's objectives include "ensur[ing] that the abundance of horseshoe crabs is not limiting the red knot stopover population or slowing recovery."[7]

In advance of the Board's decision to approve the revised ARM model, New Jersey Audubon and Defenders of Wildlife submitted analysis by independent consultant Dr. Kevin Shoemaker demonstrating that the model falls far short of that objective. Among other deficiencies that Dr. Shoemaker identified, the model recognizes scarcely any correlation between the abundance of horseshoe crabs and red knots. Despite the historical role of horseshoe crab overharvest in the decline of red knots, the model predicts red knot abundance will increase even if all horseshoe crabs vanish entirely from Delaware Bay. This deficiency heavily influences the harvest quotas that the model recommends. While the previous model never recommended allowing a bait harvest of female Delaware Bay-origin horseshoe crabs, the revised model is nearly certain to recommend a significant female harvest every year. Citing public concern, the Board maintained a male-only bait harvest for 2023. That is, the Board approved the ARM model but did not immediately adopt its recommended harvest quotas.[8]

The numerous flaws in the ARM model that Dr. Shoemaker previously identified thoroughly demonstrated that the model is unfit for recommending horseshoe crab harvest levels. That conclusion was evident even though Dr. Shoemaker could analyze only one component of the model because the rest was being withheld from public review. New Jersey Audubon and Defenders of Wildlife cautioned that additional flaws may emerge when the public gained access to the entire model and urged the Board to abstain from voting on the model until that time. The

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[3] New Jersey Department of Environmental Protection, *Wildlife Populations: Red Knot* 1-2 (2020), https://dep.nj.gov/wp-content/uploads/dsr/trends-red-knot.pdf.
[4] Sjoerd Duijns et al., *Body Condition Explains Migratory Performance of a Long-Distance Migrant*, 284 Proceedings of the Royal Society of London B 20171374, at 4-6 (2017).
[5] FWS, "Endangered and Threatened Wildlife and Plants; Final Threatened Status for the Rufa Red Knot," 79 Fed. Reg. 73,706, 73,707 (Dec. 11, 2014).
[6] ASMFC, Press Release, "Horseshoe Crab Board Sets 2023 Specifications for Horseshoe Crabs of Delaware Bay-Origin & Adopts ARM Framework Revision via Addendum VIII" (Nov. 10, 2022), http://www.asmfc.org/uploads/file/636d41cepr33_HSC2023DEBaySpecs_AddendumVIII_Approval.pdf.
[7] *See* ARM Report 25.
[8] See ASMFC, *supra* note 6.

entire model was finally released the evening before the Board approved it, and Dr. Shoemaker has now performed a comprehensive review.

Dr. Shoemaker's new analysis paints an even starker picture of the ARM model's unsuitability for managing the horseshoe crab bait harvest. Collectively, his two analyses make abundantly clear that the ARM model does not accurately represent the relationship between horseshoe crabs and red knots or the population status and trajectory of either species individually. As a result, the model cannot anticipate the consequences of its own harvest recommendations. Implementing the model's recommendations—especially its recommendation to resume a female horseshoe crab bait harvest—would place red knots at extraordinary risk and potentially destabilize the horseshoe crab population as well.

While red knots face a variety of threats, including beach development and climate change, the availability of horseshoe crab eggs is a key determinant of their survival and reproductive success. The Board cannot use the existence of other threats to deflect its responsibility to ensure that horseshoe crab levels do not limit the Delaware Bay stopover population or slow the recovery of red knots. To the contrary, the existence of other threats should impel the Board to exercise more precaution when setting harvest quotas.

These comments present Dr. Shoemaker's analysis and other material to make four principal points, all of which support the overarching conclusion that the Board cannot defensibly use the ARM model to set bait harvest quotas for Delaware Bay-origin horseshoe crabs:

1. **<u>The availability of horseshoe crab eggs on the beach, not trawl survey data, is the most direct and meaningful determinant of red knot survival.</u>**

    - The ARM model entirely ignores the most important source of data—the number of horseshoe crab eggs per square meter of beach (referred to as egg "density"). Egg density is the most direct measure of whether there are enough horseshoe crabs to fulfill the nutritional needs of red knots. Dr. Shoemaker shows that *egg density is strongly correlated with red knot survival*.
    - The ARM model's cornerstone is the relationship between two factors that bear virtually no relation: female horseshoe crab abundance data derived from trawl surveys and red knot abundance. The absence of a meaningful correlation between these data likely results from the difficulty of collecting and evaluating horseshoe crab abundance data using trawl surveys. It does not indicate that no significant correlation exists between the two species. But the ARM model mistakenly concludes that red knot population trajectories are not strongly related to horseshoe crab populations and thus that increasing the horseshoe crab harvest would scarcely impact red knots, even as it ignores egg density data that strongly show the opposite.
    - By failing to recognize the dependence of red knots on horseshoe crabs, the ARM model predicts the abundance of red knots will increase even if all horseshoe crabs suddenly disappear from Delaware Bay. By contrast, the correlation between egg density and red knot survival reveals a grave threat: if horseshoe

crab egg density stagnated at the lowest recently observed level (to say nothing of entirely disappearing), red knots would quickly plummet to near-zero levels.

2. **<u>The ARM model overestimates and misrepresents the health and resilience of red knots and horseshoe crabs at Delaware Bay.</u>**

- In order to serve as a legitimate basis for managing the ecosystem, the ARM model would need to accurately characterize the demographics of red knots and horseshoe crabs. In many key respects, the model misrepresents these demographics. As a result, its recommended harvest quotas are largely untethered from the actual condition of red knots and horseshoe crabs and would have dangerous impacts that the model cannot predict.

Red Knots

- The ARM model inaccurately concludes that the red knot lifespan is roughly three times what the data show (15 years instead of 5 years). Thus, the model assumes that red knots have many more breeding opportunities than they actually do. The model seriously underestimates the impact that one or two poor breeding years—due to a scarcity of horseshoe crab eggs, for example—can have on lifetime reproductive success and, by extension, the persistence of the species.
- When estimating red knot abundance, the ARM model draws a large number of conclusions from a very small dataset of population counts. This causes the model to falsely detect trends in the data even when no trends are present. Dr. Shoemaker tested the model with 50 sets of random, white-noise data that lacked any trend; the model spuriously detected a non-negligible trend in red knot abundance more than 80% of the time.
- The component of the model that estimates the red knot population fails standard "goodness-of-fit" tests, meaning that it does not conform to the empirical data. This failure further suggests that the model does not represent actual ecological processes. Thus, the recommended harvest quotas are unsubstantiated numbers bearing minimal connection to the condition of the ecosystem.

Horseshoe Crabs

- The ARM model estimates horseshoe crab abundance by processing data from three trawl surveys. The data from these surveys are not significantly correlated, suggesting that they largely reflect random fluctuations rather than meaningful biotic signals. By consolidating these results into a single, Delaware Bay-wide population estimate, the model manufactures a veneer of certainty that conceals the underlying prevalence of random noise.
- Beyond the inherent limitations of the trawl survey data, the model fails to adjust for confounding factors, such as water depth and temperature, that impact the survey results. When Dr. Shoemaker adjusted for these factors and reanalyzed the data, there was no conclusive trend in horseshoe crab abundance, undercutting the ARM model's claim of a modest positive trajectory.

- Dr. Shoemaker's new analysis supplements the extensive analysis submitted last year that explained how the model generates highly overoptimistic horseshoe crab population projections.

3. **Implementing the ARM model's recommendations would pose a profound risk of violating the Endangered Species Act.**

- ASMFC would violate the ESA by authorizing horseshoe crab harvest at levels that would "take" red knots, a federally protected species. Taking a species includes harming it, which in turn includes "significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding or sheltering."[9] The ESA's "take" prohibition extends to governmental authorizations to third parties to undertake actions that result in the incidental take of ESA-listed species because those authorizations "solicit" or "cause" prohibited take.[10]
- The ARM model is not informative as to whether any particular horseshoe crab harvest level would result in an unlawful take of red knots. The model does not accurately represent the status of horseshoe crabs and red knots, and it is oblivious to the dependence of red knots on horseshoe crabs. Since the model does not represent ecological conditions, the Board cannot rely on it to assess ecological impacts or ensure compliance with the law.
- USFWS's evaluation of the ARM framework provides no meaningful information about the likelihood of an ESA violation. In stating that the model's harvest recommendations would "pose[] negligible risk to red knot recovery and negligible risk of take," USFWS merely characterized the model's own outputs. Since the model claimed that its recommended harvest quotas would be harmless, the agency concluded that no take would be likely. USFWS's statement hinges on the accuracy of the model, which is deeply flawed.

4. **The ongoing stakeholder survey cannot justify a resumption of the female horseshoe crab harvest.**

- The Board must make management decisions based on the best available science and legal requirements. The vulnerability of red knots and horseshoe crabs, together with the ARM model's inability to generate accurate predictions of the effects on red knots of horseshoe crab harvest levels, mandate that the Board take a risk-averse approach and, at a minimum, maintain the prohibition on harvesting females and refrain from increasing male harvest quotas.
- To the extent that the Board also considers public opinion, the public has already spoken on this issue. When the Board accepted public comment last year on whether to adopt the new ARM model, more than 34,000 people expressed their opposition, compared to only 5 who expressed support. The overwhelming

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[9] 16 U.S.C. § 1532(19) (defining take); *id.* § 1538(a)(1)(B) (take prohibition); 50 C.F.R. § 17.3 (defining harm).
[10] *Strahan v. Coxe*, 127 F.3d 155, 163 (1st Cir. 1997); 16 U.S.C. § 1538(g).

message was clear: female Delaware Bay-origin horseshoe crabs should not be harvested for bait.

- The Board has since decided to conduct a stakeholder survey to gauge the level of support for the bait harvest of female horseshoe crabs. Unlike the public comment solicitation, this survey is open only to an undisclosed, hand-selected group of respondents.
- Whatever the survey's outcome, it cannot justify reauthorizing a female bait harvest. The Board must not discount public comments and scientific and legal imperatives through opaque engagement with its selected survey respondents.

The remainder of these comments elaborate upon each of those four points. Dr. Shoemaker's new analysis immediately follows these comments. These comments and analysis supplement the comments that New Jersey Audubon and Defenders of Wildlife submitted prior to the adoption of the ARM model (the "Addendum VIII comments"). The Addendum VIII comments—including expert reports by Dr. Shoemaker and Dr. Romuald Lipcius—are incorporated by reference and attached.

Respectfully submitted,

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Technical Comments

I. THE AVAILABILITY OF HORSESHOE CRAB EGGS ON THE BEACH, NOT TRAWL SURVEY DATA, IS THE MOST DIRECT AND MEANINGFUL DETERMINANT OF RED KNOT SURVIVAL.

The ARM model is irreparably distorted by its core finding that the abundance of female horseshoe crabs has virtually no impact on red knots. That finding defies both historical observation and empirical data, and it subverts the very purpose of utilizing a model to inform horseshoe crab harvest quotas. By contrast, the density of horseshoe crab eggs on the beach correlates strongly with red knot survival. The Board must fully account for the vital correlation between the two species when making management decisions.

A. Horseshoe Crab Eggs Are Critical to the Survival of Red Knots at Delaware Bay.

The relationship between horseshoe crabs and red knots is an extraordinary example of the interconnectedness of life on Earth. Each year, red knots fly from as far as the southern tip of South America to breed in the Arctic Circle. For most red knots, this epic journey coincides with another ecological marvel: the emergence of horseshoe crabs from the waters of Delaware Bay to spawn on the beach. Historically, an enormous population of horseshoe crabs has produced a vast resource of eggs. This bounty of eggs serves as a critical food source for red knots. Having already flown thousands of miles at significant physiological expense, red knots can consume enough eggs in less than two weeks to double their body weight and gain the energy to complete their migration and breed successfully.[11] Horseshoe crab eggs may be especially important for the most southern-wintering red knots, whose migrations are the longest and most energy-intensive.[12] Only with a superabundance of horseshoe crabs can red knots access the eggs: horseshoe crabs lay their eggs too deeply in the sand for red knots to reach, but successive waves of spawning crabs churn the sand, elevating a portion of the eggs toward the surface.[13]

The importance of horseshoe crab eggs shapes red knots' migratory paths, and the plethora of crabs has historically drawn red knots to Delaware Bay.[14] USFWS has labeled the overharvest of horseshoe crabs in Delaware Bay a "primary causal factor" in red knots' decline.[15] A key objective of the ARM framework is to "ensure that the abundance of horseshoe crabs is not limiting the red knot stopover population or slowing recovery."[16]

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[11] Lawrence Niles et al., *Effects of Horseshoe Crab Harvest in Delaware Bay on Red Knots: Are Harvest Restrictions Working?*, 59 BioScience 153, 154 (2009); New Jersey Department of Environmental Protection, *Wildlife Populations: Red Knot* 1-2 (2020), https://dep.nj.gov/wp-content/uploads/dsr/trends-red-knot.pdf; Duijns, *Body Condition Explains Migratory Performance* at 4-6.

[12] *See* FWS, *Draft Recovery Plan for the Rufa Red Knot* 13-14 (May 2021).

[13] Niles, *Effects of Horseshoe Crab Harvest* 155.

[14] The utilization of other horseshoe crab-rich stopover sites in South Carolina further bolsters the importance of horseshoe crabs to red knots.

[15] 79 Fed. Reg. at 73,707.

[16] ARM Report 25. More information about the role of horseshoe crab eggs in red knot migration is available in New Jersey Audubon and Defenders of Wildlife's comments on Addendum VIII (attached).

In light of the well-established reliance of red knots on horseshoe crabs, achieving the ARM framework's objective requires the restoration of adequate horseshoe crab egg resources. But instead, the ARM model concludes—contrary to decades of observation and belying the ARM framework's own objective statement—that red knot abundance bears almost no connection to the abundance of horseshoe crabs.[17] The model would predict that red knot numbers would most likely increase even if horseshoe crabs disappeared entirely.[18] According to the model, horseshoe crabs, including the egg-laying females, could be harvested in large numbers, and red knots would barely notice the difference.

The ARM model is wrong. As described below, and building on decades of observation, the fate of red knots is significantly correlated with the fate of horseshoe crabs. The model's contrary—and counterfactual—conclusion does not represent the dynamics of the ecosystem and results from flaws in how the model is structured and processes data.

B. <u>The density of horseshoe crab eggs on the beach strongly correlates with red knot survival and demands central consideration in management decisions.</u>

The ARM model entirely ignores the most direct measure of whether there are enough horseshoe crab eggs for red knots: the density of eggs at or near the surface of the beach. Data on egg density have reliably and consistently been collected for decades. Peer-reviewed, published research shows that egg density has declined by an order of magnitude since the 1980s.[19]

Building on that peer-reviewed research, Dr. Shoemaker found a significant positive correlation between egg density and red knot survival. The data show that higher egg density has historically tracked with higher red knot survival rates. The reverse is also true: projecting forward from this correlation, multiple years of low egg density would likely decimate the red knot population.[20]

Instead of using egg density data, the ARM model uses data that are, at best, a remote proxy of food availability for red knots: the abundance of female horseshoe crabs, as estimated from trawl surveys conducted in the open sea. The ARM model illogically assumes that the ecosystem is meeting the needs of red knots based on horseshoe crab trawl surveys, even as horseshoe crab egg densities on the beach languish at low levels. Thus, a model with the stated purpose of protecting red knots is erroneously being used to assert that red knots hardly need protection after all.

As described above, Dr. Shoemaker previously explained that the ARM model would project a likely increase in red knot abundance even if horseshoe crabs vanished entirely from Delaware

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[17] *See, e.g.*, ARM Report 86.

[18] *See* Kevin Shoemaker, *Review of 2021 ASMFC ARM Revision* 6-12 (Sept. 2022), *in* Addendum VIII comments (attached) ("Shoemaker 2022 Analysis").

[19] *See* Joseph A. M. Smith et al., *Horseshoe Crab Egg Availability for Shorebirds in Delaware Bay: Dramatic Reduction After Unregulated Horseshoe Crab Harvest and Limited Recovery After 20 Years of Management*, Aquatic Conservation: Marine and Freshwater Ecosystems 1, 8 (2022), https://doi.org/10.1002/aqc.3887.

[20] *See* Kevin Shoemaker, *Review of the Atlantic States Marine Fisheries Commission's (ASMFC) Adaptive Resource Management (ARM) framework for regulating Horseshoe Crab bait harvest in Delaware Bay* 19-27 (Sept. 2023) ("Shoemaker 2023 Analysis").

Bay.[21] He has now supplemented that finding with a projection based on the correlation between red knot abundance and horseshoe crab egg density (Figure 1).[22] The contrast between the two projections is stark and highlights the recklessness of accepting the ARM model's representation of the ecosystem. Notably, the projection based on egg density—unlike the projection based on horseshoe crab abundance—does not assume that horseshoe crabs vanish entirely but incorporates the less extreme scenario that egg density stagnates at the lowest historically observed level. Yet even under that relatively modest and more plausible scenario, the consequences for red knots would be dire.

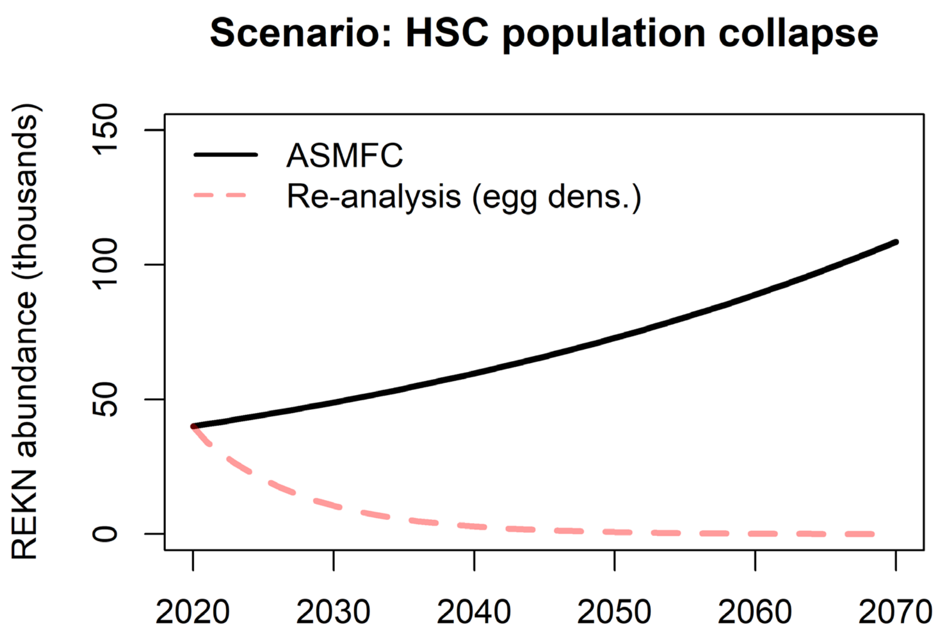

Figure 1 (appears as Figure 6 in Dr. Shoemaker's analysis). The solid black line represents the ARM model's weak correlation between red knot abundance and horseshoe crab abundance (as estimated from trawl surveys) and depicts a scenario in which horseshoe crabs completely disappear from Delaware Bay. The dashed red line represents the correlation between red knot abundance and egg density and depicts a scenario in which egg density stagnates at the lowest historically observed level.

Figure 1 shows that persistently low egg density would cause the abundance of red knots at Delaware Bay to plummet toward near-zero levels. It further undercuts the ARM model's implausible expectation that red knot abundance would increase even in the total absence of horseshoe crabs.

It bears emphasis that, while egg density is the best indicator of resource adequacy for red knots, there is almost certainly a positive correlation between the abundance of horseshoe crabs and red knots. The model's failure to find such a correlation may be attributable to trawl surveys' inaccurate measurements of horseshoe crab abundance. Section II.B, *infra*, presents Dr. Shoemaker's finding that the trawl survey data are likely more reflective of random noise than

[21] *See* Shoemaker 2022 Analysis 6-12.
[22] *See* Shoemaker 2023 Analysis 25.

horseshoe crab demographics. If the horseshoe crab abundance estimates are inaccurate, then the strength of their correlation with red knot abundance is meaningless.

Management decisions that affect a threatened species like the red knot, including by causing prohibited take, demand a precautionary approach. Basing management decisions on the ARM model would be risk-prone and invite calamity for red knots.

II. THE ARM MODEL OVERESTIMATES AND MISREPRESENTS THE HEALTH AND RESILIENCE OF RED KNOTS AND HORSESHOE CRABS AT DELAWARE BAY.

In addition to disregarding the connection between horseshoe crabs and red knots, the ARM model contains fundamental errors and deficiencies that prevent it from accurately representing the status of either species individually. As a result, its recommended harvest quotas do not reflect ecological conditions. Implementing the model's recommendations would have adverse outcomes that the model cannot accurately predict and put both red knots and horseshoe crabs at greater risk, in sharp contrast to the precautionary approach that managing an imperiled ecosystem demands.

A. The ARM model's evaluation and projections of red knot demographics are not reliable.

i. The model artificially inflates the red knot survival rate.[23]

The ARM model incorrectly estimates that red knots' lifespan is roughly three times as long as similarly sized shorebirds—nearly 15 years compared to 5 years. The lifespan estimate is derived from the annual survival rate, which the model estimates at 93%. Most other estimates of the survival rate for red knots (and similarly sized shorebirds) are closer to 80%.

Overestimating the survival rate results in the model underestimating the vulnerability of red knots to a single unsuccessful breeding year. To maintain a stable population, each female needs to replace herself at least once (on average) during her lifetime. For example, a female that is reproductively active for 14 years may be relatively unaffected by one or two poor breeding years. But for a female that is reproductively active for 4 years, the same conditions would significantly reduce her likelihood of reproductive success, even if, on average, she produces more offspring per year.

The model's erroneous survival rate flows from its method of tabulating red knot resightings. Researchers have long affixed leg bands to red knots, with each band having a unique, three-character code. By reading the codes from red knots that are banded and then return to Delaware Bay in subsequent years, researchers acquire data about what proportion of red knots survive from year to year.

The difficulty of reading codes from leg bands means that researchers need to account for two types of misread errors. The ARM model accounts for one type by ignoring a reading if the code

[23] This finding is presented at Shoemaker 2023 Analysis 8-14.

was never actually used on a leg band. But it does not account for codes that are mistaken for other existing codes. For example, assume that in year 1 of the study, a red knot is assigned the code 1AB, and in year 7, a red knot is assigned the code 7AB. In year 8, a researcher may misread "7AB" as "1AB," even though the bird assigned 1AB may have died years earlier.

To minimize misread errors, researchers can weed out codes that are sighted only once in a season. Uncorroborated by additional readings, these codes are more likely to be misreads. Dr. Shoemaker recalculated red knots' survival rate after weeding out these uncorroborated potential misreads. The resulting estimated survival rate dropped to approximately 80%, which is much more consistent with most other estimates.[24]

For further verification, Dr. Shoemaker also calculated the survival rate using readings only from red knots that were captured after previously having been banded—upon capture, the codes could be read at close range. These close-range readings constitute a much smaller data-set but would be expected to include minimal misreads. This subset of readings yielded an estimated survival rate of approximately 79%, consistent with Dr. Shoemaker's corrected overall estimate and estimates from other researchers.

The enormous overestimate of red knot survival is indicative of how profoundly the ARM model fails to represent even the basic lifecycle of the species it is supposed to protect—and why the model should not be used to make existential decisions affecting that species.

ii. The ARM model misrepresents trends in red knot abundance.[25]

The ARM model has a strong tendency to detect false trends in red knot abundance, even when no trend exists. Thus, the model cannot be trusted to assess one of the most important factors: whether and to what degree the red knot population is increasing or decreasing.

This problem results from a design flaw in a key component of the model that estimates abundance and recruitment. The component, called a "state-space" model, uses annual red knot population counts to estimate various metrics related to red knot demography (all of which feed into abundance estimates). These metrics, or "parameters," include estimates of initial red knot abundance, annual recruitment, and the effect of horseshoe crab abundance on red knot recruitment. But the initial dataset is far too small to support the large number of parameters estimated from it.

More concretely, this component of the model draws from just 14 datapoints: the peak count of red knots in Delaware Bay for each of the years 2005-2018. From that limited dataset, the model estimates at least 18 different parameters. As models become "overparameterized," they bear a decreasing relationship to the truth. Dr. Shoemaker analogizes this phenomenon to a parachutist

[24] Allan J. Baker et al., *Rapid population decline in red knots: fitness consequences of decreased refuelling rates and late arrival in Delaware Bay*, Proceedings of the Royal Society of London, Series B: Biological Sciences 271(1541), 875-882 (2004); Theunis Piersma et al., *Simultaneous declines in summer survival of three shorebird species signals a flyway at risk*, Journal of Applied Ecology 53(2), 479-490 (2016); Verónica Méndez et al., *Patterns and processes in shorebird survival rates: a global review*, Ibis 160(4), 723-741 (2018).
[25] This finding is presented at Shoemaker 2023 Analysis 34-39.

connected to a parachute with suspension cords. As the number of suspension cords declines, the parachutist and parachute become increasingly untethered. Similarly, with insufficient datapoints, the parameters lose a strong connection to the truth. Instead, the model is likely to conclude that false, or "spurious," trends exist, even when the data indicate no such thing.

Dr. Shoemaker's tests revealed that the ARM model is highly likely to find spurious trends. To test this, he generated 50 sets of random, white-noise population count data that lacked a trend in either direction. Feeding those 50 random datasets into the model, he found that the model contrived a significant, spurious trend 42 times. That is, working from a dataset of white noise, the model was more than 80% likely to project that red knot abundance was on a trajectory to increase or decrease significantly by the year 2100.

This flaw in the model is unlikely to be resolved through the accumulation of more data in future years. While the acceptable ratio of datapoints to parameters varies, Dr. Shoemaker explains that 30-to-1 is sometimes used as a rule of thumb. The affected component of the ARM model has less than 1 datapoint per parameter. Even though one additional datapoint of red knot abundance is collected each year, it would take decades before the dataset grew large enough to support the demands that the model places up on it.

iii. The model bears little resemblance to real-world data.[26]

Based on the information that ASMFC has released, the ARM model has not undergone sufficient goodness-of-fit testing. As Dr. Shoemaker explains, such "testing is a critical validation step . . . [for] ensuring that key assumptions made during the modeling process are reasonable and justified."[27]

To fill this gap, Dr. Shoemaker performed four goodness-of-fitness tests for various aspects of the ARM model, focusing on the open robust design component of the integrated population model—a portion of the model that measures red knot survival among other parameters. Each of the four tests assessed different parameters in order to test different aspects of the model.

The model failed each of the goodness-of-fit tests by a wide margin. Dr. Shoemaker explains that these failures "cast[] additional doubt on conclusions generated from this model."[28] Basing management decisions on a model that bears so little resemblance to real data would be an exercise in arbitrary and risk-prone decision-making.

B. Properly evaluated, the horseshoe crab trawl surveys do not indicate a positive trend in horseshoe crab abundance.

As discussed in Section I, the ARM model is centered around the correlation between red knot abundance and female horseshoe crab abundance as measured by trawl surveys. This overreliance on trawl survey data is inherently inappropriate because the data do not correlate with red knot abundance, and the model ignores data on horseshoe crab egg density that correlate

[26] This finding is presented at Shoemaker 2023 Analysis 39-41.
[27] *Id.* at 39.
[28] *Id.* at 41.

strongly with red knot outcomes. That problem is compounded by several flaws in how the model uses and processes the trawl survey data. Upon correcting some of those flaws, it becomes clear the trawl surveys do not support the ARM model's optimistic assessment of the horseshoe crab population trajectory. In fact, the trawl surveys reveal no conclusive trend in either direction, bolstering the need to make precautionary management decisions for this overexploited species, especially considering that the species remains depleted relative to historical levels.

To assess the horseshoe crab population, the ARM model processes data from three different trawl surveys using a catch multiple-survey analysis ("CMSA"). While the goal is to derive a meaningful signal from the three surveys collectively, the survey data seem to be heavily influenced by random fluctuations, rendering any collective signal meaningless. In fact, there is virtually no correlation among the horseshoe crab abundance data from the three surveys.[29] The resulting unified abundance estimate provides a false veneer of certainty, masking an underlying reality of random noise.

In addition, the CMSA does not adjust for confounding factors that skew the survey data. The number of horseshoe crabs counted in the surveys can be impacted by seasonality, water temperature and depth, and other factors. But the CMSA does not adjust for these impacts, allowing the data to remain skewed.

By adjusting for these confounding factors and reanalyzing the data, Dr. Shoemaker made two striking findings: first, in contrast to the ARM model's finding that horseshoe crabs are recovering, the trawl surveys do not indicate any upward trend in the population of female horseshoe crabs in Delaware Bay.[30] And second, the three surveys are even less correlated with each other—and more likely to reflect random noise—than they previously appeared.[31]

This new analysis supplements the analysis that Dr. Shoemaker performed prior to the approval of Addendum VIII, detailing serious deficiencies in the CMSA's evaluation of horseshoe crab data. For example, Dr. Shoemaker previously showed that:

- The CMSA does not properly account for uncertainty in its horseshoe crab abundance projections.[32] It treats the potential for inherent biases—which could persistently skew the model's projections too high or too low—as if they were year-to-year variations that would cancel each other out over time. If the CMSA properly accounted for uncertainty, it would show that horseshoe crabs face a realistic risk of falling to extremely low levels even in the absence of any harvest (bait or biomedical) or discard mortality.

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[29] *See id.* at 17-19.
[30] *See id.* at 28-33.
[31] *See id.* at 17-19. While Dr. Shoemaker adjusted the trawl survey data for confounding factors, the trawl surveys remain unsuitable for quantifying the correlation between horseshoe crabs and red knots. Even with adjusted data, the surveys appear inherently random and vastly inferior to egg density data as a corollary to red knot survival. Instead, Dr. Shoemaker's analysis reveals that the trawl survey data are completely uncorrelated, and, even using the ARM model's preferred data source, horseshoe crab abundance is not increasing.
[32] *See* Shoemaker 2022 Analysis 12-18.

- For years when horseshoe crab recruitment data were not available, the CMSA filled in numbers that are absurdly higher than the estimates from any year with empirically observed data, resulting in significantly inflated long-term abundance projections.[33]

The Addendum VIII comments also presented analysis by Dr. Romuald Lipcius highlighting many worrying trends in the trawl survey data from Virginia Polytechnic Institute (which collects the most detailed demographic information on horseshoe crabs in Delaware Bay). For example, the Virginia Tech survey data indicate that the body size of female horseshoe crabs in Delaware Bay is decreasing, the ratio of females to males is decreasing, and the number of newly mature females is disturbingly low, among other troubling developments.[34] As Dr. Lipcius explained, these are not the trends that one would expect to find in a recovering population, especially one in which females have been protected from harvest.[35]

The prior analyses, together with Dr. Shoemaker's new analysis, strongly suggest that horseshoe crabs are not recovering in Delaware Bay. They require protection for their own sake, as well as for the nourishment that their eggs provide to red knots and other species. They certainly should not be harvested at levels recommended by a model that misrepresents the condition and trajectory of both of the species that it considers.

III. IMPLEMENTING THE ARM MODEL'S RECOMMENDATIONS WOULD POSE A PROFOUND RISK OF VIOLATING THE ENDANGERED SPECIES ACT.

In their Addendum VIII comments, New Jersey Audubon and Defenders of Wildlife cautioned that, by utilizing the ARM model, ASMFC would risk violating the Endangered Species Act. The ESA prohibits any person from "tak[ing] any [endangered] species within the United States or the territorial sea of the United States."[36] Such prohibited "take" includes actions that "harm" listed species, including "significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding or sheltering."[37] The ESA's "take" prohibition extends to governmental authorization to third parties to conduct activities that themselves result in unauthorized incidental take, thus "solicit[ing]" or "caus[ing]" an offense.[38] By virtue of a regulation in effect at the time the red knot was listed as threatened, the statutory take prohibitions apply to the take of many USFWS-listed threatened species, including the red knot.[39]

The Addendum VIII comments explained that ASMFC would likely commit a take by authorizing a harvest of female horseshoe crabs, impairing red knots' ability to feed. While the Board did not accept the model's recommendation to authorize a female harvest for 2023, that

[33] *See id.* at 22-24.
[34] *See* Romuald Lipcius, *Expert Report* 6, 10 (Sept. 2022), *in* Addendum VIII comments (attached).
[35] *See id.* at 4-5.
[36] 16 U.S.C. § 1538(a)(1)(B).
[37] 50 C.F.R. § 17.3.
[38] *Strahan v. Coxe*, 127 F.3d at 163; 16 U.S.C. § 1538(g).
[39] 50 C.F.R. § 17.31(a) (applying the provisions of § 17.21 (addressing endangered species) to threatened species listed on or prior to September 26, 2019, unless USFWS has promulgated a species-specific rule); *id.* § 17.21(a), (c) ("[I]t is unlawful . . . to solicit another to commit or to cause to be committed" the taking of an endangered species.).

remains a threat for future years due to the ARM model's proclivity for recommending a substantial female harvest quota.

Because the model does not accurately represent the relationship between horseshoe crabs and red knots, it offers no useful guidance on whether *any* particular harvest level amounts to a take. Notably, while much of the discussion around the ARM model has addressed the risk of a female horseshoe crab harvest, the model is similarly unable to assess the risk posed by a male harvest. In this information void, allowing any horseshoe crab harvest is a roll of the dice.

The Endangered Species Act requires a precautionary approach. As the Supreme Court has stated, "Congress has spoken in the plainest of words, making it abundantly clear that the balance has been struck in favor of affording endangered species the highest of priorities, thereby adopting a policy which it described as 'institutionalized caution.'"[40] In line with that principle, the ARM framework's stated objective includes "*ensur[ing]* that the abundance of horseshoe crabs is not limiting the red knot stopover population or slowing recovery."[41] It would be inconsistent with Endangered Species Act requirements (and the ARM framework's objective) to utilize a model that, among other deficiencies:

- by virtually disregarding the correlation between red knots and horseshoe crabs, fails to appreciate the importance of the very resource that it is managing for;
- takes no account of egg density on the beach surface—the one datapoint that directly measures whether the horseshoe crab population is providing adequate nutrition for red knots;
- significantly misapprehends the life cycle of red knots, vastly overestimating their lifespan;
- through an overparameterized model, incorrectly concludes that there are trends in red knot abundance even when no trends exist;
- generates horseshoe crab abundance estimates from trawl surveys that are heavily influenced by random noise; and
- produces erroneously optimistic projections of horseshoe crab abundance while disregarding multiple, persistent negative trends in horseshoe crab demographics.

Without a clearer understanding of the impact of the horseshoe crab harvest, the only lawful, precautionary, and ecologically defensible approach is for the Board to set conservative (if any) bait harvest levels. Certainly, no reauthorization of a female bait harvest could be defensible under these circumstances.

Moreover, as explained in the Addendum VIII comments, ASMFC cannot rely upon USFWS's statement that the ARM model's harvest recommendations would "pose[] negligible risk to red knot recovery and negligible risk of take."[42] USFWS's evaluation was based entirely on the model's own outputs and thus harbors all of the flaws inherent in the model itself. In particular, the evaluation accepts that the correlation between horseshoe crab abundance and red knot success is minimal without considering other evidence of a correlation (like egg density).

[40] *Tenn. Valley Auth. v. Hill*, 437 U.S. 153, 194 (1978).
[41] ASMFC, *ARM Report* 25 (emphasis added).
[42] FWS Evaluation 3.

Unsurprisingly, it concludes that "there is a very small probability (<1%) ARM management will result in a lower abundance of red knots."[43]

By merely repackaging the ARM model's findings, the USFWS evaluation never provided significant additional information about the effects of implementing the model's recommendations. Dr. Shoemaker's new analysis highlights additional flaws in the model and, by extension, in the USFWS evaluation, demonstrating that the evaluation is even less informative than previously known. The USFWS evaluation lends no independent factual or legal support for the Board's reliance on the ARM model.

IV. THE ONGOING STAKEHOLDER SURVEY CANNOT JUSTIFY A RESUMPTION OF THE FEMALE HORSESHOE CRAB HARVEST.

It is imperative that the Board base horseshoe crab harvest quotas "on the best scientific information available"[44] and the requirements of the ESA. As detailed extensively in the comments above and the attached analyses and comments, the ARM model does not provide a firm scientific basis for setting horseshoe crab bait harvest quotas and cannot predict the impact of its recommended quotas. Implementing those quotas would therefore imperil the ecosystem in ways that the Board cannot foresee. In the absence of reliable information about what harvest levels the ecosystem can sustain, the only scientifically defensible approach is to set highly conservative harvest quotas—continuing the prohibition on harvesting females and certainly not increasing male harvest quotas from current levels.

The results of a stakeholder survey cannot alter the Board's obligation to make scientifically grounded and legally sound management decisions. But to the extent that the Board also considers public opinion, the Board must respect the overwhelming opposition to a female horseshoe crab bait harvest expressed in the comments submitted on Addendum VIII last year. The Board's comment solicitation yielded 34,631 submissions, all but 5 of which opposed the adoption of the new ARM model—a tally that reflected the public's "[o]pposition to female horseshoe crab harvest."[45] Although the Board approved the new ARM model, it appropriately rejected the model's recommendation to authorize a female harvest, "[a]cknowledging public concern about the status of the red knot population in the Delaware Bay."[46] Shortly after the Board's decision to adopt the revised ARM model but decline to adopt its recommendation for 2023, the chair of the subcommittee responsible for the ARM model wrote:

> [T]here is absolutely no appetite for female harvest from any stakeholder. Not only were the shorebird advocates strongly against any resumption of female harvest, but it appears that the bait industry is completely satisfied with male only harvest. . . . [W]hen ASMFC is asked by NGOs in the media where the pressure for female harvest is coming from, it's really coming from us scientists in our

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[43] *Id.*
[44] ASMFC, *Interstate Fisheries Management Program Charter* § 6(a)(2) (Aug. 2019).
[45] *See* Memorandum from Caitlin Starks on Public Comment on Draft Addendum VIII to the Horseshoe Crab Fishery Management Plan 1 (Oct. 20, 2022), *in* ASMFC, Materials for the 2022 Annual Meeting of the Horseshoe Crab Management Board, http://www.asmfc.org/files/Meetings/2022AnnualMeeting/HorseshoeCrabBoard_Nov2022.pdf.
[46] ASMFC, *supra* note 6.

> desire to find an optimal solution to the problem statement. Perhaps our problem statement is no longer applicable in this situation.[47]

While the Board maintained protections for female horseshoe crabs in 2023, it did not resolve whether those protections would extend to future years. Instead, the Board expressed interest in a process "with stakeholders and managers and scientists, to try to help better inform future goals and objectives and modeling approaches" and "to really start to talk about what our goals and objectives are for both the fishery and the ecosystem."[48] In a subsequent meeting, Board members repeatedly conveyed that the primary objective of the stakeholder engagement was to determine whether any public appetite exists for a female bait harvest—and if not, to adjust the management framework accordingly.[49] After reviewing options for stakeholder engagement, the Board opted to proceed with a survey. Unlike the public comment period, however, this survey would seek the perspectives only of hand-selected respondents, not all interested members of the public.[50]

The public has already spoken on this issue. Whatever the outcome of the stakeholder survey, the Board must respect the overwhelming opposition to a female harvest expressed in the public comments on Addendum VIII. The entire public, including everyone invited to participate in the stakeholder survey, had the opportunity to weigh in during the public comment period, but only a small fraction of commenters were invited to complete the survey. ASMFC appears to be denying requests for additional stakeholders—even longtime horseshoe crab advocates—to complete the survey, and it has denied a request to disclose the list of people who received the survey.[51] This method of secretive, restricted engagement falls far short of ASMFC's obligation to "provide adequate opportunity for public participation."[52] Public transparency is essential

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[47] Email from John Sweka to Conor McGowan, David Smith, James Lyons, Clinton Moore, Anna Tucker, Richard Wong, Kristen Anstead, Caitlin Starks (additional recipients redacted) re Kristen's presentation to the HSC board (Nov. 17, 2022) (obtained via FOIA).

[48] Comments of Shanna Madsen 28, *Draft Proceedings of the Horseshoe Crab Management Board Hybrid Meeting: November 2022* (as approved at the May 2023 meeting), https://www.asmfc.org/files/Meetings/2023SpringMeeting/May3/HorseshoeCrabManagementBoard_May2023.pdf.

[49] *See, e.g.*, *Horseshoe Crab Board Proceedings May 2023*, at 1:00:21, https://www.youtube.com/watch?v=QFw9N1LJF-A, Comments of John Clark ("We decided to move ahead with this item to see what we want to do in the future 'cause of course, if there is no desire for female harvest, that's a whole different way to manage the species."); *id.* at 1:03:47, Comments of Shanna Madsen ("I'd like to see us start with option one, which is putting together a survey to ask that very direct question: do our constituents want us to harvest female horseshoe crabs? And if the answer is no, then I think that really helps us outline what that objective statement is."); *id.* at 1:05:48, Comments of Rick Jacobson ("I agree, too, with the previous speakers that we do have a fundamental question that we need to ask ourselves first: what is the public appetite for the harvest of female horseshoe crabs from Delaware Bay? It is a critical question.").

[50] *See id.* at 1:12:21, Comments of ASMFC Fisheries Policy Director Toni Kerns ("I just want to make it clear that it's not our intention to send this survey to the world. We intend to hit the major stakeholders. . . . We're not trying to exclude the public, but we have just done a management document where we received, how many, 34,000 comments, and we heard from the general public on their intentions, and we still want to make sure we're capturing all the stakeholders here, but we're also not looking for that many comments to have to summarize in order to provide feedback to this Board.").

[51] *See* email from Caitlin Starks to Susan Linder denying request for survey (Aug. 24, 2023); email from Toni Kerns to Susan Linder denying request for list of survey recipients (Sept. 13, 2023). The stated rationale for withholding the list of survey recipients was to preserve the anonymity of responses, but no information about responses was requested.

[52] ASMFC, *Interstate Fisheries Management Program Charter* § 1(c).

when setting harvest quotas for a public resource. The Board must not discount public comments based on feedback from a limited, undisclosed group of hand-selected survey recipients.

V. CONCLUSION

Independent analysis powerfully demonstrates that the ARM model is not suitable for managing the bait harvest of Delaware Bay-origin horseshoe crabs. The ARM model entirely fails to accurately represent what scientific study of the relationship between red knots and horseshoe crabs has already incontrovertibly established—that robust horseshoe crab populations capable of generating a superabundance of eggs on red knot stopover beaches are critical for the red knot's survival and reproduction. The model is oblivious to the strong correlation between red knots and horseshoe crabs and misconstrues data about each species, creating an unbridgeable chasm between its harvest recommendations and actual ecological conditions. Consistent with the Endangered Species Act and its own stated objective to protect red knots, as well as its obligation under the Interstate Fisheries Management Program Charter to base its decisions about horseshoe crab harvest quotas on the best available scientific information, the Board must not implement the model's recommendations. The Board's obligation includes, at a minimum, maintaining the zero-harvest bait quota for female horseshoe crabs and not increasing male-only harvest quotas from current levels.

Review of the Atlantic States Marine Fisheries Commission's (ASMFC) Adaptive Resource Management (ARM) framework for regulating Horseshoe Crab bait harvest in Delaware Bay

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This is an expert review of the Atlantic States Marine Fisheries Commission (ASMFC)'s Adaptive Resource Management (ARM) framework – which has been approved for use in managing the Horseshoe Crab fishery in Delaware Bay – performed by Kevin Shoemaker, Ph.D. This document is intended to supplement the review of the ARM completed by Dr. Shoemaker in Fall 2022.

Dr. Shoemaker holds a Ph.D. and an M.S. in Conservation Biology from SUNY-ESF in Syracuse, NY, and a B.S. degree in Biology from Haverford College. He was a Postdoctoral Fellow in the Department of Ecology and Evolution at Stony Brook University and has served as Senior Scientist at Applied Biomathematics, an ecological research and development company located in Setauket, NY. Dr. Shoemaker is currently an Associate Professor at the University of Nevada, Reno, where he uses quantitative models to inform wildlife conservation and management. He has over 15 years of experience as a wildlife ecologist and conservation modeler and has authored over 50 peer-reviewed scientific articles and book chapters on topics in ecology and conservation. He has expertise in Bayesian inference, population ecology, population viability analysis (PVA) and ecological modeling.

OVERVIEW

This report reviews the scientific merits of the Adaptive Resource Management (ARM) framework that has been approved for use by the Atlantic States Marine Fisheries Commission (ASMFC) as a tool for guiding management of the horseshoe crab (HSC) fishery in Delaware Bay and protecting the Federally Threatened *Rufa* Red Knot (*Calidris canutus rufa*; REKN). In Fall 2022

I completed an initial review of the ARM, in which I pointed out five major areas of concern: (1) the fitted relationship linking HSC abundance to REKN survival was functionally insignificant as a driver of REKN population dynamics, (2) the HSC simulation model did not correctly address parameter uncertainty, (3) the statistical model used to estimate HSC demographic processes (Catch Multiple Survey Analysis, or CMSA) exhibited poor fit to the data, (4) the CMSA results were compromised by a 4-year period during which a key source of data was not collected, and (5) the ARM lacked performance benchmarks (null models) to ensure that key model components (e.g., the effect of HSC abundance on REKN survival) meaningfully improved predictive performance versus simpler approaches. The purpose of this follow-up report is to evaluate components of the ARM for which the source code was unavailable for evaluation in my initial review. In particular, I focus on the Integrated Population Model (IPM) approach used by ASMFC for estimating REKN demographic parameters and for quantifying the influence of HSC abundance on the REKN population.

Delaware Bay is a critical stopover site used by REKNs and other shorebirds as they migrate to breeding grounds in the high arctic from their wintering grounds as far south as Tierra del Fuego (USFWS 2021). In particular, HSC eggs deposited on coastal beaches provide a necessary high-calorie food resource for REKNs and other migrating shorebird species as they replenish fat reserves depleted from their long migration and prepare for breeding. At the heart of ASMFC's ARM framework is a set of 'harvest functions' for setting HSC harvest recommendations on the basis of annual estimates of HSC and REKN abundance. In theory, these harvest functions are calibrated to maximize HSC harvest yields while causing minimal risk to the HSC or REKN populations. Optimization of the harvest functions is accomplished by running numerous alternative harvest scenarios using a two-species (HSC and REKN) demographic simulation model and weighing the benefits (harvest) and costs (population risks to HSCs and REKNs) of the simulated outcomes. The cornerstone of this two-species demographic simulation model is a weak (but statistically conclusive) positive effect of female HSC abundance on REKN survival, which serves as a formal, quantitative linkage between the two species. Therefore, the validity of the ARM framework depends upon proper specification of each species' demographic rates (e.g., survival and recruitment) and the degree to which the modeled HSC-REKN interaction is an appropriate representation of the real-world biotic interaction between these species.

Building on the issues raised in my initial review, this report identifies six additional areas of concern (see below). Based on these concerns, I conclude that the ARM framework is not useful for managing risk to the REKN population due to HSC harvest. Furthermore, my results suggest that the revised ARM misrepresents the importance of HSCs to the REKN population and thereby underestimates both the existential risk to the REKN population posed by female HSC harvest and the potential for promoting REKN recovery through increased regulatory protections and conservation efforts aimed at promoting HSC population increases in the Delaware Bay region. The six primary areas of concern are summarized below, with technical details provided in the "supporting evidence and analyses" section.

(1) **Estimates of REKN survival used in the ARM appear to be artificially inflated, likely resulting in falsely optimistic estimates of population resilience**. The majority of previously reported estimates of annual survival for REKNs and similar shorebirds are in the neighborhood of 80%, corresponding to an average lifespan of approximately five years. In contrast, ASMFC reported a mean annual REKN survival estimate of 0.93, which corresponds to an expected lifespan of nearly 15 years. By nearly tripling the expected REKN lifespan *vis-a-vis* previous estimates, ASMFC is effectively classifying the REKN as a uniquely long-lived species among medium-sized shorebirds. Since individual females must only replace themselves once during their lifetime (on average) for a population to be stable, longer-lived species can afford a higher per-capita failure rate in breeding attempts than shorter-lived species. Therefore, long-lived species are expected to be more resilient to short-term fluctuations in recruitment. However, my findings strongly indicate that ASMFC's estimate of REKN survival is biased high due to the presence of misread errors (by which a flag code is mistaken for a code previously deployed on a different bird). The potential for misread errors in the study system has been previously acknowledged (Tucker et al. 2019). After correcting for potential misread errors, REKN survival estimates fall to approximately 80% annually – a rate more consistent with previous estimates for REKN and similar species. The apparent positive bias in ASMFC's survival estimates is likely to result in falsely optimistic estimates of population resilience to short-term environmental fluctuations, raising

concerns about the adequacy of the ARM framework for assessing population-level risks to this federally Threatened species.

(2) **Trawl-based indices of HSC abundance are inadequate for detecting robust links to REKN demography**. ASMFC documented a very weak (and not ecologically meaningful; see attachment) positive effect of female HSC abundance on REKN survival. This relationship is the cornerstone of the revised ARM framework, as it represents the primary functional link between the two focal species. The effect of HSC abundance on REKN survival was estimated using the output from a Catch Multiple Survey Analysis (CMSA) as a proxy for annual HSC abundance in Delaware Bay. The CMSA in turn was trained using data from three trawl-based surveys, conducted by Virginia Tech, New Jersey, and Delaware, respectively (in addition to data on known sources of HSC mortality). However, my reanalysis of the available data uncovered no conclusive relationship between REKN survival and any trawl-based index of HSC abundance. Notably, after including several additional years of REKN mark/resight data (I used REKN banding and resighting data from 2003 through 2022, whereas ASMFC's used data from 2005 to 2018), the effect of HSC abundance on REKN survival became negative (lower REKN survival with more female HSCs) when using the code and data provided by ASMFC. This result underscores the frailty of the foundational relationship on which ASMFC's two-species ARM is based. Trawl-based surveys are necessarily imperfect snapshots of the abundance of HSCs occupying Delaware Bay, obscured by differing survey methodologies and poorly understood aspects of HSC ecology, including seasonal and daily activities, habitat preferences, and degree of clustering on the seafloor. Moreover, the functional link between HSC abundance and REKN demographic rates is eroded by additional, poorly understood processes that govern the availability of HSC eggs for shorebirds, including variation in the timing of HSC egg deposition and the factors that dislodge eggs from their clusters, rendering them accessible to shorebirds. Therefore, the lack of a demonstrable effect of trawl-based HSC indices on REKN vital rates likely reflects the weakness of these indices and not the weakness of the underlying biotic interaction.

(3) **REKN survival is strongly sensitive to HSC egg-density, indicating that persistent**

degradation of the HSC egg resource could have dire consequences for the REKN population. Intuitively, surveys of HSC egg densities measured on the same beaches used by foraging shorebirds during their spring migration should more directly capture the biotic interaction between these two species. Although researchers have been consistently measuring the surface density of HSC eggs at multiple beaches across Delaware Bay (NJ side only) since 2000, ASMFC chose to rely on trawl-based surveys instead of egg-density surveys as a proxy for the HSC resource available to REKNs. My reanalysis of the Delaware Bay mark-resight database indicates that REKN survival is strongly and positively influenced by annual fluctuations in HSC egg density. Unlike the weak relationship documented in the ARM, the fitted relationship between HSC egg-density and REKN survival implies severe risks to the REKN population under a scenario of sustained low HSC egg densities. In contrast to ASMFC's two-species ARM, this alternative characterization of the HSC-REKN interaction is capable of explaining the observed decline in REKN populations during the late 20th century, which is widely attributed to unregulated harvest of HSCs in Delaware Bay. These new results strongly suggest that ASMFC's ARM framework misrepresents the importance of HSCs to the REKN population. As a result, the ARM not only severely underestimates the consequences of HSC population declines on the REKN population, but it severely underestimates the critical role that a rebound of the HSC population could play in the recovery of this federally Threatened species.

(4) **The ARM exaggerates the evidence for an increasing trend in the number of female HSCs in Delaware Bay.** Based on my reanalysis, neither the trawl-based surveys used by ASMFC nor the egg-density surveys (recently used to document an increasing trend in the HSC population) show strong evidence for increasing abundance of female HSCs in Delaware Bay over the last 20 years. As a case in point, the raw data (catch-per-unit-effort; CPUE) from New Jersey's ocean trawl survey (one of the data sources used by ASMFC for documenting a positive trend in HSC abundance) appears to indicate increasing female HSC abundance over time (statistically significant at alpha=0.05); however, when the raw CPUE numbers are adjusted for strong effects of seasonality, water temperature, depth and dissolved oxygen on HSC captures in Delaware Bay (NJ ocean trawl survey), the apparent positive trend in

HSC CPUE becomes inconclusive. Notably, the trawl-based indices used by ASMFC in their CMSA model did not control for these confounding factors. Therefore, the increasing trend in the HSC population reported by ASMFC and used in the ARM may be an artifact of differing survey conditions (e.g., differences in trawl depth or water temperature) rather than evidence of recovery of the HSC population over time. Furthermore, regression models combining the CPUE estimates (both adjusted and unadjusted) from all three trawl-based surveys showed no conclusive evidence for a trend in HSC abundance over time. Similarly, when the egg-density data were adjusted for known differences in survey methodologies, the apparent positive trend (reported in Smith et al. 2022) became inconclusive (note that this adjustment did not impact the estimated relationship between REKN survival and HSC egg-densities). Overall, my reanalysis suggests that the ARM framework exaggerates the potential for recovery of the female HSC population under present conditions, and thereby likely underestimates the risk of harvest to the HSC (and REKN) populations in Delaware Bay.

(5) **The statistical model (IPM) used for estimating REKN population parameters is over-parameterized and likely to yield spurious results**. The IPM framework used to train the REKN population model comprises two integrated sub-models: (1) a "state-space" model for estimating abundance and recruitment on the basis of population counts over time, and (2) a "capture-recapture" model for estimating survival rates from observation records of uniquely marked individuals. Whereas the data available for fitting the capture-recapture model (over 100,000 resighting records of tens of thousands of unique REKN individuals) was information-rich and well-suited for training complex models, the data available for training the state-space model was sparse by any standard, comprising 14 unique data points (one count per year from 2005 to 2018). In fact, the number of parameters estimated in the state-space model appears to exceed the number of data points. As an analogy, consider a parachute whose canopy is attached to its user with suspension cords. A minimum of three cords is necessary for the parachute to have any chance of operating correctly, yet many more cords are typically incorporated to ensure robust performance. Similarly, a free parameter (an "unknown") must be tethered to the truth using data points

as suspension cords. A model's claim to truth strengthens as the ratio of data points to free parameters increases; statisticians often recommend a ratio exceeding 30 or more for robust model performance. With less than 1 data point per parameter, the IPM's state-space model is occupying a danger zone statisticians refer to as "over-parameterization", or "over-fitting". Over-parameterized models have a strong tendency to produce spurious results (results that fail to replicate when confronted with new data). To confirm the tendency of the REKN IPM to yield spurious results, I generated artificial REKN count data under a model with no underlying trend (a white-noise process) and assessed how often the IPM erroneously detected a trend. After running 50 replicates (iteratively replacing the peak-count data with newly simulated white-noise), the IPM falsely detected an ecologically meaningful temporal trend (increase or decline in abundance over time) over 80% of the time. Among the unknown quantities estimated from the 14 peak-count data points are several terms critical for understanding and forecasting REKN population dynamics, including initial abundance, population trends (growth or decline), mean recruitment, and the effect of HSC abundance on recruitment. Lacking sufficient data for parameter estimation, the REKN recruitment and population trend estimates used in the ARM model are more likely to reflect random noise in the peak count data rather than the demographic reality of the REKN population. Therefore, the REKN demographic simulations used in the ARM should not be considered a robust representation of the real-world population of *Rufa* Red Knots that uses Delaware Bay each year.

(6) **The IPM exhibits poor fit to the observed REKN data**. Goodness-of-fit (GOF) testing is a critical validation step in any model-fitting workflow, ensuring that key assumptions made during the modeling process are reasonable and justified. For example, the results from a linear regression or ANOVA test can only be interpreted once the analyst confirms that important assumptions are satisfied (e.g., that model residuals are approximately normally distributed). Although the REKN IPM is much more complex than a linear regression model, assessing goodness-of-fit is no less important. In the context of hierarchical Bayesian analysis (the paradigm used by ASMFC to fit the REKN IPM), a commonly used approach is to run a Posterior Predictive Check (PPC), in which data are repeatedly simulated under the

fitted model and compared to the actual data. If a model is unable to generate data resembling what was actually observed, the model is determined to be an inadequate representation of the true processes that generated the data. In their ARM report, ASMFC mentions (but does not further document) two PPCs that were performed to assess goodness-of-fit. One of these tests – the only test included in the publicly shared IPM code – uses a PPC to assess the degree to which the state-space model adequately represented the 14 peak-count data points. However, this test has been shown to be an insufficient gauge of model adequacy. The second and final goodness-of-fit test mentioned in the ARM report (for which the result suggests moderate lack of fit) is absent from the version of the IPM code shared publicly, so it is not possible to assess what test was actually run. However, I ran three additional PPCs to assess the degree to which the IPM adequately represented the REKN resighting data from 2003 to 2022. These tests, which were applied and reported in an earlier version of the open-robust-design (ORD) model for estimating REKN survival and stopover use (Tucker et al. 2021), indicated poor fit to the data, suggesting that the IPM is an inadequate representation of key processes operating in the REKN population – including survival. The failure of the IPM to pass rigorous goodness-of-fit tests casts additional doubts on the conclusions generated from this model.

SUPPORTING EVIDENCE AND ANALYSES

The remainder of this report supplies supporting details for the six major areas of concern identified above, including results and figures from re-analyses of the data presented in the ARM report. I report additional findings in the “supplemental analyses” section located at the end of this report.

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

The majority of published survival estimates for REKNs and other medium-sized shorebirds indicate a mean annual survival of approximately 80% (Baker et al. 2004; Piersma et al. 2016; Mendez et al. 2018), corresponding to an expected lifespan of approximately five years. In contrast, ASMFC reported a mean adult REKN survival rate of 0.93 on the basis of the REKN IPM, corresponding to an expected lifespan of nearly 15 years. By nearly tripling the expected REKN lifespan (versus previous estimates), ASMFC is effectively classifying the REKN as a longer-lived species than other similar-sized shorebirds (Mendez et al. 2018). Since a stable population requires only that individual females replace themselves once during their lifetime, longer-lived species can afford to fail in more of their breeding attempts than shorter-lived species. Therefore, longer-lived species are expected to be more resilient to short-term fluctuations in breeding success and juvenile survival than species with a shorter lifespan (Lovich et al. 2015). ASMFC argues that their characterization of the REKN life history is accurate, and that previously reported estimates may be biased low (ASMFC 2021). In contrast, my findings strongly indicate that ASMFC's estimate of REKN survival is biased high, most likely due to the presence of misread errors in the REKN resighting database.

The presence of potential misread errors in the study system has been previously acknowledged (Tucker et al. 2019). Studies with simulated and real-world data have shown that misread errors can induce biases in survival estimates (Tucker et al. 2019; Rakhimberdiev et al. 2022). Because the data used to fit the REKN IPM was adjusted for one type of potential misread error (i.e., any observed flag codes that were never deployed in Delaware Bay were discarded), the only type of misread error that ASMFC did not account for was the possibility that a flag code was mistaken in the field for a different previously deployed code (effectively ascribing that observation to a bird that may no longer be alive). This type of misread error (if present in sufficient numbers) is known to falsely inflate survival, especially for the early years of a long-term mark-resight study (Tucker et al. 2019). Tucker et al. (2019) showed that this source of bias can be corrected by discarding observations for which a flag code was sighted only once (i.e., by a single observer during a single sampling occasion) in a given season. Although this technique necessarily discards some correct observations (only a fraction of these 'singlet' observations are likely to be in error) and thereby reduces the precision of the resulting estimates (Tucker et al. 2019; Rakhimberdiev et al. 2022), Tucker et al. (2019) demonstrated that this method was effective in removing biases induced by this class of misread error. Furthermore, Tucker et al. (2019) demonstrated that, when applied to the flag-resighting data from Delaware Bay, REKN survival estimates from early in the study period dropped from 87% to 81%, suggesting that these survival estimates were artificially inflated due to misread errors.

The number of leg-flag codes that can be manufactured is necessarily limited by the number and type of symbols and colors used. Notably, given the very large number of leg flags that have been deployed on REKNs in Delaware Bay since 2003, shorebird biologists have cycled through all possible flag code permutations for the flag color (lime green) most commonly deployed in Delaware Bay. Therefore, any leg-flag codes that are read or transcribed in error are more likely to be falsely attributed to a different bird in the database than to be discarded (as it would be if there were no match in the database). Furthermore, the risk of this type of error is likely to increase substantially as the years pass and as a greater fraction of flag code permutations are deployed in the field. Coupled with the fact that longer time series are likely to manifest increasingly strong biases due to misread errors (Tucker et al. 2019) the risk of biased survival estimates and spurious trends is likely to increase markedly as the database continues to grow (e.g., in future iterations of the ARM model if potential misread errors continue to be ignored).

To assess whether ASMFC's survival estimates were biased due to the inclusion of misread errors, I used REKN banding and resighting data from Delaware Bay to estimate annual REKN survival using two different statistical frameworks: Cormack-Jolly-Seber (CJS; a standard approach to survival estimation using capture-recapture data) and the open-robust-design (ORD) framework for survival estimation used by ASMFC. First, I ran standard CJS models to estimate annual survival rates as a function of the banding data only (Cooch 2008) (i.e., ignoring all flag-resighting data). This model generated separate estimates of survival and detection probability for each year, and included additional terms for transience and 'trap-response' (Pradel and Sanz-Aguilar 2012). The banding data were much less information-rich than the re-sighting observations, with far fewer observations and a much lower re-capture rate. However, misread errors should be virtually absent from the banding records (as captured birds can be examined at close range). I trained this model (and all models presented in this section) using Markov Chain Monte Carlo (MCMC) in a Bayesian framework using JAGS (Plummer 2012), which was called from R using 'JagsUI' (Kellner et al. 2019). The 'band-only' models yielded an estimated mean annual REKN survival of 79% (Fig. 1). Based on a posterior predictive check (PPC), the Bayesian p-value for this model was 0.1, indicating reasonable fit, with the observed data slightly over-dispersed relative to the fitted model (Fig. 1).

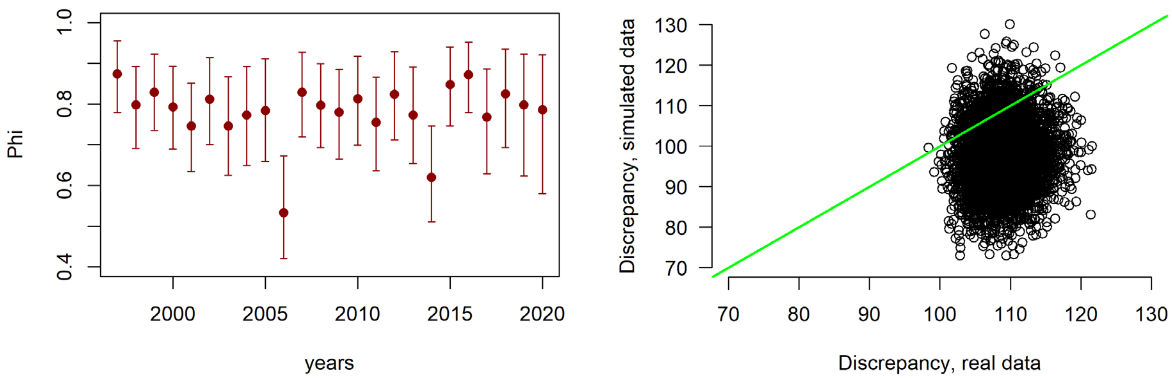

Figure 1*. Left: mean annual (apparent) REKN survival (y axis) based only on banding data (no resighting data) from Delaware Bay from 1997 to 2022, using a Bayesian CJS model. Mean estimated apparent survival was 0.79, much lower than ASMFC's estimate of 0.93. Apparent survival (Phi) is a compound parameter indicating the probability of surviving and remaining within the study area. This model accounts for the presence of transients, which can bias survival estimates low. Right: Goodness-of-fit plot for the Bayesian CJS model using only banding data from Delaware Bay. This model exhibited reasonable fit to the data, with a Bayesian p-value of 0.1.*

Next, I fitted CJS models that incorporated the resighting data along with the banding data. When potential misread errors (flag codes observed only once by a single observer in a given season) were retained for analysis, mean apparent survival across all years was ~88%, with a steady decline in survival observed over the period from approximately 2005 to 2015 (Fig. 2). When potential misread errors were removed, mean REKN survival estimates dropped to ~80% annually – a rate more consistent with previous estimates for REKNs and other similar-sized shorebirds (Fig. 2). After correcting for potential misread errors, no temporal trend in survival was apparent across the study period (Fig. 2). This pattern is consistent with the known effects of misread errors, which tend to induce a spurious negative trend in survival (more positively biased estimates going further back in time) for long-term studies (Tucker et al. 2019).

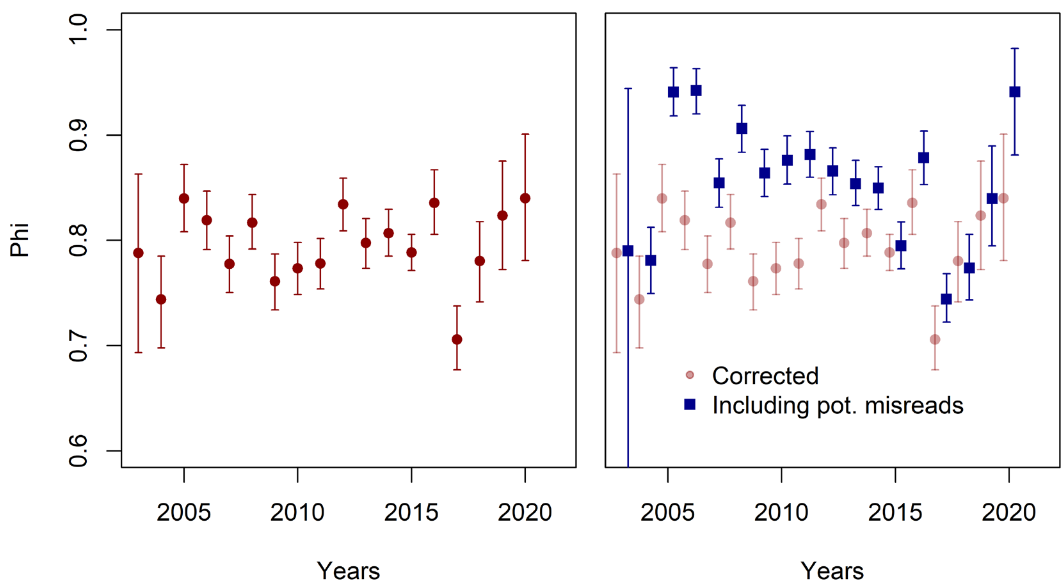

Figure 2*. Left: REKN annual apparent survival estimates (Phi; error bars indicate Bayesian 95% credible intervals) based on banding and resighting records from Delaware Bay, using a Bayesian CJS model with inter-annual process variance in survival, accounting for potential transients and 'trap response' (whereby individuals are more likely to be resighted if they were resighted in the previous year). This analysis uses only birds first banded in Delaware Bay (resighting observations of birds first captured elsewhere were discarded prior to analysis, following ASMFC 2021). To correct for misread errors, only birds resighted more than once in a particular year were considered to have been resighted that year. After correcting for potential misread errors, the estimated average apparent survival (Phi) was 0.80 annually, much lower than ASMFC's estimate of 0.93. Right: Comparison of REKN apparent survival with potential misreads (blue squares, including individuals resighted only once in a given year) versus the corrected version of the data with single-resight observations removed (transparent red; same results reported in left panel). As noted by Tucker et al. (2019), misread errors are more likely to bias survival estimates high in the early years of long time series- we see this effect here, especially in the period from 2005 to 2015.*

Finally, I used ASMFC's open robust design (ORD) framework to estimate annual REKN survival rates. This model, described by Tucker et al. (2022), is capable of estimating survival in addition to temporary emigration and the timing of arrival and departure from the stopover site each year. When potential misread errors are retained in the data set, the ORD model indicated a mean REKN survival rate of 0.9 (somewhat lower than ASMFC's estimate of 0.93, but similar to the survival rate reported in Tucker et al. 2022), with survival rates generally declining across the study period, as expected for data sets with misread errors (Tucker et al. 2019) (Fig 3). When potential misread errors were removed following the methods of Tucker et al. (2019), mean apparent survival rates dropped to ~80% or below throughout most of the 20-year study period, with no apparent trend over time (Fig. 3).

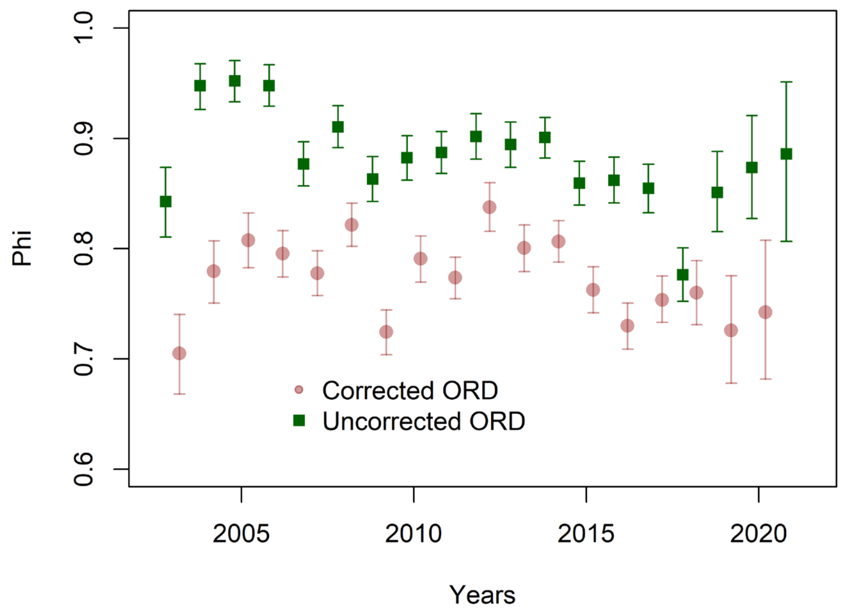

***Figure 3**. Annual apparent survival (phi; y axis) estimates from the open robust design (ORD) model used by ASMFC, fitted to REKN banding and resighting data from Delaware Bay from 2003 to 2022. Red circles and confidence intervals represent estimates from the model after correction for potential misread errors (i.e., by removing instances in which a REKN was re-sighted only once in a season). Estimated survival from the uncorrected ORD model (green squares; without correction for potential misread errors) are nearly always substantially higher than the corresponding estimates after accounting for potential misread errors. In addition, the uncorrected time series (green squares) displays the characteristic (spurious) negative trend in survival typically associated with survival estimates from long time series that include misread errors (Tucker et al 2019).*

Overall, these tests strongly indicate that the REKN survival rates used by ASMFC's ARM framework are artificially inflated and do not accurately reflect the real-world population of *Rufa* Red Knots. This artificially exaggerated longevity is likely to result in falsely optimistic estimates of REKN population resilience to short-term environmental fluctuations. In reality, the REKN population is likely to be much more vulnerable to one or two bad breeding years than the ARM model would suggest. The misspecification of the REKN demographic model raises serious concerns about the adequacy of the ARM framework for assessing population-level risks to this federally protected species.

2. Trawl-based indices of HSC abundance are inadequate for modeling the biotic interaction between REKNs and HSCs

ASMFC's IPM indicated a weak (and not ecologically meaningful; see attachment) positive effect of female HSC abundance on REKN survival. This relationship is in many ways the cornerstone of the ARM framework, as it represents the primary functional interaction between the two focal species. In the IPM, the effect of HSC abundance on REKN survival was trained using output from a Catch Multiple Survey Analysis (CMSA) as a proxy for female HSC abundance in Delaware Bay. In the CMSA, the HSC population was estimated on the basis of data from three trawl-based surveys (in addition to known sources of HSC mortality), conducted by Virginia Polytechnic Institute and State University (VT), New Jersey (NJ), and Delaware (DE), respectively.

I was able to obtain the survey records from each of the three Delaware Bay trawl surveys for reanalysis up to and including data from 2022. For my reanalysis, I only analyzed data on female HSCs due to their unique importance for REKNs. For each trawl survey, I generated a 'raw' annual catch-per-unit-effort (CPUE; often used as an indicator of abundance) by dividing the total number of female HSC captures by the total survey effort (generally reported as the length of seafloor surveyed). However, raw CPUE values do not control for other factors that can affect the number of expected HSC captures, such as time of year (seasonality), water temperature, salinity, depth, and dissolved oxygen. Therefore, comparing raw CPUE estimates across years can be misleading if (for example) the surveys were conducted at different seasons, or under disparate water temperatures or depths. To control for these unwanted effects, I used generalized linear models (GLM) and generalized additive models (GAMs) to model the number of female HSCs captured in each trawl survey as a function of seasonality (Julian date), water temperature, dissolved oxygen, salinity, and depth, using an offset term to account for differences in survey effort (tow length) among surveys (e.g., Fig. 10). Nonlinear responses were accommodated with quadratic terms or spline fits. All models assumed a negative binomial error distribution and a log-link. Models were fitted in R using the package 'glmmTMB' (Brooks et al. 2017), with goodness-of-fit assessed using the 'DHARMa' package (Hartig and Hartig 2017).

In my reanalysis I attempted to replicate the biotic interaction reported by ASMFC using trawl-based indices of female HSC abundance. Specifically, I used the REKN banding and resighting records from 2003 to 2022 (including 6 years of additional data relative to the ASMFC model, which only used data from 2005 to 2018) to model REKN apparent survival as a function of HSC several trawl-based indices of HSC abundance: (1) the CMSA results reported by ASMFC, (2) raw (unadjusted) and adjusted indices of HSC abundance from the DE, NJ and VT trawl surveys, and (3) design-based estimates of HSC abundance derived from the VT trawl survey (Wong et al 2022). In my reanalysis, I used conventional capture-recapture methods (Cormack-Jolly-Seber; CJS) in addition to the open-robust-design (ORD) framework used by ASMFC to estimate the effect of these indices on REKN survival.

Despite running multiple analyses with alternative trawl-based indices, my reanalysis efforts have uncovered no conclusive link between REKN survival and any trawl-based index of HSC abundance (including the CMSA-based indices used by ASMFC) (Table 1). Neither classical capture recapture methods (CJS) nor ASMFC's ORD method yielded evidence for a positive HSC-REKN relationship. Notably, the model that most closely resembled ASMFC's model – using the ORD framework for parameter estimation and the CMSA results as a proxy for HSC abundance – indicated a statistically significant *negative* effect of HSC abundance on REKN survival (Table 1). This surprising result is likely to be a spurious correlation, and should not be interpreted to suggest that higher HSC abundance in Delaware Bay leads to lower REKN survival (higher mortality). Critically, this result demonstrates that ASMFC's documented relationship between REKN survival and HSC abundance (upon which this two-species ARM framework is based) is unstable, underscoring the tenuousness and uncertainty of this critical relationship. Interestingly, this relationship could not be replicated even after (1) using the ORD parameter estimation framework and the code provided by the ASMFC modelers (2) reducing the dataset to cover the same period analyzed by ASMFC (2005 through 2018), (3) using the same CMSA-based estimates of female HSC abundance used by ASMFC, and (4) including the other time-varying covariates used in the ASMFC model (arctic snow cover and spawn timing). The instability of the HSC-REKN relationship reported by ASMFC suggests both that it is unlikely to be meaningful reflection of reality and that it is a poor foundation upon which to base a two-species risk assessment framework.

Table 1*. Tests of alternative HSC abundance indices as drivers of REKN survival. Gray shading reflects non-significant results (95% CI overlaps zero, suggesting coefficient could plausibly be positive or negative), green shading reflects significant positive coefficients (more HSC implies higher REKN survival), light green shading represents weakly (marginally) significant positive coefficients, and red shading reflects significant negative coefficients (more HSC implies lower REKN survival).*

HSC Abundance index	HSC survey type	Survival coef, CJS	Survival coef, ORD
CMSA (uses DE, NJ and VT), 2005-2018	Ocean Trawl	0.02 (-0.18 to 0.22)	-0.18 (-0.31 to -0.06)
Virginia Tech (VT), abundance estimate	Ocean Trawl	-0.03 (-0.21 to 0.23)	-0.24 (-0.45 to 0.00)
Virginia Tech, CPUE	Ocean Trawl	0.23 (-0.01 to 0.54)*	-0.19 (-0.37 to -0.02)
Virginia Tech, CPUE adjusted	Ocean Trawl	0.01 (-0.18 to 0.18)	0.08 (-0.12 to 0.26)
DE trawl, CPUE**	Ocean Trawl	0.01 (-0.14 to 0.18)	-0.14 (-0.31 to 0.04)
DE trawl, CPUE adjusted**	Ocean Trawl	-0.02 (-0.17 to 0.17)	-0.10 (-0.27 to 0.09)

NJ trawl, CPUE	Ocean Trawl	-0.05 (-0.31 to 0.15)	-0.16 (-0.32 to 0.10)
NJ trawl, CPUE, adjusted	Ocean Trawl	-0.07 (-0.28 to 0.09)	0.09 (-0.16 to 0.28)
Delaware Bay Spawning Survey	Beach survey	0.02 (-0.18 to 0.27)	-0.09 (-0.26 to 0.12)
NJ Surface Egg Density	Beach survey	-0.08 (-0.24 to 0.06)	-0.09 (-0.29 to 0.09)
NJ Surface Egg Density (NJ REKN data only)***	Beach survey	0.29 (0.07 to 0.52)	0.32 (0.01 to 0.58)

*This relationship has weak statistical support but could be interpreted as evidence for a positive effect of HSC abundance on REKN survival.

*** Data provided on Aug 10, 2023. This work does not represent the opinions of the State of Delaware, Delaware Department of Natural Resources and Environmental Control or Delaware Division of Fish & Wildlife

*** This analysis used REKN capture and recapture records from the NJ side of the bay, since surface egg density was only collected on the NJ side of the bay.

The lack of a demonstrable effect of trawl-based HSC indices on REKN survival (Table 1) likely reflects the weaknesses of these indices rather than the weakness of the underlying biotic interaction. Trawl-based surveys are highly imperfect snapshots of the population of HSCs inhabiting Delaware Bay, obscured by differing survey methodologies and poorly understood aspects of HSC ecology, including seasonal and daily activities, habitat preferences, and degree of clustering on the seafloor. Furthermore, trawl-based surveys ignore that REKNs and other shorebirds do not feed on HSCs directly, but instead use their eggs to fuel their northward migration; therefore, the utility of trawl-based indices may be further eroded as a useful metric by additional, poorly understood processes such as annual variation in the timing of HSC egg deposition and the processes that dislodge eggs from their clusters and thereby render the eggs accessible to shorebirds.

To assess the degree to which the Delaware Bay trawl survey results reflected signal about true annual fluctuations in HSC abundance versus random noise (likely driven by unmodeled variations in survey conditions, HSC clustering and seasonal movements and other poorly understood aspects of HSC ecology), I tested for pairwise correlations of the raw and adjusted CPUE estimates. Pearson correlations among the raw and adjusted CPUE results ranged from 0 to 0.45 (Fig. 4). The only statistically significant correlation among the three surveys was between the unadjusted CPUE estimates for the NJ and DE trawl surveys. However, this relationship weakened to 0.16 and became inconclusive after controlling for seasonality and site conditions (Fig. 4). Overall, the correlation tests indicated that the results from the three trawl surveys are largely uncorrelated with one another (Fig. 4). Therefore, it is likely that the trawl survey results (and the resulting indices and estimates of HSC abundance) largely reflect factors unrelated to variation in the underlying HSC population.

If annual trawl-based estimates (and estimates derived from these surveys, like the CMSA) are largely uncorrelated with the underlying dynamics of the HSC population, REKN survival could conceivably be strongly correlated with true HSC abundance yet show little correlation with trawl-based HSC indices (Table 1). In this way, the use of trawl-based indices as a proxy for HSC abundance (e.g., in models of REKN survival) may severely misrepresent the true nature of the interaction between these two species. Overall, the results of my reanalysis indicate that trawl-based indices of HSC abundance are a noisy and unreliable indicator of annual fluctuations in the HSC population, and are likely an inadequate metric for quantifying the biotic interaction between REKNs and HSCs in Delaware Bay.

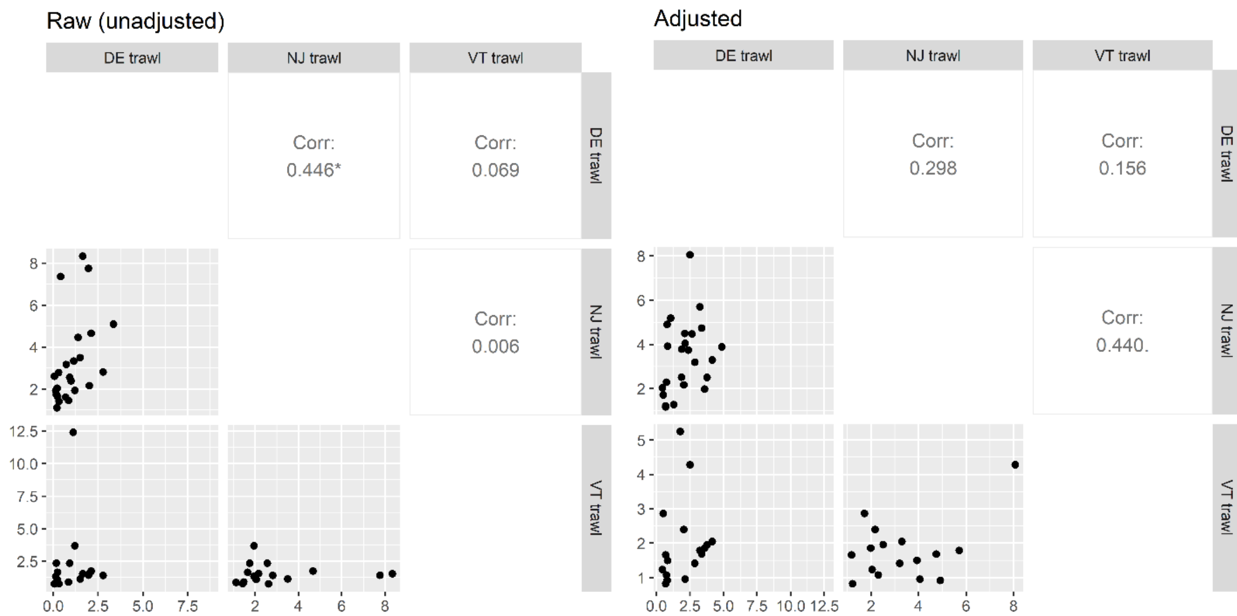

Figure 4*. Scatterplot matrices (lower diagonals) and Pearson correlation tests (upper diagonals) for raw (left) and adjusted (right) catch-per-unit-effort (CPUE; HSC abundance indices) from three trawl-based surveys conducted in the Delaware Bay area from 1990 to 2022. Pearson correlations among the different trawl surveys ranged from 0 to 0.45. The only statistically significant correlation among the three surveys was between the unadjusted CPUE estimates for the NJ and DE trawl surveys. This relationship weakened to 0.16 after controlling for seasonality and site conditions. DE trawl data were provided on Aug 10, 2023. This work does not represent the opinions of the State of Delaware, Delaware Department of Natural Resources and Environmental Control or Delaware Division of Fish & Wildlife. Note that fulfillment of data requests does not constitute endorsement by the NJ Marine Resources Administration of any analyses or end products derived from the requested data.*

3. REKN survival is strongly sensitive to HSC egg-density, indicating that persistent degradation of the HSC egg resource could have dire consequences for the REKN population

In contrast to trawl-based HSC survey data, surveys of HSC egg densities measured directly on the beaches used by REKNs and other shorebirds are likely to be a far more direct representation of the functional ecological link between these two species. Fortunately, such data are available: researchers have been consistently measuring the shallow-depth (0 to 5 cm) density of HSC eggs in Delaware Bay (NJ side only) since 2000. While beach surveys (like all ecological data) are subject to sources of error that can obscure underlying signals, there are far fewer intermediate processes that may compromise the signal of the ecological relationship between these species. Although HSC egg surveys and spawning counts have been conducted in Delaware Bay for many years, ASMFC chose to use trawl-based surveys instead of surface egg density surveys to represent the HSC resource available to REKNs in their models (although they also used information on the timing of HSC spawning). To explain this decision, ASMFC has stated (1) that HSC abundance in Delaware Bay (CMSA model and results) has a clearer nexus with their management directive (ASMFC manages the HSC stock rather than the density of eggs deposited on beaches), and (2) that the egg data are highly variable across both space and time (seemingly making a case, without strong evidence, that the surface egg density surveys may be unreliable). Whatever their rationale for ignoring the long-term surveys of HSC surface egg-densities, it is misguided if it misrepresents the true nature of the underlying biotic interaction.

To evaluate the HSC surface egg density data as a proxy for the HSC egg resource available to migrating REKNs, I first reanalyzed the raw data to ensure that comparisons were valid across years for which survey methodologies differed. Overall, three different survey methodologies were used for measuring surface egg density during the period from 2000 to 2023. Although egg densities were always measured in the top 5 cm of the surface, the total area of beach surface measured per sample differed substantially among survey periods. To correct for these differences (effectively putting all samples on an even playing field) I used a modified version of the methods described in Smith et al. (2022) that included an offset term in the linear model formula. Briefly, I used generalized additive mixed models (GAMM) to model the number of eggs counted in each sample as a function of year (fixed effect) and seasonality (Julian day, using a smoothing spline to accommodate a non-linear functional response), with a random intercept term to accommodate for among-site variation, using an offset term (log of surface area sampled) to account for differences in survey effort (surveyed area) among samples. Following Smith et al. (2022), I assumed a negative binomial error distribution and a log link. Also following Smith et al. (2022), models were fitted in R, using the package 'glmmTMB' (Brooks et al. 2017), with goodness-of-fit assessed using the 'DHARMa' package (Hartig and Hartig 2017).

To assess the annual estimates of HSC surface egg density as a proxy for HSC egg resource availability in the REKN survival models, I used the annual adjusted surface egg density estimates as a covariate in the CJS and CMSA models. Since the HSC egg data were only collected on the NJ side of the bay, I only used REKN banding and resighting data from NJ for this analysis. The results of this analysis indicated a strong, positive effect of HSC density on REKN survival (Fig. 5). Years with high HSC egg densities were associated with mean REKN survival rates approaching 85%, whereas survival was reduced to approximately 65% in years with low HSC egg densities. Although these results were based on a standard Cormack-Jolly-Seber model for survival estimation, the open-robust-design model used by ASMFC yielded similar results, although with a wider range of parameter uncertainty (Table 1, section 2).

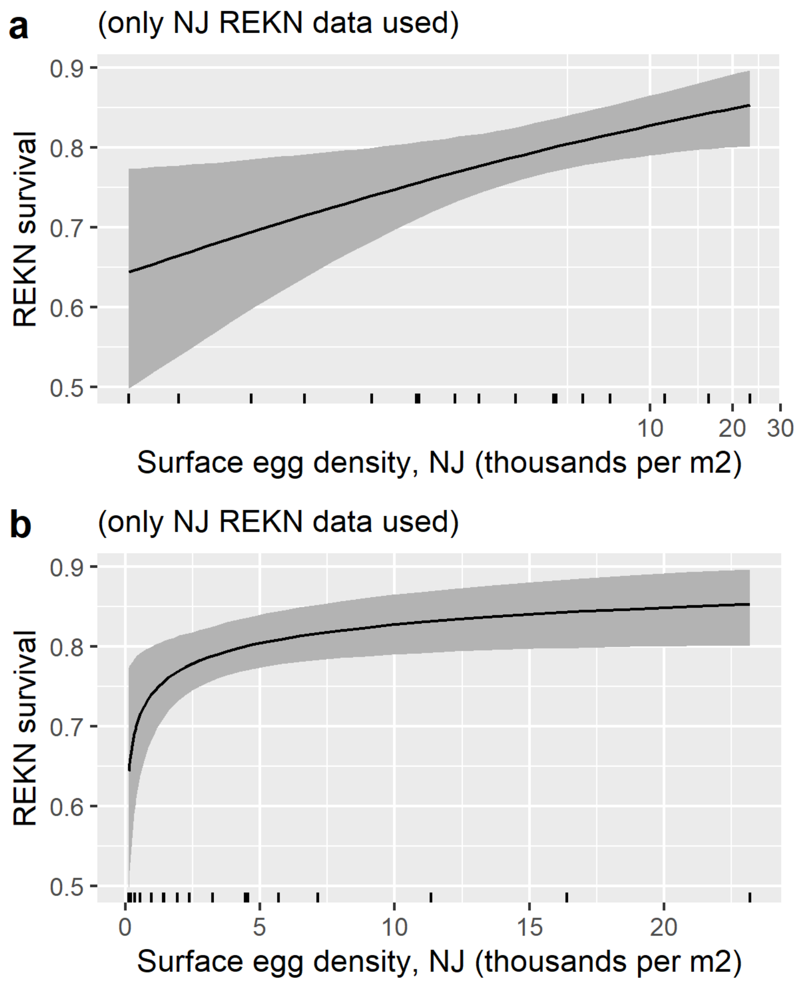

***Figure 5**. REKN survival as a function of the observed surface density of HSC eggs (thousands of eggs per m2, top 5 cm) on the NJ side of Delaware Bay. The top panel shows this relationship on the log scale (the scale at which the relationship was modeled), and the bottom panel shows the same relationship on the raw, untransformed scale. These results are derived from a Cormack-Jolly-Seber (CJS) model fitted to REKN banding and resighting data from 2003 to 2022. The rug (additional tick-marks along the x-axis) represents the observed egg densities during the study period. Since egg density data was not collected on the DE side of Delaware Bay, only birds resighted in NJ were used for this analysis.*

In contrast to the HSC-REKN relationship used by ASMFC, under which the REKN population would be expected to increase even under the complete elimination of the HSC population in Delaware Bay (see attached), the effect of HSC egg density on REKN survival (Fig. 6) forecasted a steep decline in the REKN population under sustained low densities of HSC eggs (held constant at the lowest observed levels from 2000 to 2022), resulting in near-extinction of the REKN population after 2-3 decades (Fig. 6). The magnitude of this relationship suggests that even 5 years of low HSC egg densities could result in a 50% decline of the REKN population. The strength of the estimated relationship between HSC egg densities with REKN survival is much more consistent (in comparison with the ARM framework) with the observed decline in the REKN population during the late 20th century, which is widely attributed to unregulated HSC harvest. Also in sharp contrast to the ASMFC model, the estimated relationship between REKN survival and HSC egg density indicate that sustained high HSC egg densities (held constant at the highest observed levels) can potentially promote the rapid recovery of the REKN population (Fig. 7).

It is important to recognize that the relationship between HSC abundance and HSC surface egg densities, which is critical for assessing the link between HSC harvest (which affects abundance) and REKN population persistence (which depends upon surface egg densities) remains unclear. Notably, surface egg densities are uncorrelated (in many cases, weakly negatively correlated) with the CMSA results and other trawl-based indices of HSC abundance (Fig. 8). Although knowledge of the link between HSC abundance and egg densities is clearly critical for managing the HSC stock in Delaware Bay, the true HSC abundance in Delaware Bay remains poorly characterized (see part 2, above), and the relationship between HSC abundance and the density of eggs accessible to shorebirds remains poorly understood. Therefore, caution should be used in interpreting any direct comparisons between models using HSC abundance versus egg density as a predictor variable (Figs. 6, 7), as these covariates are not strictly comparable. However, common sense dictates that there is a relationship between HSC egg availability and HSC abundance. Furthermore, the dependability of the egg resource year after year (and ultimately, the recovery of the REKN population) may require a "superabundance" of horseshoe crabs in Delaware Bay, ensuring an adequate supply of eggs available to REKNs even in years where environmental processes may be unfavorable to horseshoe crabs, the timing of their spawning, or the processes that dislodge eggs and make them available to foraging shorebirds. Finally, given the limited state of knowledge about the relationship between surface egg densities and HSC abundance, it is precautionary to assume a strong direct relationship whereby lower HSC population numbers (e.g., via harvest or other anthropogenic sources of mortality) can reduce the number of HSC eggs available for shorebirds during the critical stopover period.

Finally, the results of this reanalysis strongly argue for continued rigorous monitoring of HSC surface egg densities at multiple beaches across Delaware Bay (on both the DE and NJ sides), as these data are critical for assessing the ecological link between HSCs and REKNs. By ignoring this source of data, ASMFC's revised ARM framework misrepresents the importance of the HSC egg resource to the REKN population and thereby underestimates the risk posed by HSC harvest to the long-term viability of the REKN population. By recommending harvest of female horseshoe crabs each year, the ASMFC's ARM framework has the potential to impede both the survival and the recovery of the REKN population.

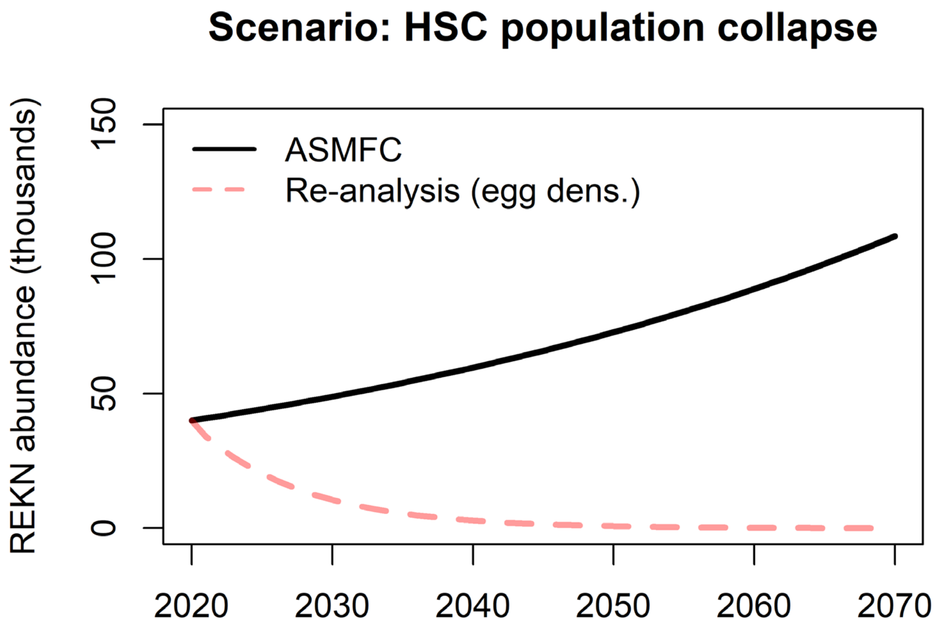

Figure 6*. Results from 'back of the envelope' calculations of REKN population growth under scenarios with a depleted HSC population. The solid black line represents REKN abundance from 2020 through 2070 under the HSC-REKN relationship described in the ASMFC ARM framework, which was trained using the CMSA model as a proxy for the HSC egg resource in Delaware Bay. The numbers used for this calculation reflect the mean survival and fecundity values assuming a HSC population of zero. The dashed red line represents REKN abundance from 2020 through 2070 under a reanalysis in which the HSC-REKN relationship was trained using surface egg density data as a proxy for the HSC egg resource in Delaware Bay. In sharp contrast to the ASMFC model, the relationship fitted to the HSC egg density data indicate that collapse of the HSC population (here defined as the lowest observed annual surface egg density values) could easily drive the collapse of the REKN population in Delaware Bay. Note that this figure is based on a simple age-structured population model and does not incorporate a density-dependence mechanism (the revised ARM includes a density ceiling that prevents the REKN population from growing above ~150k).*

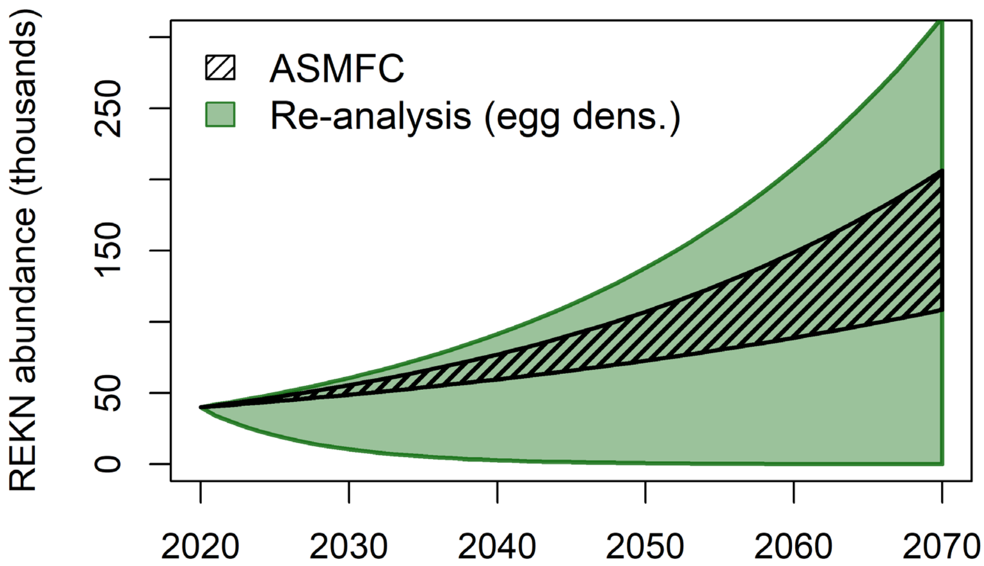

***Figure 7**. Results from 'back of the envelope' calculations of REKN population growth under scenarios ranging from a worst-case scenario of HSC population depletion (see Fig. 6) to a favorable scenario with constant HSC abundance/egg density at the highest levels observed from the early 2000s to present. The black hashed polygon (with diagonal lines) represents REKN abundance from 2020 through 2070 under the HSC-REKN relationship described in the ASMFC ARM framework, which was trained using the CMSA model as a proxy for the HSC egg resource in Delaware Bay. The light green polygon represents REKN abundance from 2020 through 2070 under a reanalysis in which the HSC-REKN relationship was trained using surface egg density data as a proxy for the HSC egg resource in Delaware Bay. In sharp contrast to the ASMFC model, this reanalysis indicates that HSC egg densities can strongly impact whether the population thrives (under consistently high surface egg densities) or declines to extinction (under consistently low egg densities). Note that this figure is based on a simple age-structured population model and does not incorporate a density-dependence mechanism (the revised ARM includes a density ceiling that prevents the REKN population from growing above ~150k).*

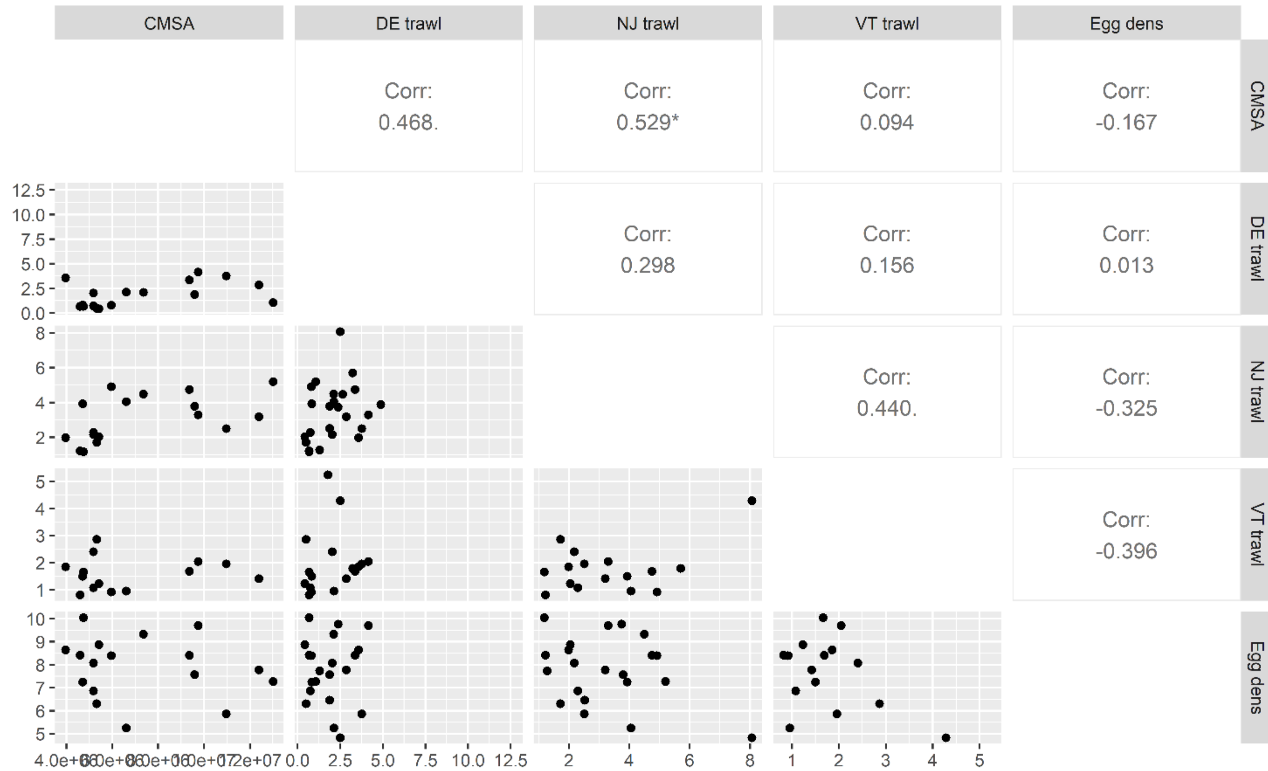

Figure 8*. Scatterplot matrices (lower diagonals) and Pearson correlation tests (upper diagonals) for HSC abundance indices derived the CMSA model (used as an estimate of HSC abundance in the ARM framework), three trawl-based surveys conducted in the Delaware Bay area from 1990 to 2022 (used for training the CMSA model; adjusted for seasonality and survey conditions), and surface egg densities (NJ side only). The only statistically significant correlation among these five indices was between the CPUE estimates from the NJ trawl survey and the CMSA results. There was no apparent correlation between surface egg density measurement and any trawl-based index of HSC abundance (including the CMSA results). In fact, surface egg density had a weakly negative relationship with most trawl-based indices of HSC abundance. DE trawl data were provided on Aug 10, 2023. This work does not represent the opinions of the State of Delaware, Delaware Department of Natural Resources and Environmental Control or Delaware Division of Fish & Wildlife. Note that fulfillment of data requests does not constitute endorsement by the NJ Marine Resources Administration of any analyses or end products derived from the requested data.*

4. The ARM exaggerates the evidence for an increasing trend in the number of female HSCs in Delaware Bay

ASMFC used their CMSA model (which used the DE, NJ and VT trawl surveys as primary data sources) to claim that the HSC population in Delaware bay has been undergoing a recovery (population increase) during the period from 2003 to 2018 (ASMFC 2001). Furthermore, Smith et al. (2022) documented evidence for an increase in HSC surface egg densities during the same period. However, after controlling for potentially confounding factors like seasonality, water temperature, and differences in survey effort and methodology, neither the trawl-based surveys used by ASMFC nor the egg-density surveys show strong evidence for increasing abundance of female HSCs in Delaware Bay over the last 20 years.

The NJ trawl data provides an interesting case-in-point. The raw catch-per-unit-effort (CPUE) from New Jersey's ocean trawl survey (one of the major data sources used by ASMFC for documenting a positive trend in HSC abundance) appears to indicate increasing female HSC abundance from 2003 to 2022 (statistically significant at alpha=0.05; Fig. 9). However, when raw CPUE numbers are adjusted for strong effects of seasonality, water temperature, depth and dissolved oxygen on HSC captures in Delaware Bay (Fig. 10) the apparent positive trend in HSC CPUE disappears, becoming statistically inconclusive on the basis of a linear regression weighted by the inverse of sampling variance (Fig. 9). The values used by ASMFC to represent the NJ trawl data values in their CMSA model (which used only trawl data from April and August; ASMFC 2021) match closely with the unadjusted CPUE numbers (Fig. 9; results are similar using all months instead of only April and August trawl results), indicating that ASMFC's estimates of HSC population dynamics failed to control for differences in season and survey conditions. This result was consistent whether or not all NJ trawl results were used for model fitting or whether the data were filtered to include only the months used by ASMFC (April and August). Therefore, the increasing trend in the HSC population reported by ASMFC and used in the ARM may (at least in part) be an artifact of differing survey conditions (e.g., differences in trawl depth or water temperature) rather than evidence of recovery of the HSC population over time.

Similarly, when the egg-density data were adjusted for known differences in survey methodologies (primarily, differences in sampled area), the apparent positive trend in HSC surface egg densities (Smith et al. 2022) became weak and inconclusive (note that this correction did not impact the estimated relationship between REKN survival and HSC egg-densities) (Fig. 11). Thus, my reanalysis of both the trawl-based surveys (Figs. 9, 10) and the egg-density surveys (Fig. 11) indicates that perceived positive trends in HSC population indices may reflect sampling differences and not trends in the underlying HSC population. Although these findings suggest the trend estimates reported by Smith et al. (2022) may be in error, this finding does not call other findings from Smith et al. (2022) into question, as these findings do not strictly depend upon the comparability of surface egg density samples collected during the study period.

Finally, I tested whether the aggregate evidence from the three trawl-based surveys (both adjusted and unadjusted; see part 2 of this report) showed evidence for HSC population recovery. Specifically, I ran linear regression models combining the CPUE estimates (both adjusted and unadjusted) from all three trawl surveys to assess evidence for an aggregate trend in abundance over time. Neither the raw HSC capture efficiencies (CPUE) from the trawl surveys nor the adjusted CPUE estimates showed conclusive evidence for a trend in HSC abundance over time (Fig. 12). With little correlation in inter-annual variation among trawl surveys (Figs 4, 8), years in which one trawl-based survey tended to indicate a large HSC population were rarely reinforced by the other surveys, resulting in a regression to the mean (Fig. 12).

Overall, the above results suggest that the ARM framework exaggerates the evidence for an increasing trend in female HSC abundance over the first two decades of the 21st century. In so doing, the ARM framework predicts recovery of the HSC population in Delaware Bay under a *status quo* scenario whereby HSC harvest regulations and other protections are maintained at current levels. In contrast, the results from my reanalysis suggest that the recovery of the female HSC population may require additional safeguards – including possibly decreasing harvest and continuing to improve and restore habitat at spawning beaches. Furthermore, by overstating the evidence for recent increases in the HSC population, ASMFC thereby likely underestimates both the vulnerability of the HSC population to harvest pressures in Delaware Bay and the potential carryover impacts on the REKN population.

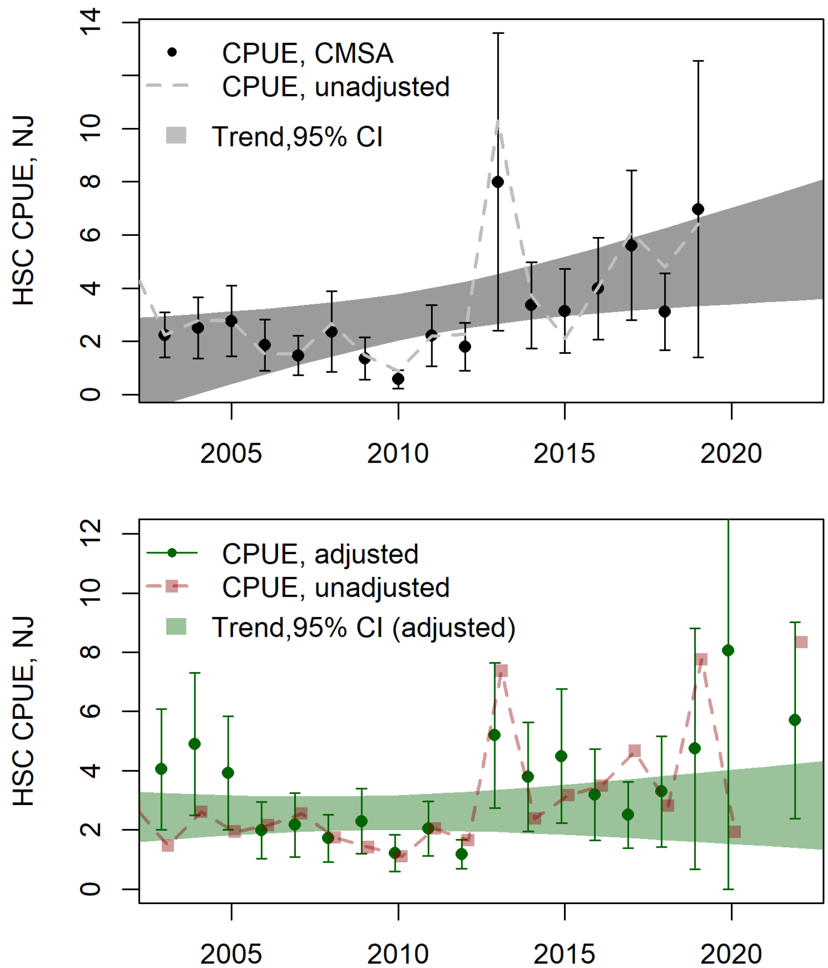

***Figure 9**. Annual HSC catch-per-unit-effort (CPUE; a type of abundance index) for trawl surveys conducted by the state of New Jersey from 1999 to present. The top figure compares the numbers used by ASMFC for their Catch Multiple Survey Analysis (CMSA) model (black), compared with the unadjusted, raw CPUE computed from the raw data (for comparison, only surveys conducted in April and August were used to compute CPUE; however, results look similar with raw CPUE for all months combined). The gray polygon represents the 95% confidence interval for the linear regression of the unadjusted CPUE against time in years. The bottom panel displays CPUE estimates adjusted for the effects of seasonality, water temperature, depth, and dissolved oxygen, with the dashed gray line and points again representing the (unadjusted, all months combined) CPUE computed from the raw data. Error bars represent 95% credible intervals. The green polygon represents the 95% confidence interval for the linear regression of the adjusted CPUE against time in years, showing no substantive trend over time.*

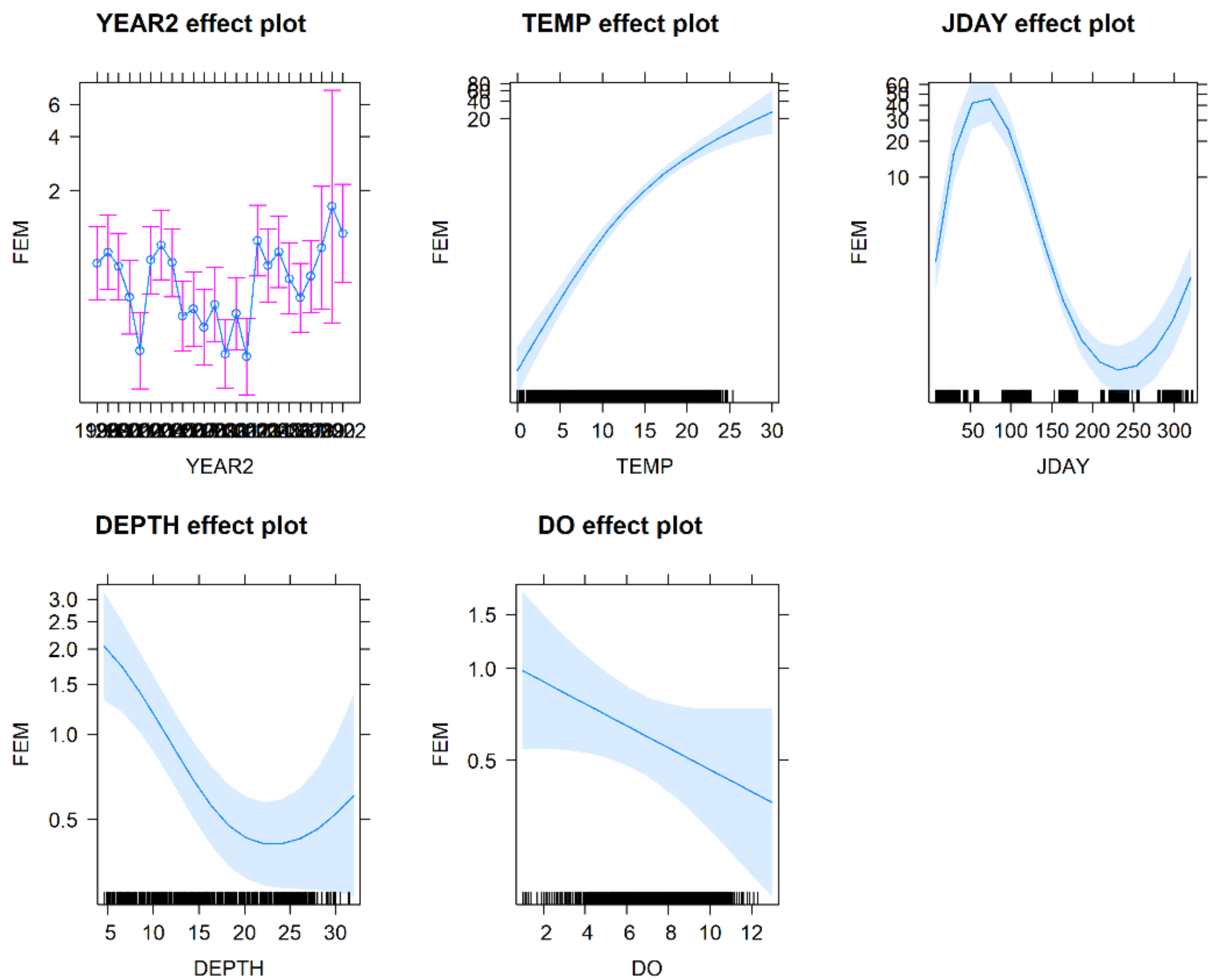

***Figure 10**. Effects plots illustrating strong, non-linear effects of season and environmental covariates (from top left to bottom right: year, temperature, Julian day, trawl depth, and dissolved oxygen) on the results of the ocean trawl surveys conducted in the Delaware Bay region by the state of NJ. These figures are predictions from a generalized linear model (GLM) using a negative binomial error distribution, quadratic terms to represent non-linear relationships, and an offset term to accommodate differing effort among surveys (amount of seafloor surveyed). The 'rug' on each plot illustrates the distribution of data for each quantitative covariate. Each panel represents the expected effect of a single predictor variable (indicated by the x-axis label), holding all other predictor variables at their mean or most frequent value. Therefore, although temperature and dissolved oxygen (DO) are closely linked, the DO effect plot illustrates the effect of DO after factoring out the effect of temperature.*

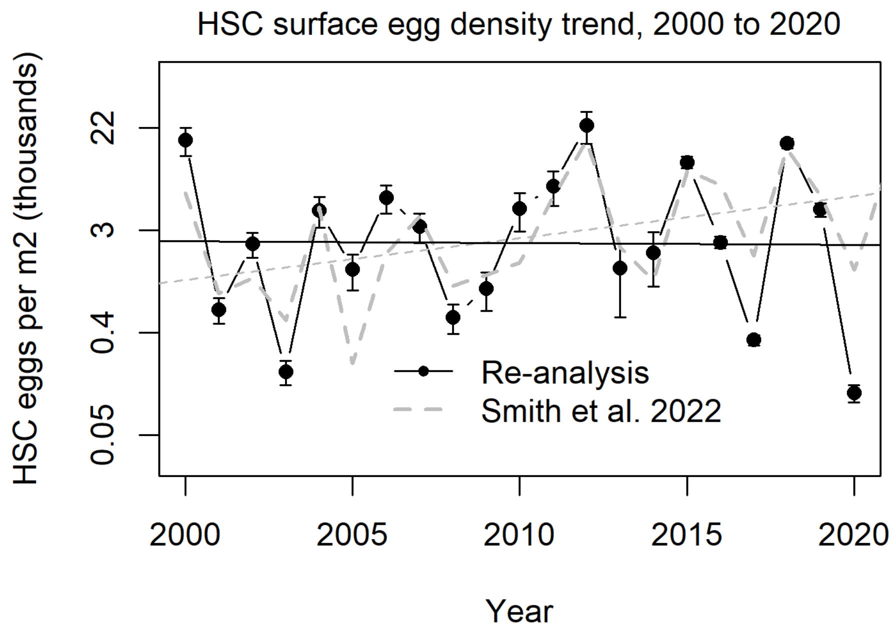

Figure 11. *Reanalysis of the evidence for a temporal trend in long-term surface egg density data from 2000 to 2020. Although the original analysis (Smith et al. 2022) detected a weak but non-negligible positive trend over time (dashed grey line), this regression relationship became inconclusive after accounting for differences in survey methodology across the 20 year study period (area represented by each sampling unit). Therefore, the increasing trend reported in Smith et al. (2022) appears to be an artifact of differing sampling methodologies used during this time frame.*

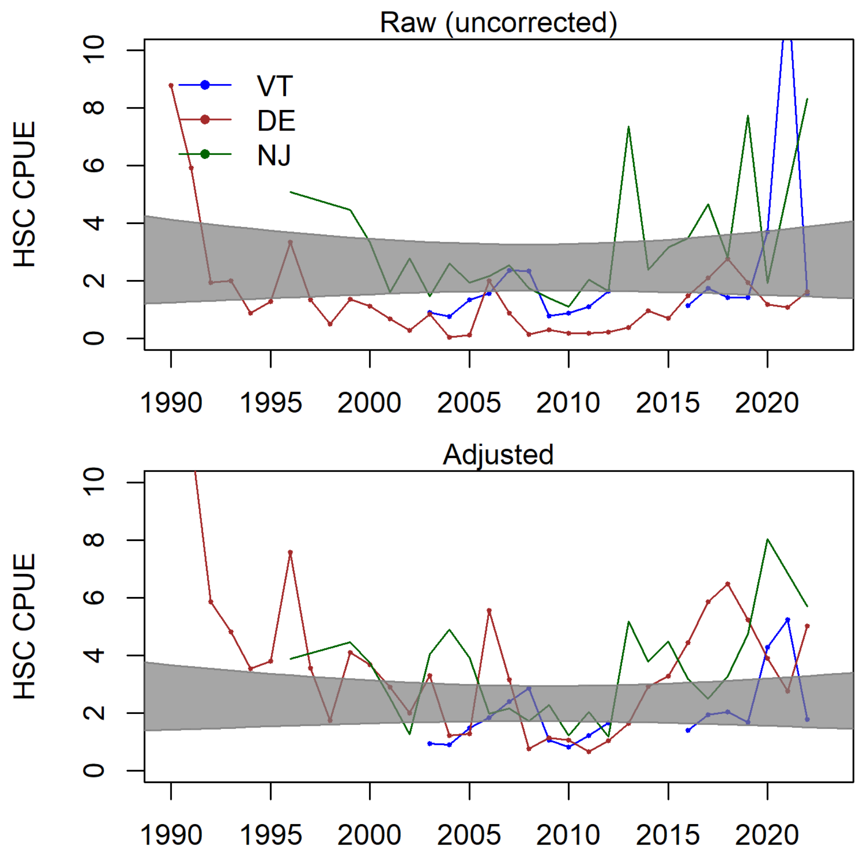

Figure 12*. Raw and adjusted HSC catch-per-unit-effort (CPUE, which serves as an index of abundance) from three trawl surveys conducted in the Delaware Bay area from 1990 to 2022. Transparent gray polygons represent the 95% confidence region for a linear regression of CPUE (aggregated across the three surveys) across time. Top panel represents raw CPUE, whereas CPUE values in the lower panel are adjusted for the effects of seasonality, water temperature, salinity, dissolved oxygen, and depth. Taken in aggregate, the trawl data indicate an uncertain and variable population that is neither increasing nor decreasing over time. DE trawl data (Delaware Division of Fish & Wildlife, Delaware Department of Natural Resources and Environmental Control) were provided on Aug 10, 2023. This work does not represent the opinions of the State of Delaware, Delaware Department of Natural Resources and Environmental Control or Delaware Division of Fish & Wildlife. Note that fulfillment of data requests does not constitute endorsement by the NJ Marine Resources Administration of any analyses or end products derived from the requested data.*

5. The statistical model (IPM) used for estimating REKN population parameters is over-parameterized and likely to yield spurious results

Like many Integrated Population Models (IPMs), ASMFC's Red Knot IPM comprises two sub-models: (1) a "state-space" model for estimating abundance and recruitment on the basis of population counts over time, and (2) a model for estimating survival on the basis of capture-recapture data (history of observation records for all uniquely marked individuals) (Schaub and Kery 2021). In the REKN IPM, the state-space model is trained using annual 'peak count' data (total number of REKNs observed during annual aerial and ground surveys), and the capture-recapture model is trained using REKN banding and resighting records from Delaware Bay. Whereas adult REKN survival (capture-recapture model) can be estimated directly from available capture-recapture records (banding and re-sighting data from Delaware Bay), recruitment of juvenile REKNs into the adult population (state-space model) is not directly estimable from the peak-count data. Instead, the IPM estimates annual recruitment rates indirectly, as the offsets required to match the observed dynamics of the peak-count data while accounting for expected losses to mortality (the latter estimated from the capture-recapture sub-model).

While the data sources for training the capture-recapture model are information-rich (tens of thousands of banding records and hundreds of thousands of resighting observations), the peak-count data used by ASMFC to train the state-space model comprised a total of 14 data points: one for each year from 2005 to 2018. Mathematically, this implies that these data could be used to assign values to a maximum of 14 unknown parameters. However, with several sources of 'noise' present in the data (sources of variation that obscure the important underlying signals), these data are likely to support far fewer than 14 parameters. Some statisticians informally recommend a rule of thumb of 30 data points per parameter for robust parameter estimation; however, the optimal ratio differs depending upon many factors, including the signal-to-noise ratio in the system as well as the risk tolerance of the researcher (Muthen and Muthen 2002). Nonetheless, the REKN IPM treats the peak-count dataset as a much richer source of information than it actually is. In fact, the number of parameters estimated by the state-space model exceeded the number of data points, resulting in a highly over-parameterized model that is inherently prone to generating spurious results. Table 2 (below) enumerates the unknown parameters estimated in the REKN IPM on the basis of the REKN peak-count dataset.

***Table 2**. Free parameters ('unknowns') estimated using the peak-count data (n = 14) in the REKN IPM*

Description	Number of free parameters
Initial abundance	1
Annual recruitment	2 to 12*
Effect of HSC abundance on recruitment	1
Observation error, ground counts	1
Observation error, aerial counts	1
"Availability" parameters	12**
TOTAL	18 to 28

* Random effect
** Strong priors assigned

Taken together, the state-space model used in the REKN IPM estimated between 18 and 28 free parameters on the basis of 14 data points (Table 2). There are two reasons why it is not possible to pinpoint the exact number of free parameters estimated in this model. First of all, the state-space model includes a 'random effect' (representing annual recruitment of new REKNs into the breeding adult population) whereby 12 separate estimates of annual recruitment (12 parameters) are generated on the basis of a two-parameter Gaussian ('normal') distribution (mean and variance; known as 'hyperparameters'). Therefore, the number of free parameters used to estimate annual recruitment could be as high as 12 (number of annual recruitment estimates) or as low as 2 (number of 'hyper-parameters' used for generating the 12 annual estimates); the "truth" lies somewhere between those two extremes. Secondly, several parameters in the state-space model (notably, the 12 'availability' parameters, representing the fraction of the stopover population observable in the aerial and ground counts) were assigned relatively strong priors (in Bayesian inference, parameter estimates combine prior knowledge with additional knowledge inferred from the data). These strong prior distributions were assigned to the ‘availability’ parameters on the basis of comparisons between the peak-count data and REKN abundance estimates generated annually as part of the ARM (Lyons ‘superpopulation’ models). Therefore, one could argue that the 12 ‘availability’ parameters were not strictly ‘free parameters’ (or ‘unknowns’) since they were constrained by previous information from the Lyons models. However, my tests indicate that the ‘availability’ parameters remained sensitive to the peak-count data, and therefore it is more correct to treat these terms as free parameters (‘unknowns’) rather than as fixed parameters. Nonetheless, even in the most generous interpretation (~8-10 free parameters), the number of unknowns in the state-space model is far greater than the peak-count data (n = 14) could reasonably support, resulting in an over-parameterized model.

Models that fit more parameters than the data can support have a strong tendency to produce spurious results (results that fail to replicate when challenged with new data). Statisticians call such models “over-parameterized”, or “over-fitted”, and this problem is widely understood by quantitative researchers and statisticians (McNeish 2015). Among the free parameters estimated from this over-fitted model are several terms vital for understanding and simulating REKN population dynamics, including initial abundance, population trends (growth or decline), mean recruitment rate, and the effect of HSC abundance on recruitment. Due to over-fitting, these key parameters in the ARM model are likely to reflect random noise in the peak count data rather than the demographic reality of the REKN population.

To confirm the tendency of the REKN IPM to generate spurious results, I simulated artificial ‘peak-count’ data under a ‘white noise’ process (with no underlying trend) and assessed how often the IPM detected a spurious trend. To do this, I ran the IPM 50 times, each time replacing the REKN peak count data with random “white noise” generated using the same mean and variance as the observed peak-count data. Using the REKN abundance estimates from each of the 50 replicates, I ran a linear regression model with log transformed median REKN abundance as the response variable and time (year; 2003 to 2022) as a continuous predictor variable. For each replicate, I recorded whether the temporal trend of abundance over time was “significant” at alpha=0.05, along with the sign and magnitude of the inferred trend. As a second test, I ran 100 80-year projections (one set of projections for each of the 50 replicates) using the time-varying survival and recruitment estimates from the IPM to project REKN abundance from 2023 to 2100 (propagating uncertainty using standard Bayesian demographic modeling techniques; Goodman 2002). Since the 'peak-count' data in these replicates were simulated with no underlying trend, the final abundance should match the initial abundance on average.

The results demonstrated that the IPM more often than not detected spurious temporal trends in REKN abundance (increases or declines in abundance over time) during the study period (Fig. 13). In fact, linear regressions (n = 50) fitted to the estimated log-median abundance from 2003 to 2022 indicated a non-negligible spurious temporal trend for 84% (42 of 50) of replicates at alpha = 0.05. Consequently, the results from projecting abundance forward to the year 2100 showed a strong tendency to erroneously produce estimates of final REKN abundance either much lower or much higher than the initial abundance (Fig. 14). Surprisingly, spurious negative trends were more common in my analysis than spurious positive trends in my analysis (Fig. 14). However, it is likely that this result is an artifact of the particular data simulation methods, model specification and initial values I used, and I caution against using this result to infer a systemic bias in the REKN IPM results. The apparent biases in my test results may be sensitive to many aspects of model specification, from the distribution and transformations used for simulating the peak-count data, to the prior distributions specified, to the initial values used for Markov-chain Monte Carlo (MCMC) simulations. Lacking access to the full modeling workflow used by ASMFC, I specified many of these parameters somewhat arbitrarily (lacking the bandwidth to complete a full sensitivity analysis). In addition, I modified the capture-recapture data to account for potential misread errors (see above), and this change could have potentially changed or even reversed any apparent biases in the modeling framework used by ASMFC. Therefore, additional sensitivity tests would be necessary to understand the conditions under which systemic biases may manifest in this modeling framework.

Due to over-parameterization, the REKN IPM is unstable and has a strong tendency to produce spurious results. Therefore, the REKN demographic simulations used in the ARM framework are unlikely to accurately capture the dynamics of the real-word population of *Rufa* Red Knots inhabiting Delaware Bay each Spring. Overall, the tendency of the REKN IPM to produce spurious results suggests that this model should not be used for assessing REKN conservation status, running scenario tests, or guiding recovery efforts for a federally Threatened species.

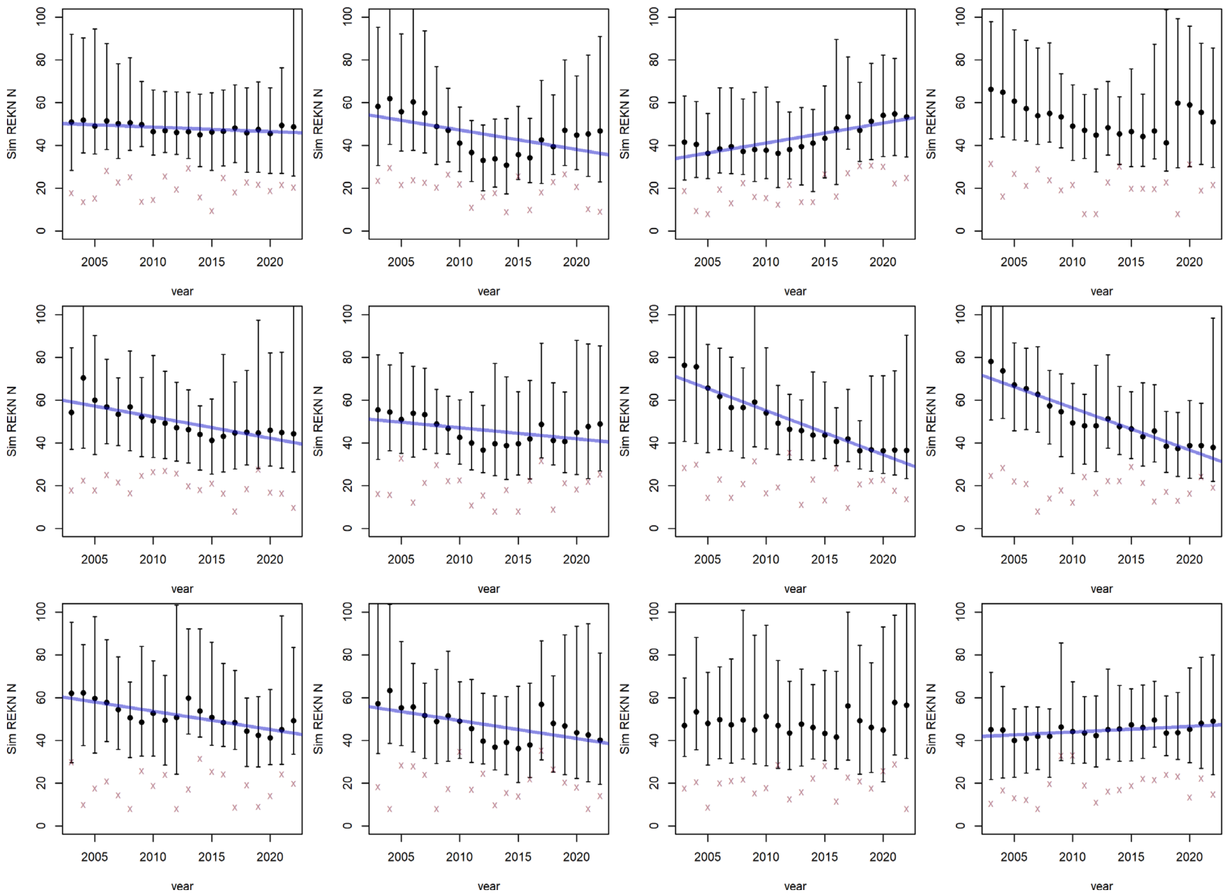

***Figure 13**. Simulated REKN abundance (in thousands) over time for 12 replicates (randomly chosen from among 50) of the REKN IPM from 2003 to 2023 in which the peak-count data were replaced with random noise with no underlying trend (simulated data are represented by "X" symbols in the above panels). In many of these replicates, the IPM results detected a spurious trend over time (regression lines in the above panels) despite the lack of a trend in the count data.*

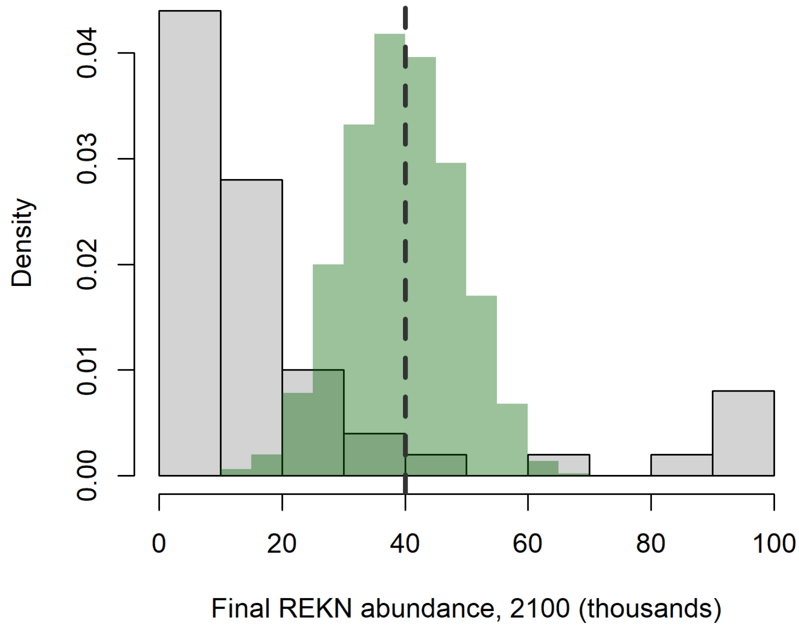

***Figure 14**. Histogram of median simulated REKN abundance at year 2100, based on the results from 50 replicates of the REKN IPM whereby the 'peak-count' data were iteratively replaced by randomly generated white noise with the same mean and standard deviation as the observed peak-count data (bars with gray fill). The vertical dashed line represents the initial abundance for the simulations (40,000 REKNs). Since the peak-count data were simulated with no trend, the final simulated abundance should match the initial abundance on average – which in this case would imply a single peak centered on the initial abundance (green histogram). However, the peaks at abundances near zero and 100 indicate that many of these simulations (fitted to white-noise) spuriously projected either near-extinction or a full recovery of the population after 80 years. The fact that more replicates projected spurious declines versus spurious growth is likely to be an artifact of the simulations rather than a systematic bias inherent to the REKN IPM.*

6. The IPM exhibits poor fit to the available data

Goodness-of-fit (GOF) testing is a critical validation step in any model-fitting workflow (e.g., assessing the normality of residuals in linear regression), ensuring that key assumptions made during the modeling process are reasonable and justified (Conn et al. 2018). In the case of IPMs, simulation studies have indicated that indirect estimates of latent parameters (like recruitment rates in the REKN IPM) can be highly sensitive to model assumptions, and can produce biased and nonsensical results if key assumptions are violated (Riecke et al. 2019; Schaub and Kery 2021). Therefore, it is critical to assess model goodness-of-fit (GOF) to assess whether IPM assumptions are reasonable (Conn et al. 2018). If an IPM fails to exhibits a reasonable fit to the data, key model parameters (like recruitment rates in the REKN IPM) should be used with extreme caution (Riecke et al. 2019).

In the context of hierarchical Bayesian analysis (the paradigm used by the ASMFC modelers), a commonly used approach is to run a Posterior Predictive Check (PPC), in which data are repeatedly simulated under the fitted model and compared to the actual data (Kery and Schaub 2011; Schaub and Kery 2021). If a model is unable to simulate data resembling the real-world observations, the model is determined to be an inadequate representation of the true processes that generated the data. 'Bayesian p-values' are often used to summarize GOF for IPMs, and represent the fraction of simulated datasets whose variance from expected values exceeds that of the true observations (Kery 2010). Whereas statisticians have noted that Bayesian p-values tend to understate a model's lack of fit (Conn et al. 2018), and research on assessing GOF for IPMs is ongoing, Bayesian P-values remain the most commonly used and reported GOF statistic for models like the REKN IPM (Schaub and Kery 2021).

In their ARM report, ASMFC mentions (but does not further document) two PPCs that were performed to assess goodness-of-fit for the IPM. One of these tests – the only test included in the publicly shared IPM code – uses a PPC to assess the degree to which the state-space model adequately represented the peak-count data. However, this test has been previously demonstrated to be an insufficient gauge of model adequacy (Schaub and Kery 2021). Furthermore, the over-parameterization of the state-space model (see above) virtually guarantees that the state-space model will pass this test (over-parameterized models tend to exhibit excellent fit to the observed data, although they tend to perform poorly in other contexts). The second and final goodness-of-fit test mentioned in the ARM report (which suggests mild lack of fit) is not included in the version of the IPM code shared publicly, so it is impossible to assess what test was actually run. However, I ran three additional PPCs to assess the degree to which the IPM (specifically, the open robust design component of the IPM) adequately represented the REKN resighting data from 2003 to 2022. These tests, which were used and reported in an earlier version of the open robust design (ORD) model for estimating REKN survival and stopover use (Tucker et al. 2021), indicated poor fit to the data (Figure 15), suggesting that the IPM is an inadequate representation of key processes operating in the REKN population – including survival and recruitment. The failure of the IPM to pass rigorous goodness-of-fit tests casts additional doubt on conclusions generated from this model.

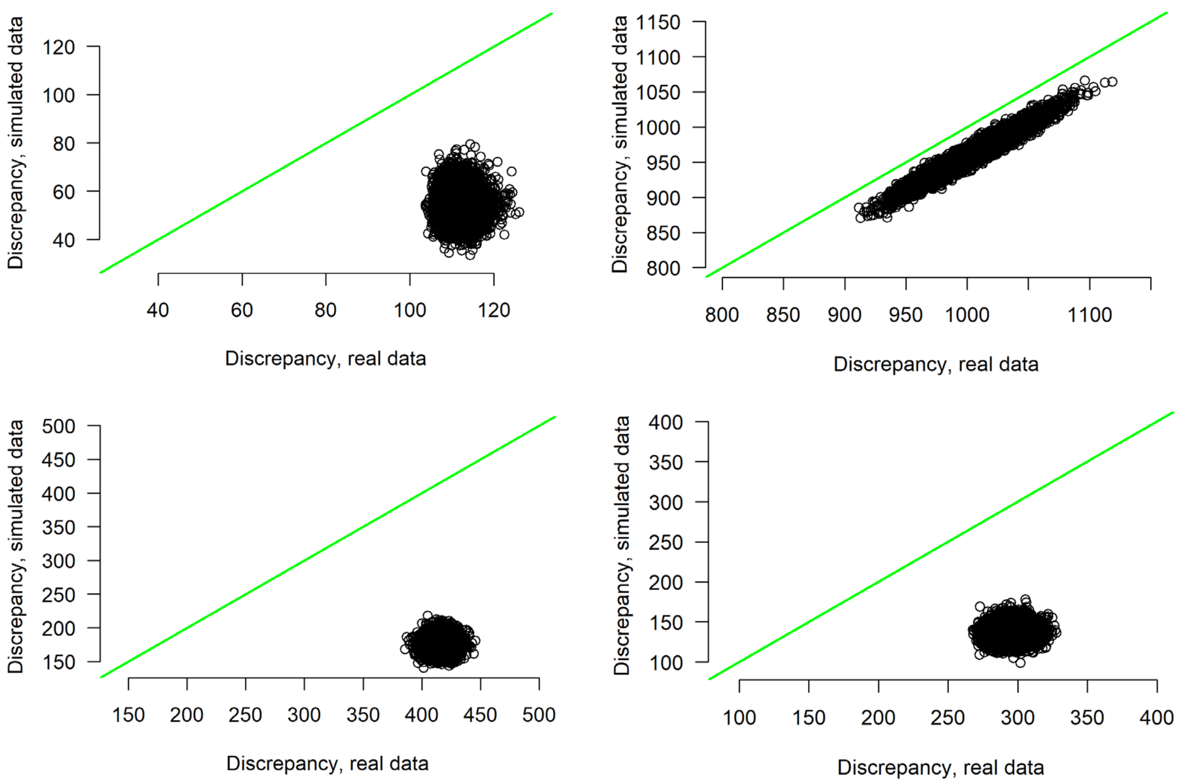

Figure 15*. Four goodness of fit (GOF) tests for the open robust design (ORD) component of the REKN IMP. GOF test #1 (upper left) assesses the adequacy of the survival and temporary emigration parameters, and is therefore the most directly relevant to the REKN population model. The remaining tests assess model fit to the timing of arrival within each year (upper right), numbers of 'transients' observed during each 3-day survey period (lower left), and recaptures of non-transients during each 3-day survey period (lower right). Bayesian p-values for all tests are equal to 1, indicating severe over-dispersion of the data relative to model predictions.*

CONCLUSION

Building on the issues identified in my 2022 review of this ARM framework, I have outlined six additional concerns about the validity of ASMFC's revised ARM framework as a tool for assessing and managing the risks to the *Rufa* Red Knot posed by the horseshoe crab harvest in Delaware Bay. First, I demonstrated that a major component of the Integrated Population Model (used for modeling REKN population dynamics) is severely over-parameterized and prone to generating spurious results. Second, I presented evidence that ASMFC's estimates of REKN survival were biased high due to failure to account for misread errors, thereby artificially inflating the resilience of the REKN population to short-term fluctuations in recruitment. Third, my reanalysis showed that trawl-based indices of HSC abundance – and the CMSA model used by ASMFC for estimating HSC abundance dynamics – have no conclusive relationship with REKN survival. Fourth, I showed that HSC surface egg density has a strong relationship with REKN survival, suggesting that ASMFC is strongly underestimating the strength of the biotic interaction and the dependency of REKNs on HSC eggs for population survival and recovery. Fifth, I show that the ARM exaggerates the evidence for an increasing trend in the number of female HSCs in Delaware Bay, thereby likely over-estimating HSC population resilience to harvest pressure. Finally, I present evidence that ASMFC's model of REKN population dynamics exhibits poor fit to the data, casting additional doubts on the validity of the ARM's model of REKN population dynamics. Based on these concerns, I conclude that this ARM framework is not useful for managing risk to the REKN population due to HSC harvest. Furthermore, my results suggest that the revised ARM misrepresents the importance of HSCs to the REKN population and thereby underestimates both the existential risk to the REKN population posed by female HSC harvest and the potential for promoting REKN recovery through increased regulatory protections and conservation efforts aimed at promoting HSC population increases in the Delaware Bay region.

Acknowledgments

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Referenced literature:

Atlantic States Marine Fisheries Commission (ASMFC). 2021. Revision to the Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Inclusive of Red Knot Conservation and Peer Review Report. Arlington, VA. 302 pp. http://www.asmfc.org/species/horseshoe-crab

Baker, A. J., Gonzalez, P. M., Piersma, T., Niles, L. J., de Lima Serrano do Nascimento, I., Atkinson, P. W., ... & Aarts, G. (2004). Rapid population decline in red knots: fitness consequences of decreased refuelling rates and late arrival in Delaware Bay. Proceedings of the Royal Society of London. Series B: Biological Sciences, 271(1541), 875-882.

Brooks, M. E., Kristensen, K., Van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., ... & Bolker, B. M. (2017). glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. The R journal, 9(2), 378-400.

Conn, P. B., Johnson, D. S., Williams, P. J., Melin, S. R., & Hooten, M. B. (2018). A guide to Bayesian model checking for ecologists. Ecological Monographs, 88(4), 526-542.

Cooch, E. (2008). Program MARK," A gentle introduction". http://www. phidot. org/software/mark/docs/book/.

Dietze, M. C. (2017). Ecological forecasting. Princeton University Press.

Goodman, D. (2002). Predictive Bayesian population viability analysis: a logic for listing criteria, delisting criteria, and recovery plans. Population viability analysis, 447, 454.

Hartig, F., & Hartig, M. F. (2017). Package ‘DHARMa’. R package.

Kellner, K., Meredith, M., & Kellner, M. K. (2019). Package ‘jagsUI’. A Wrapper Around'rjags' to Streamline'JAGS'Analyses. R Package Version, 1(1).

Kéry, M. (2010). Introduction to WinBUGS for ecologists: Bayesian approach to regression, ANOVA, mixed models and related analyses. Academic Press.

Kéry, M., & Schaub, M. (2011). Bayesian population analysis using WinBUGS: a hierarchical

perspective. Academic Press.
Koons, D. N., Riecke, T. V., Boomer, G. S., Sedinger, B. S., Sedinger, J. S., Williams, P. J., & Arnold, T. W. (2022). A niche for null models in adaptive resource management. Ecology and evolution, 12(1), e8541.
Lovich, J. E., Ennen, J. R., Yackulic, C. B., Meyer-Wilkins, K., Agha, M., Loughran, C., ... & Madrak, S. (2015). Not putting all their eggs in one basket: bet-hedging despite extraordinary annual reproductive output of desert tortoises. Biological Journal of the Linnean Society, 115(2), 399-410.
McNeish, D. M. (2015). Using lasso for predictor selection and to assuage overfitting: A method long overlooked in behavioral sciences. Multivariate behavioral research, 50(5), 471-484.
Méndez, V., Alves, J. A., Gill, J. A., & Gunnarsson, T. G. (2018). Patterns and processes in shorebird survival rates: a global review. Ibis, 160(4), 723-741.
Muthén, L. K., & Muthén, B. O. (2002). How to use a Monte Carlo study to decide on sample size and determine power. Structural equation modeling, 9(4), 599-620.
Nichols, J. D., Runge, M. C., Johnson, F. A., & Williams, B. K. (2007). Adaptive harvest management of North American waterfowl populations: a brief history and future prospects. Journal of Ornithology, 148(2), 343-349.
Niles, L. J., Bart, J., Sitters, H. P., Dey, A. D., Clark, K. E., Atkinson, P. W., ... & Veitch, C. R. (2009). Effects of horseshoe crab harvest in Delaware Bay on red knots: are harvest restrictions working?. BioScience, 59(2), 153-164.
Piersma, T., Lok, T., Chen, Y., Hassell, C. J., Yang, H. Y., Boyle, A., ... & Ma, Z. (2016). Simultaneous declines in summer survival of three shorebird species signals a flyway at risk. Journal of Applied Ecology, 53(2), 479-490.
Plummer, M. (2012). JAGS Version 3.3. 0 user manual.
Pradel, R., & Sanz-Aguilar, A. (2012). Modeling trap-awareness and related phenomena in capture-recapture studies. PloS one, 7(3), e32666.
Radosavljevic, A., & Anderson, R. P. (2014). Making better Maxent models of species distributions: complexity, overfitting and evaluation. Journal of biogeography, 41(4), 629-643.
Rakhimberdiev, E., Karagicheva, J., Saveliev, A., Loonstra, A. J., Verhoeven, M. A., Hooijmeijer, J. C., ... & Piersma, T. (2022). Misidentification errors in reencounters result in biased estimates of survival probability from CJS models: Evidence and a solution using the robust design. Methods in Ecology and Evolution, 13(5), 1106-1118.
Regan, H. M., Colyvan, M., & Burgman, M. A. (2002). A taxonomy and treatment of uncertainty for ecology and conservation biology. Ecological applications, 12(2), 618-628.
Riecke, T. V., Williams, P. J., Behnke, T. L., Gibson, D., Leach, A. G., Sedinger, B. S., ... & Sedinger, J. S. (2019). Integrated population models: model assumptions and inference. Methods in Ecology and Evolution, 10(7), 1072-1082.
Schaub, M., & Kéry, M. (2021). Integrated population models: Theory and ecological applications with R and JAGS. Academic Press.
Simmons, J. P., Nelson, L. D., & Simonsohn, U. (2016). False-positive psychology: undisclosed flexibility in data collection and analysis allows presenting anything as significant.
Smith, J. A., Dey, A., Williams, K., Diehl, T., Feigin, S., & Niles, L. J. (2022). Horseshoe crab egg availability for shorebirds in Delaware Bay: Dramatic reduction after unregulated

horseshoe crab harvest and limited recovery after 20 years of management. Aquatic Conservation: Marine and Freshwater Ecosystems, 32(12), 1913-1925.

Tucker, A. (2019). Stopover ecology and population dynamics of migratory shorebirds. Dissertation. Auburn University.

Tucker, A. M., McGowan, C. P., Lyons, J. E., DeRose-Wilson, A., & Clark, N. A. (2022). Species-specific demographic and behavioral responses to food availability during migratory stopover. Population Ecology, 64(1), 19-34.

Tucker, A. M., McGowan, C. P., Nuse, B. L., Lyons, J. E., Moore, C. T., Smith, D. R., ... & Clark, N. A. (2023). Estimating recruitment rate and population dynamics at a migratory stopover site using an integrated population model. Ecosphere, 14(2), e4439.

USFWS 2014. Endangered and Threatened Wildlife and Plants; Threatened Species Status for the Rufa Red Knot. Federal Register / Vol. 79, No. 238

USFWS 2021. Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for Rufa Red Knot (*Calidris canutus rufa*). Federal Register / Vol. 86, No. 133

Williams, B. K. (2011). Resolving structural uncertainty in natural resources management using POMDP approaches. Ecological Modelling, 222(5), 1092-1102.

Wong, C. Jiao, Y. and Hallerman, E. Report to the Atlantic States Marine Fisheries Commission Horseshoe Crab and Delaware Bay Ecology Technical Committees (ASMFC, Arlington, VA, 2018). 27 p.

SUPPLEMENTAL ANALYSES

Note on the incorrect specification of the "pi" parameter in the REKN IPM

Although not directly related to any of the six primary critiques in this report, it is nonetheless important to note here that the "*pi*" parameter in the REKN IPM, which represents the fraction of the flyway population that is present at the stopover site at any given 3-day time window, is incorrectly specified in the ARM model. This parameter is used internally within the IPM for adjusting the total estimated flyway abundance to reflect the number of REKNs using the stopover at the time of the peak count surveys. Therefore, this parameter provides a critical link between the open robust design model and the state-space model within the IPM, helping to refine estimates of REKN abundance and population trends.

In the REKN IPM, the computation of *pi* follows two steps. First, for each 3-day occasion during the stopover period each year, the probability of being present in the stopover (conditional on using the stopover at least once that year) is computed using the *delta* (arrival) terms, the *tau* (stopover residency) and the *psi* (stopover retention/persistence) parameters. This derived term, which appears to be performed correctly, is called *alpha* in ASMFC's IPM code. To compute *pi* (proportion of the entire flyway present at the stopover site during each period) from *alpha* (the proportion of stopover users present at the stopover site each period) we just need to multiply alpha by a factor representing the fraction of flyway individuals using the stopover each year (we will call this factor "*z*"). ASMFC computed '*z*' as the sum of two parameters from the open-robust-design (ORD) model: '*gammaII*' and '*gammaOI*', which represent the probability of returning to the stopover (conditional on having been there last year), and the probability of returning to the stopover (conditional on having NOT been in the stopover last year), respectively. Importantly, the '*gammaII*' and '*gammaOI*' parameters are conditioned on two distinct segments of the flyway population; these parameters have no meaning when added together. For 'gammaII' and 'gammaOI' to have meaning at the level of the flyway population, we would need to know the fraction of the flyway population that used the stopover last year, which we call '*f*'. With this information, we could compute *z* and *pi* as:

z = gammaII(f) + gammaOI*(1-f)* (Correct formulation)

*pi = z * alpha*

Multiplying this term (*z*) by *alpha* would yield the appropriate estimate of *pi*. However, ASMFC computed the *z* parameter as:

z_i = *gammaII + gammaOI* (Incorrect formulation)

$pi_i = z_i * alpha$

Since z_i does not have meaning as a probability (this quantity can theoretically exceed 1), the resulting estimate of *pi* has no discernible meaning. Since *pi* is used to make the link between the annual peak counts and true flyway abundance, this error may introduce another source of bias in the estimates of REKN abundance and growth rate derived from the IPM. Although this is an important error, likely to have implications for the IPM results and the ARM framework, I consider this issue secondary in importance to the over-parameterization of the state-space model.

Note on over-parameterization of ASMFC's REKN survival model

In contrast to the ORD model, the 'classical' Cormack-Jolly-Seber (CJS) framework yielded estimates of the REKN-HSC relationship that were neither positive nor negative (inconclusive; Table 1). The increased tendency of the ORD model to yield conclusive (but negative) relationships may be a consequence of the increased complexity of the ORD model versus the CJS models, as more complex models have a greater tendency to generate spurious results. Furthermore, there is reason to suspect that the ASMFC model of REKN survival tried to estimate more parameters than the data could support. With 14 years of data used for training the ASMFC model (2005 to 2018), there are 13 years for which survival is theoretically estimable (one fewer than the years of data; Cooch 2008). In the IPM, these 13 estimable rates represent the degrees of freedom (independent information used for parameter estimation) needed for modeling annual variation in REKN survival. In ASMFC's IPM, these 13 data points are used to estimate no fewer than five parameters: (1) the effect of HSC abundance on REKN survival, (2) the effect of spawn timing on REKN survival, (3) the effect of arctic snow cover on REKN survival, (4) an interaction between HSC abundance and spawn timing, and (5) a temporal process variance that allows survival to vary among years. Fitting five parameters using 13 degrees of freedom (a ratio of 2.6 data points per free parameter) suggests that this model (like the model of REKN recruitment; see above) is prone to over-fitting and thereby producing spurious results (see above).

The model instability that is characteristic of over-fitted models is apparent in the estimation of the effect of trawl-based HSC indices on REKN survival. Notably, when I specified the ORD model with the full set of time-varying covariates used by ASMFC – including HSC abundance derived from the CMSA model, the fraction of HSCs spawning in May, arctic snow cover, and an interaction between HSC and HSC spawn timing -- the previously significant (and nonsensical) negative relationship between HSC abundance and REKN survival disappeared (B= -0.04, 95% CI: -0.20 to 0.08). This relationship remained inconclusive regardless of whether potential misread errors were included in the model training set.

Potential biases due to over-representation of Mispillion harbor in the REKN resighting dataset

Tabular summaries of the number of observations by site and by state exposed a strong over-representation of a single study site (Mispillion harbor, in DE) in the REKN resighting dataset, raising concerns that patterns in the REKN survival results used for the ARM framework may represent the idiosyncrasies of a single site rather than general patterns across Delaware Bay

(Fig. S1). In fact, some Delaware Bay shorebird experts indicated to me that Mispillion harbor likely has a greater concentration of HSC eggs than many other sites and tends to support rapid weight gain in REKNs, which could induce lower mortality rates. To test this, I ran multiple models of REKN survival – including the ORD formulation used by ASMFC in addition to simpler Cormack-Jolly-Seber (CJS) models – using data sets excluding Mispillion harbor and including only data from Mispillion harbor. Overall, I found that mean REKN survival estimates were very similar for birds captured inside and outside of Mispillion harbor. However, patterns in survival among years showed some marked differences that could potentially indicate different drivers of survival inside and outside of Mispillion harbor (Fig. S2). In particular, survival for birds captured and resighted in Mispillion harbor was more stable across years, yet showing a slight declining trend. In contrast, survival for birds captured and resighted outside of Mispillion harbor was more variable (showing a strong reduction in 2010 and 2017), with no apparent trend over time.

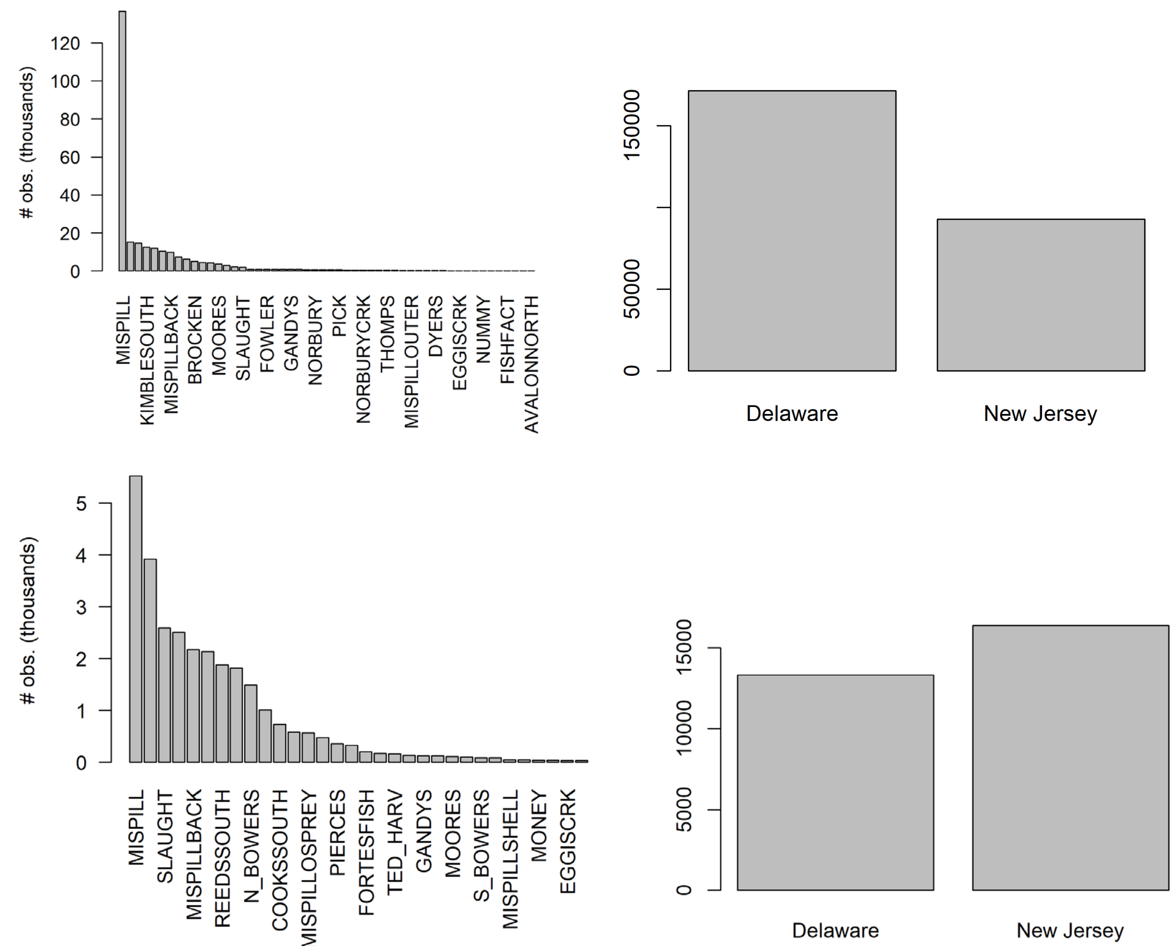

Figure S1*. Top panels: number of resighting observations per site and by state. Note that resighting observations within Mispillion harbor ("MISPILL" in the above figures) far outweigh all other sites, leading to some concern that analysis results may be biased if this site differs from other sites. Delaware (which is dominated by Mispillion harbor data) has about 2x the number of resighting observations than NJ. Bottom panels: banding data summary by site and by state. As opposed to the resighting data, there are more banding records from New Jersey, and Mispillion harbor does not dominate the banding records to the same degree as it does the resighting data.*

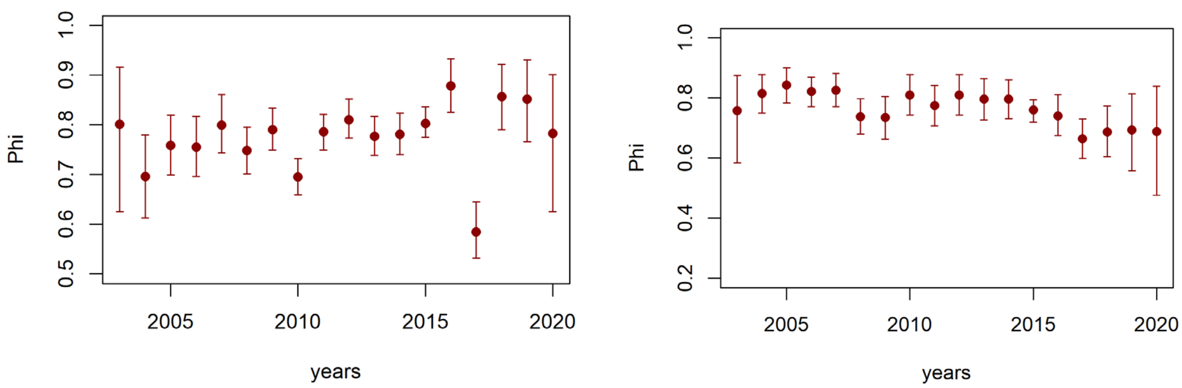

Fig. S2. *Comparison of annual REKN apparent survival estimates using (left) only birds marked and re-sighted outside of Mispillion harbor, and (right) only birds marked and re-sighted inside Mispillion harbor. Only birds first captured in Delaware Bay were included in the analysis, following ASMFC's stated data protocols. This figure illustrates different temporal patterns in survival, with REKN survival showing little trend outside of Mispillion harbor and decreasing slightly for birds captured and resighted inside Mispillion harbor. Outside of Mispillion harbor, estimated apparent survival was particularly low for two years: 2010 and 2017. Both models indicated reasonable goodness of fit.*

Trawl-based indices of HSC abundance

The figures below are a supplement to section 5 of this report, which documents that the evidence for a recent increase in the HSC population in Delaware Bay may be overstated. The figures below illustrate my efforts to generate adjusted indices of HSC abundance from trawl surveys to control for factors known to influence HSC capture rates: seasonality, trawl depth, salinity, and temperature (note that dissolved oxygen also emerged as an important factor in the New Jersey trawl surveys; Fig. 10).

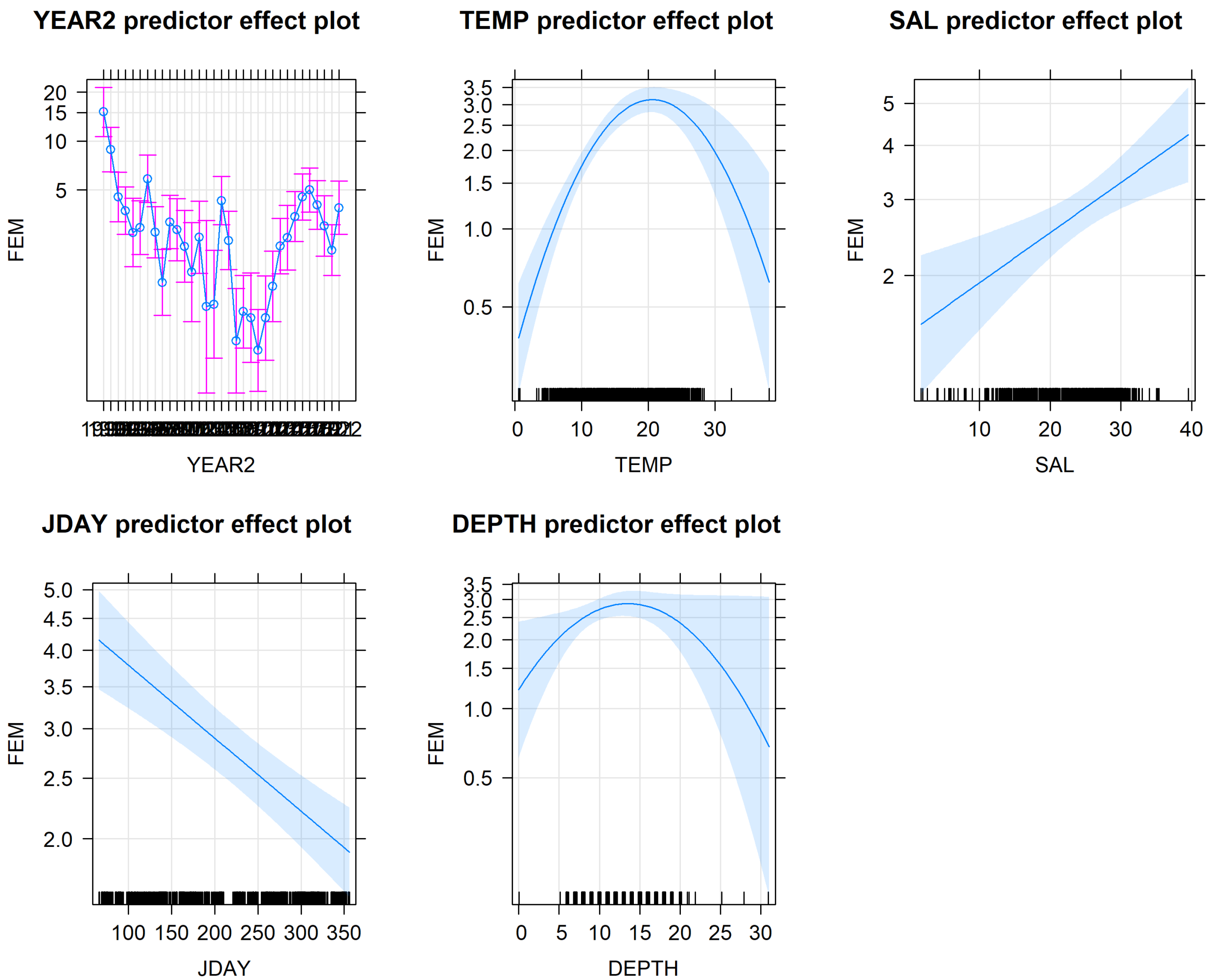

Figure S3*. Effects plots illustrating strong linear and non-linear effects of season and environmental covariates (from top left to bottom right: year, temperature, salinity, Julian day, and trawl depth) on the results of the Delaware Bay trawl surveys conducted by the state of DE. These figures are predictions from a generalized linear model (GLM) using a negative binomial error distribution, quadratic terms to represent non-linear relationships, and an offset term to accommodate differing effort among surveys (amount of seafloor surveyed). The 'rug' on each plot illustrates the distribution of data for each quantitative covariate. DE trawl data were provided on Aug 10, 2023 by Delaware Division of Fish & Wildlife, Delaware Department of Natural Resources and Environmental Control. This work does not represent the opinions of the State of Delaware, Delaware Department of Natural Resources and Environmental Control or Delaware Division of Fish & Wildlife*

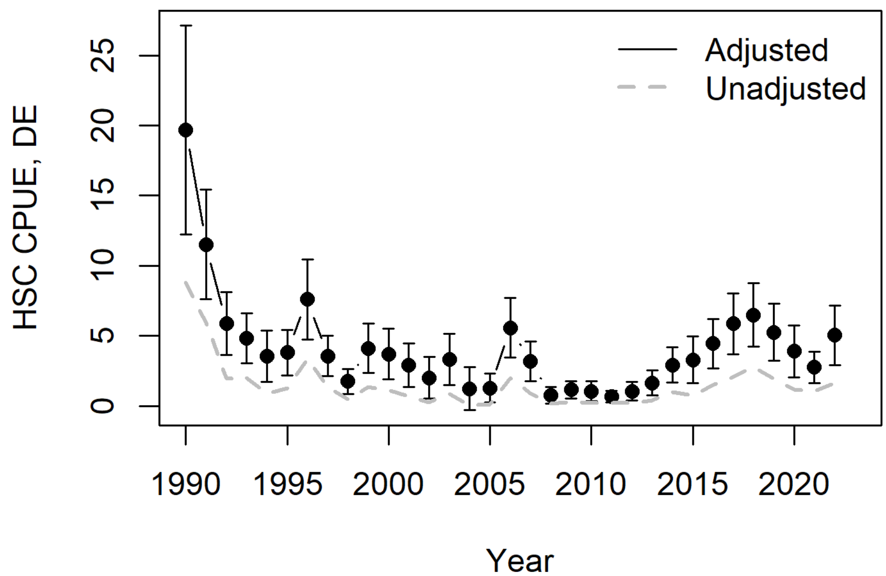

Figure S4. *Annual HSC catch-per-unit-effort (CPUE; a type of abundance index) for trawl surveys conducted by the state of Delaware from 1990 to present. Solid black dots are adjusted for the effects of seasonality, water temperature, depth, and salinity, while dashed gray line represents the unadjusted CPUE. Error bars represent one standard error on either side of the adjusted CPUE estimate. Unlike for the NJ data, the correction does not alter the general pattern of HSC abundance versus the unadjusted CPUE. DE trawl data were provided on Aug 10, 2023 by Delaware Division of Fish & Wildlife, Delaware Department of Natural Resources and Environmental Control. This work does not represent the opinions of the State of Delaware, Delaware Department of Natural Resources and Environmental Control or Delaware Division of Fish & Wildlife*

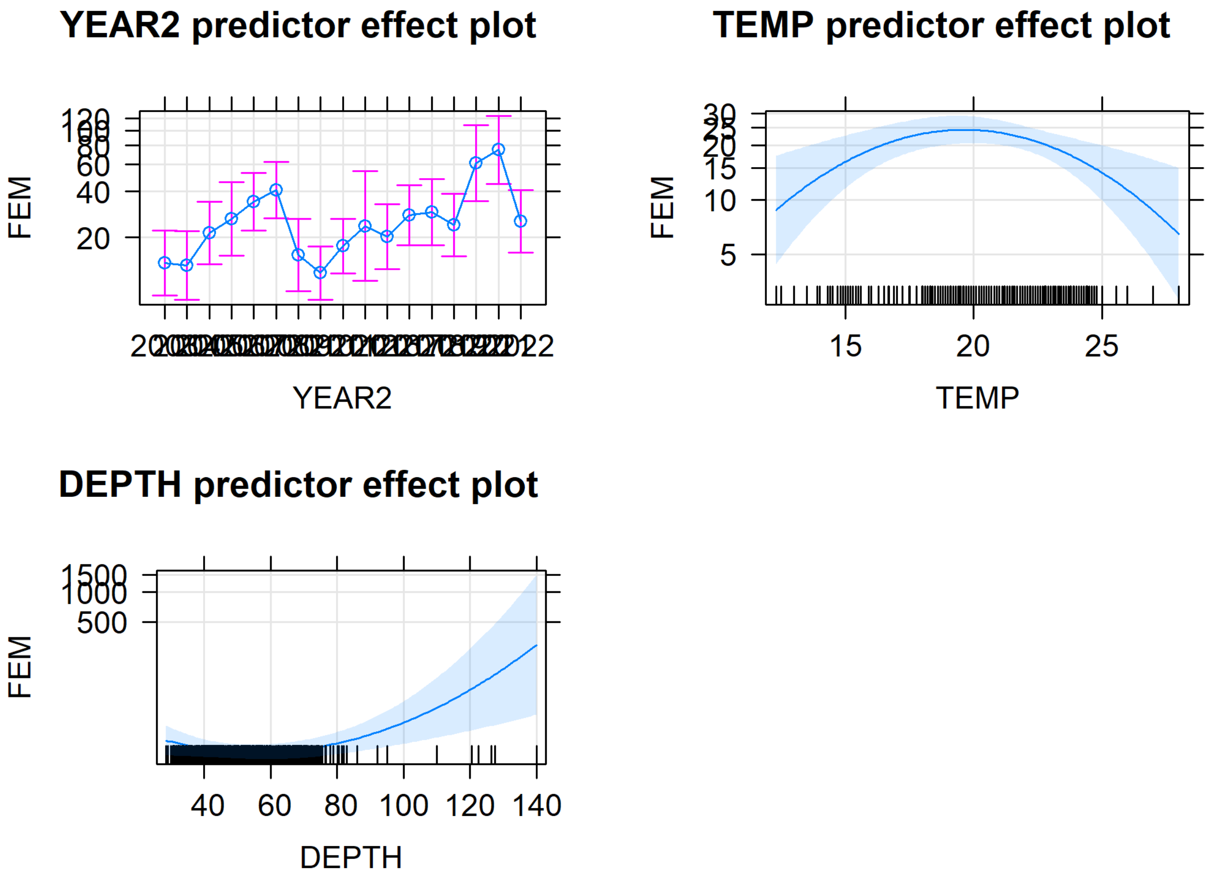

Figure S5. *Effects plots illustrating strong effects of year and environmental covariates (temperature and trawl depth) on the results of the Delaware Bay trawl surveys conducted by Virginia Tech (VT). These figures are predictions from a generalized linear model (GLM) using a negative binomial error distribution, quadratic terms to represent non-linear relationships, and an offset term to accommodate differing effort among surveys (amount of seafloor surveyed). The 'rug' on each plot illustrates the distribution of data for each quantitative covariate.*

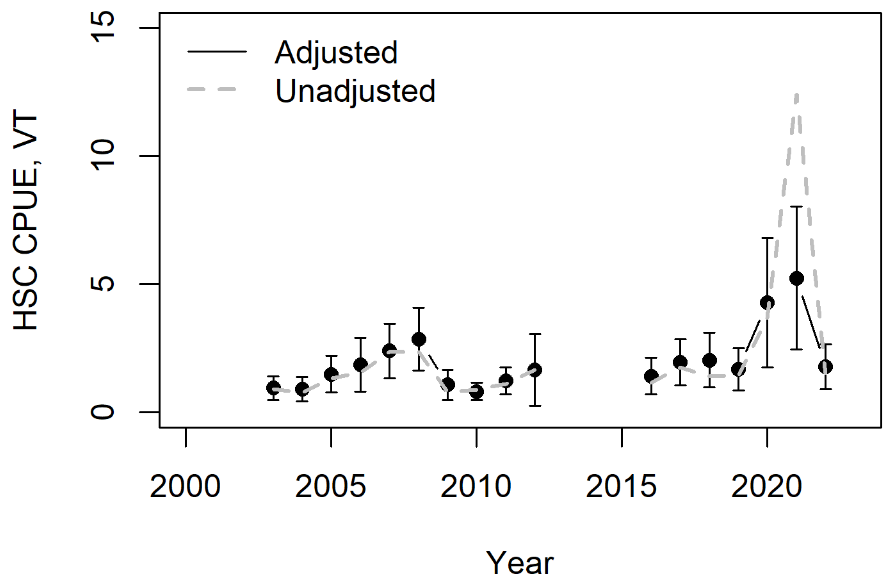

***Figure S6**. Annual HSC catch-per-unit-effort (CPUE; a type of abundance index) for trawl surveys conducted by Virginia Tech from 2003 to present. Solid black points are adjusted for the effects of seasonality, water temperature, and depth, while dashed gray line represents the unadjusted CPUE. Error bars represent one standard error on either side of the adjusted CPUE estimate. Unlike for the NJ data, the correction does not generally alter the pattern of HSC abundance versus the unadjusted CPUE.*

Open robust design (ORD) validation tests

In this section, I report validation tests for assessing the ability of the open robust design (ORD) model to estimate the known values of key parameters (like survival) from simulated band-resighting data. In general, the ORD model successfully recovered the true parameters used to simulate the data, indicating that this model was correctly specified and capable of estimating parameters correctly. Overall, the ORD model was able to estimate many parameters related to survival, temporary emigration, the timing of stopover arrivals and departures, and detection probability (Figs S7-10). However, while the ORD model appears to perform well in simulation tests, recall that goodness of fit (GOF) tests showed that this model was not an adequate representation of the observed REKN data from Delaware Bay (see section 6, above). In addition, issues with potential misread errors further compromised the validity of the results (see above).

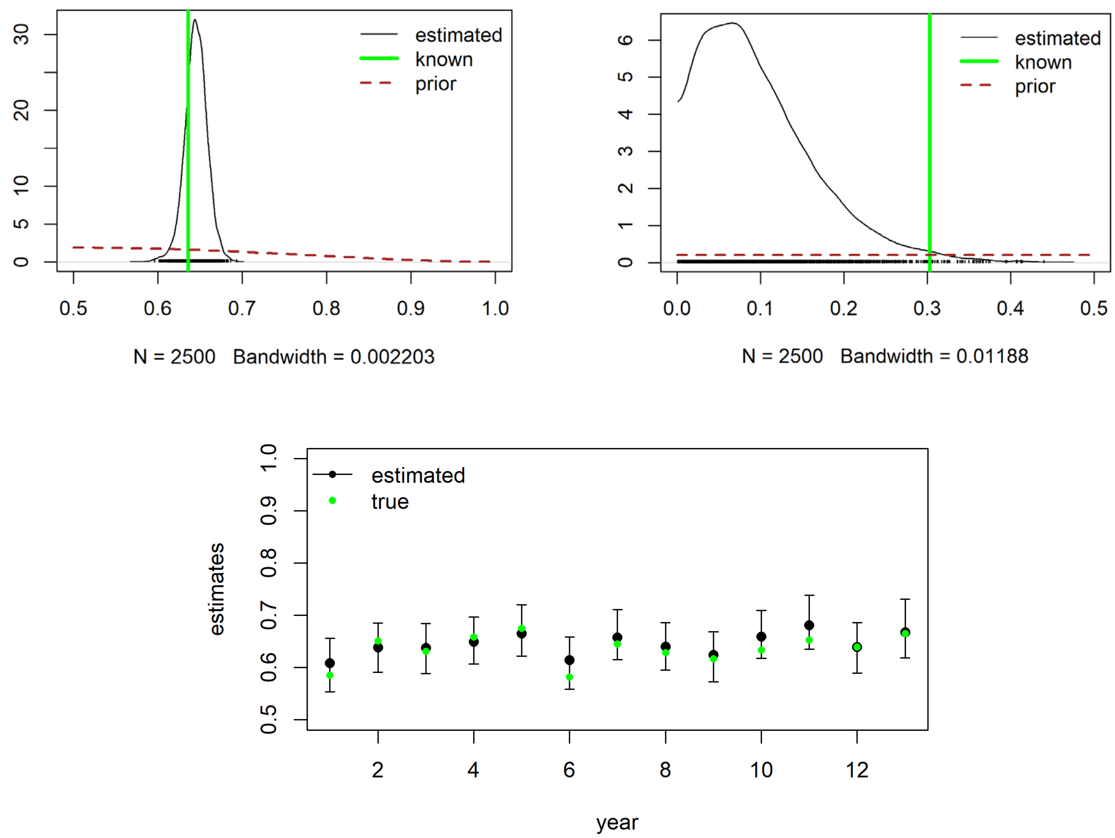

__Figure S7__. In simulation tests, the ORD model seems to do a good job of recovering true mean survival (top left) from simulated data. The ORD model frequently fails to capture the true variance in survival (top right), leading to some concern about its ability to model annual variation in survival. However, the model performs well in capturing true annual survival values (bottom). Green dots and vertical lines represent the true values used in simulations, black curves, points, and confidence intervals represent parameter estimates from the ORD model, and dashed brown curves represent the prior probability distributions used for Bayesian model fitting.

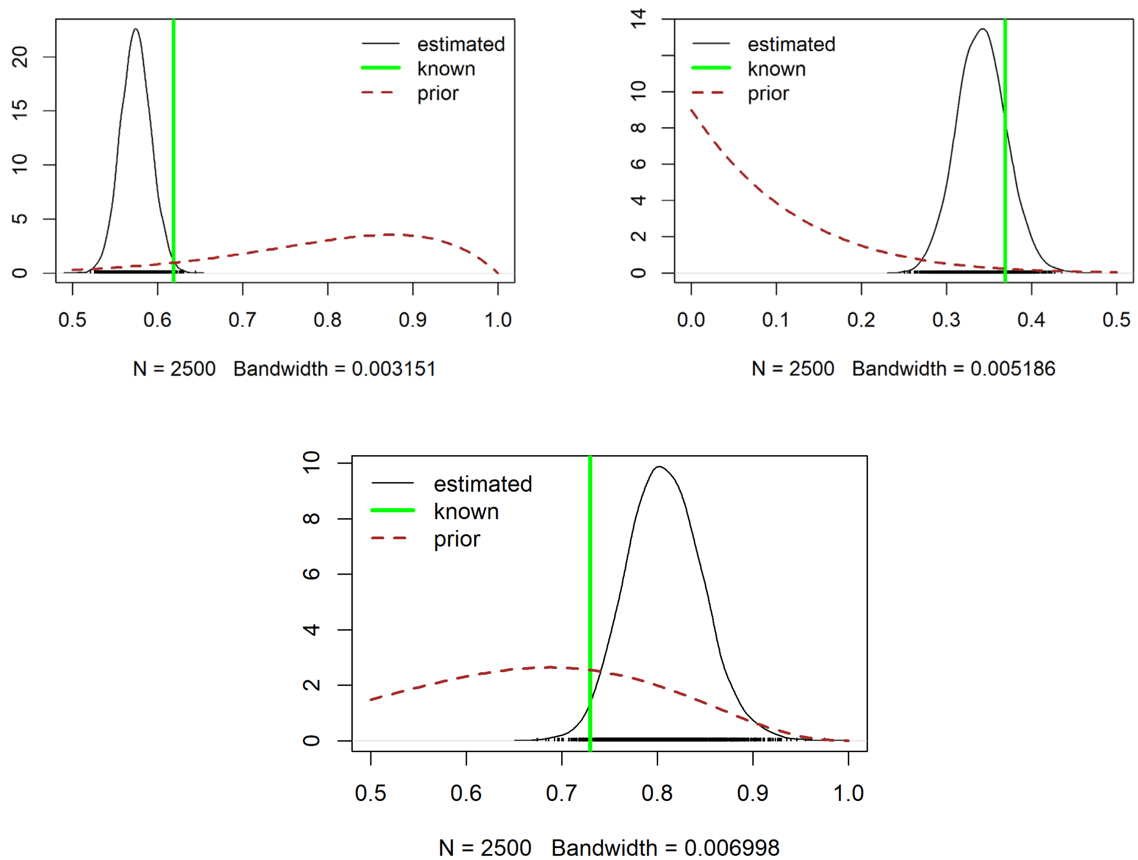

Figure S8*. In simulation tests, the ORD model tended to perform moderately well at recovering the true gammaII term (temporary emigration- prob of returning to the stopover after using it last year) from simulated data (top left), GammaOI term (temporary emigration- prob of returning to the stopover after skipping last year) (top right) and Tau (stopover residency probability) (bottom panel). Green dots and vertical lines represent the true values used in simulations, black curves, points, and confidence intervals represent parameter estimates from the ORD model, and dashed brown curves represent the prior probability distributions used for Bayesian model fitting.*

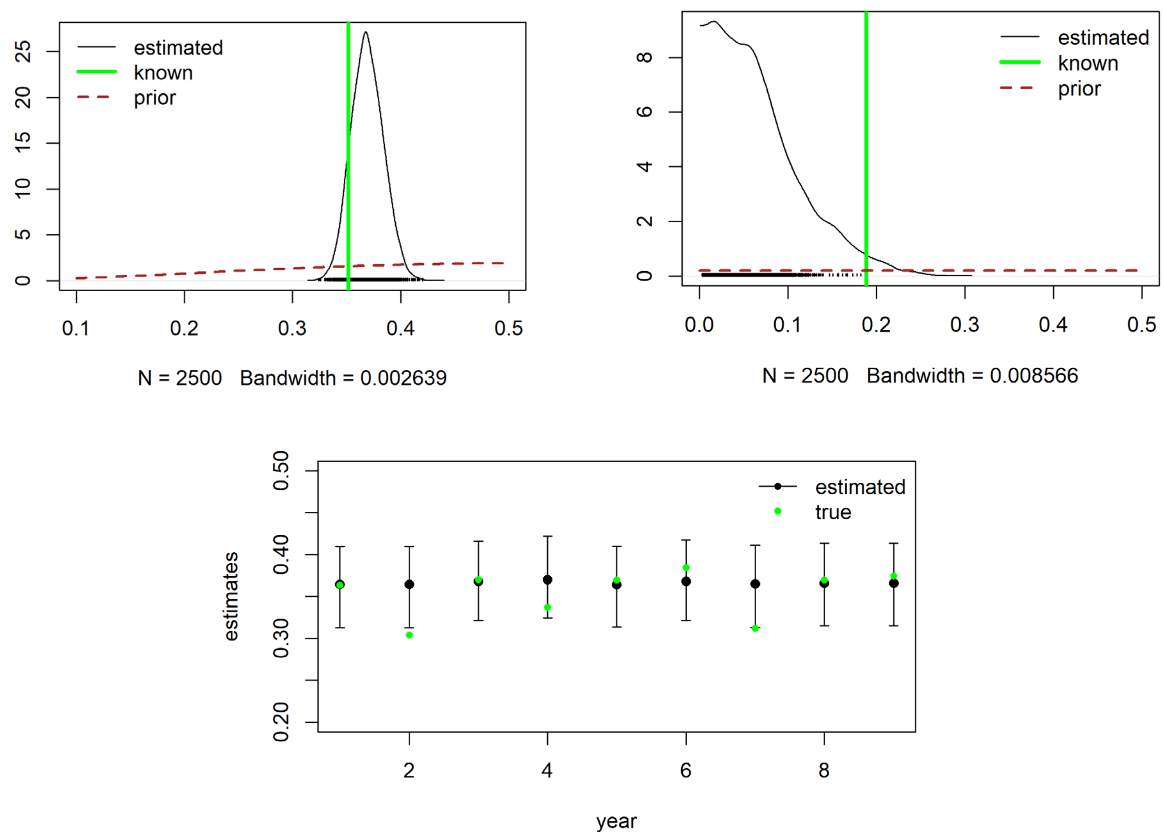

Fig. S9. *In simulation tests, the ORD model tended to perform moderately well at recovering the true temporal mean detection probability (top left). However, the ORD model performed somewhat poorly at recovering the temporal process variation in p (variation across both primary and secondary occasions); this parameter doesn't seem to fit well, and the chains exhibited very slow mixing. The bottom panel indicates detection probability per 3-day sampling occasion; the model appears to be underestimating variation among secondary occasions. Green dots and vertical lines represent the true values used in simulations, black curves, points, and confidence intervals represent parameter estimates from the ORD model, and dashed brown curves represent the prior probability distributions used for Bayesian model fitting.*

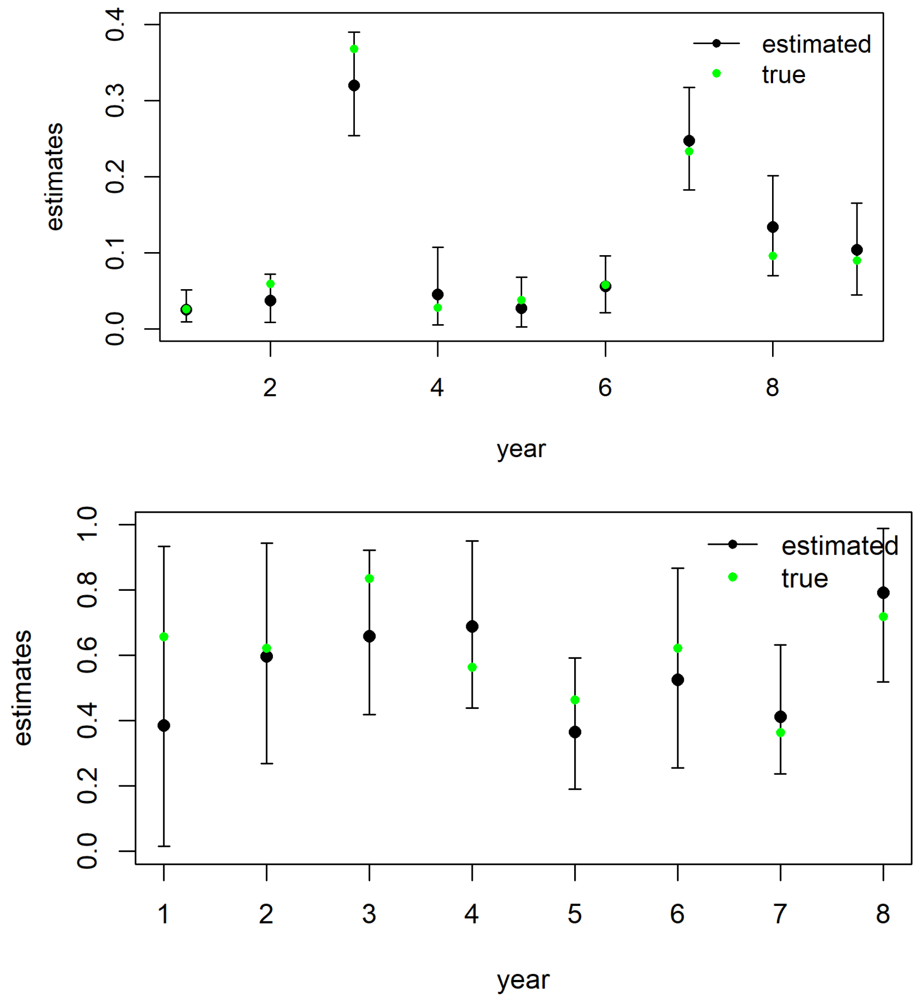

***Fig. S10**. In simulation tests, the ORD model tended to perform moderately well at recovering the 'Delta' parameter (entrance probabilities) (top panel)— here, estimated from simulated data for year 8 (selected randomly from among years). The ORD model also performed well in recovering information about the 'Psi' parameter (probability of stopover persistence) (bottom panel). The green dots and vertical lines represent the true values used in simulations, while black curves, points, and confidence intervals represent parameter estimates from the ORD model.*

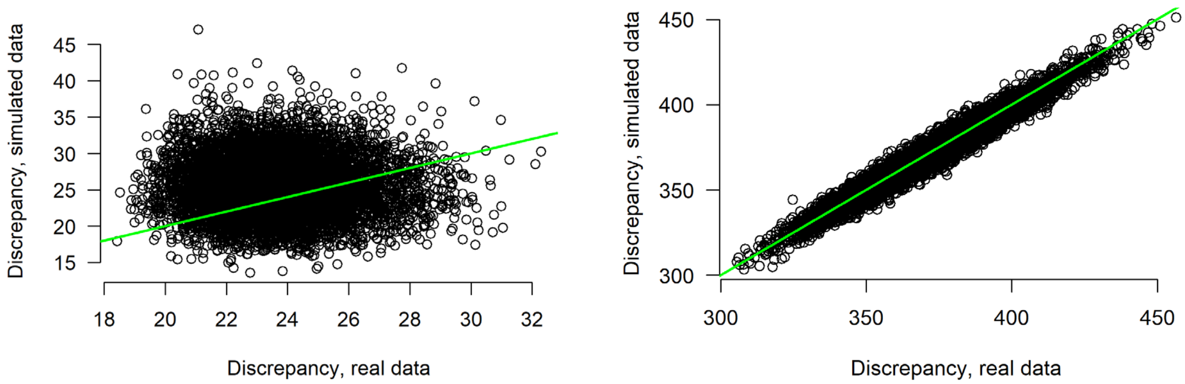

***Fig. S11**. In simulation tests, the open-robust-design (ORD) model exhibited adequate goodness of fit, demonstrated here through posterior predictive checks (PPCs) involving the among-year survival process (L1; left panel) and the timing of first entry to the stopover each year (L2; right panel). The ORD model passed all four GOF tests when data were simulated using the same model assumptions used for model fitting (two tests not shown). In contrast, when the real REKN mark-resight data were used for model fitting, these tests indicated poor model fit (see section 6, above).*

ATTACHMENT

The following materials were submitted in September 2022 to inform the ASMFC Horseshoe Crab Management Board's consideration of Addendum VIII to the Horseshoe Crab Fishery Management Plan. They are included here for reference.

EARTHJUSTICE

September 30, 2022

Horseshoe Crab Management Board
Atlantic States Marine Fisheries Commission
1050 N. Highland Street, Suite 200 A-N
Arlington, VA 22201
comments@asmfc.org

VIA ELECTRONIC MAIL

Re: Draft Addendum VIII to the Horseshoe Crab Fishery Management Plan for Public Comment

Dear Members of the Horseshoe Crab Management Board:

I write on behalf of New Jersey Audubon and Defenders of Wildlife to urge you to reject Addendum VIII to the Horseshoe Crab Fishery Management Plan. Since the Board instituted the Adaptive Resource Management ("ARM") Framework in 2012, red knot[1] abundance at Delaware Bay has fallen to historically low levels, and the U.S. Fish & Wildlife Service ("FWS") has listed the species as "threatened" under the Endangered Species Act ("ESA"). Horseshoe crabs, too, remain severely depleted compared to historical benchmarks. These circumstances demand greater protections and a precautionary strategy. But Addendum VIII would instead weaken the protections currently in place. Among other harmful outcomes, the Addendum almost certainly would reinitiate the female horseshoe crab bait harvest. Recognizing that neither red knots nor horseshoe crabs have recovered, the ARM Framework, until this proposal, has prohibited female harvest to protect the eggs on which the red knots rely.

Horseshoe crab eggs are critical to the red knot's ability to survive its 9,000-mile migration from as far south as Tierra del Fuego and to breed successfully in the Arctic Circle. The importance of horseshoe crab eggs to red knot success has long been recognized by scientists, government agencies, and the Atlantic States Marine Fisheries Commission ("ASMFC" or "Commission"), and the overharvest of horseshoe crabs has been a primary cause of the red knots' decline over the past three decades.

Nevertheless, despite the well-established link between horseshoe crab eggs and red knot survival and reproduction, Draft Addendum VIII proposes a starkly different version of reality. Through a combination of modeling defects and risk-prone decision-making, the revised ARM Framework now determines that the relationship between these species is scarcely perceptible, and that red knots would be virtually indifferent to the renewed harvest of female horseshoe crabs.

[1] In this document, "red knot" refers to the *rufa* subspecies.

As detailed in these comments and the attached expert reports by Dr. Kevin Shoemaker and Dr. Romuald Lipcius, this depiction of the relationship between horseshoe crab eggs and red knot demography is deeply flawed. Contrary to the conclusions represented in Draft Addendum VIII, adopting a new management approach that would enable resumption of the harvest of female horseshoe crabs at this juncture, when both red knots and horseshoe crabs are depleted, would harm red knots and present risks to the horseshoe crab population itself. Accordingly, the revised ARM Framework is not suitable for recommending horseshoe crab bait harvest quotas.

More specifically, the Board should reject Addendum VIII for reasons including but not limited to:

- **The revised ARM Framework errs in concluding that red knots are not highly dependent on horseshoe crabs at Delaware Bay.**
    - After flying thousands of miles, red knots arrive at Delaware Bay to renourish on horseshoe crab eggs. Under ideal conditions, red knots can double their body weight in less than two weeks. In the late 20th century, the peak count of red knots at Delaware Bay usually exceeded 40,000 and sometimes exceeded 90,000.
    - Horseshoe crabs were overharvested in the 1990s. In 2015, FWS listed red knots as "threatened" under the ESA and called horseshoe crab overharvest and corresponding egg depletion a "primary causal factor" in red knot decline. The peak red knot count has stayed below 13,000 for each of the past two years.
    - Despite this strong evidence of the importance of horseshoe crab eggs to red knots, the revised ARM Framework posits a weak link between the two species. By so doing, the revised ARM Framework subverts the premise of ASMFC's management regime for the horseshoe crab fishery, which is to manage the horseshoe crab harvest for red knot recovery.

- **New analysis reveals significant technical flaws that make the revised ARM Framework unsuitable for managing the horseshoe crab harvest.**
    - The revised ARM Framework abandons the well-established understanding of the importance of horseshoe crab eggs to red knots in favor of an extreme, contrary reconstruction of the ecosystem that defies history and reality. Even if horseshoe crabs vanished entirely today, the revised ARM Framework's computer model predicts that red knot abundance would remain stable on average or even increase over the next 50 years. The model clearly would not have predicted the decline of red knots that resulted from horseshoe crab overharvest in the 1990s, which discredits its usefulness in making projections that could help both species recover.
    - The revised ARM Framework also undermines sustainable management of horseshoe crabs. By miscalculating uncertainty, the horseshoe crab projection model generates artificially stable horseshoe crab population projections, when there actually exists a significant threat of decline.
    - The horseshoe crab population projections are significantly influenced by nonsensically high recruitment rates that were plugged in for years when recruitment was not measured empirically, thus further undermining the reliability of its projections.

- The horseshoe crab population model bears very little correlation even to the data that the model is based upon, raising significant additional doubt about its predictive power and usefulness.

- **<u>The revised ARM Framework's risk-prone assumptions and decisions are inappropriate, especially when a threatened species is at stake.</u>**
  - Horseshoe crab demographic information, including size and sex ratio, strongly suggests that the species is not recovering and that a risk-averse management approach is required.
  - The Framework does not consider the availability of horseshoe crab eggs, which is the most direct measure of food resources for red knots. Analysis of horseshoe crab demographic trends indicates that egg production may be declining more than abundance estimates suggest.
  - The model finds a weak relationship between horseshoe crabs and red knots partly because it is based on data from years when both species had already declined rather than when the ecosystem was flourishing. Modeled projections of a depleted ecosystem offer no guidance on managing to achieve recovery of either red knots or horseshoe crabs.
  - The Framework does not assess whether Delaware Bay provides adequate food for Southern wintering red knots, which are especially dependent on horseshoe crab eggs.
  - The Framework would eliminate protective population thresholds that must be met prior to any female harvest, creating risks to red knots and horseshoe crabs and contravening stakeholders' precautionary intent.
  - For population estimates, the model equally weights three surveys, despite stakeholders' express preference—and ASMFC's practice until now—to rely exclusively upon the model that is purpose-designed for counting horseshoe crabs. This results in artificially inflated horseshoe crab population estimates.

- **<u>ASMFC has repeatedly excluded input from stakeholders and the broader public.</u>**
  - In addition to its other flaws, the revised ARM Framework is based on a model that has never been released to the public. Analysis of even the limited information made available to the public to date indicates significant problems with the model, as discussed above. If the Board approves Addendum VIII now and the model is subject to public evaluation, new concerns and critiques will inevitably arise after the revised ARM Framework is already in use.
  - The ARM Subcommittee failed to solicit formal stakeholder input in this proceeding, in violation of its own procedures and past practice.
  - By designating Addendum VI the "No Action" alternative, the Board artificially narrowed its options to two addenda that would reinitiate the female horseshoe crab harvest, thus deciding the most important issue before the public comment period even began.

- **<u>The flaws in the revised ARM Framework must be addressed now.</u>**
  - The authority of ASMFC to deviate from the ARM Framework's harvest quotas in the future is not a rationale for approving Addendum VIII based on a flawed modeling framework now. Prematurely approving Addendum VIII would set the stage for contentious and arbitrary decisions about annual quotas for years to come.
  - The authority of states to set lower quotas than ASMFC provides does not lessen the Board's obligation to ensure that the revised ARM Framework is fully vetted and reflects stakeholder values.
  - Updating the revised ARM Framework's model as new data become available will not correct its fundamental flaws, many of which—as explained in these comments—are apparent from expert reviews of even the limited data made publicly available to date.

- **<u>Approving Addendum VIII would likely lead to a violation of the Endangered Species Act by ASMFC.</u>**
  - The ESA requires a precautionary approach to protecting threatened species.
  - By reinitiating the bait harvest of female horseshoe crabs, ASMFC would commit "take" of red knots. ASMFC is responsible under the ESA for harvests conducted pursuant to the quotas it sets.
  - FWS's purported "evaluation" of the revised ARM Framework merely repackages ASMFC's modeling, with all of its flaws, and uses it to generate an unreliable conclusion regarding the impact of red knots. It therefore sheds no new light on the Board's stewardship responsibilities or the Commission's legal obligations.

The objections listed above are elaborated in the comments and expert reports that follow. Each objection is an independently sufficient reason to reject Addendum VIII. Collectively, they demonstrate that Addendum VIII is incompatible with the Board's mandate to maintain the ecosystem integrity of Delaware Bay and to comply with the Endangered Species Act.

Respectfully submitted,

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Table of Contents

I. THE REVISED ARM FRAMEWORK ERRS IN CONCLUDING THAT RED KNOTS ARE NOT HIGHLY DEPENDENT ON HORSESHOE CRABS AT DELAWARE BAY.

Each year, a population of red knots completes one of the most epic migrations in the animal kingdom. Starting from Tierra del Fuego at the southern tip of South America, the red knots fly more than 9,000 miles to their breeding grounds in the Arctic Circle. For most red knots, the final staging area before the Arctic Circle is Delaware Bay, where their stopover coincides with another ecological marvel: the spawning of millions of horseshoe crabs that emerge from the water and lay clusters of approximately 4,000 eggs, with the potential for an individual to lay more than 100,000 eggs over the course of several nights.[2] For red knots that have already flown thousands of miles at enormous physiological expense, the eggs provide essential replenishment, enabling a doubling of body mass in fewer than 14 days, versus 21 to 28 days at comparable stopovers where they eat clams and mussels.[3] This unique resource fuels the duration of their journey and enhances breeding success in the Arctic.[4]

The abundance of red knots and horseshoe crabs at Delaware Bay as recently as the 1990s is almost unimaginable today. From 1981 to 2002, the peak red knot count in Delaware Bay usually exceeded 40,000 and twice surpassed 90,000.[5] One participant in an aerial survey of shorebirds during that period described "lines of deposited horseshoe crab eggs set like mineral veins in smooth white marble, virtually an unlimited food supply."[6] In a single day, his survey tallied 62,000 red knots and 318,000 total shorebirds on just the New Jersey side of Delaware Bay.[7]

In the 1990s, increasing and unregulated horseshoe crab harvest by the bait and biomedical industries crashed the population of horseshoe crabs.[8] Red knots, no longer able to rely on the irreplaceable horseshoe crab eggs, declined in tandem. ASMFC adopted a fishery management plan for horseshoe crabs in 1998 and instituted adaptive management in 2012. Since then, the female bait harvest has been prohibited. But the fate of horseshoe crabs remains highly uncertain, and red knots have continued to decline. Red knot peak counts that previously topped 90,000 have, for the past two years, languished below 13,000, including a record low of 6,800 in 2021. Twenty years have passed since the population topped a modest 33,000.[9] Instead of these peak

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[2] NOAA Fisheries. *Horseshoe Crabs: Managing a Resource for Birds, Bait, and Blood* (July 31, 2018), https://www.fisheries.noaa.gov/feature-story/horseshoe-crabs-managing-resource-birds-bait-and-blood.

[3] Lawrence Niles et al., *Effects of Horseshoe Crab Harvest in Delaware Bay on Red Knots: Are Harvest Restrictions Working?*, 59 BioScience 153, 154 (2009); New Jersey Department of Environmental Protection, *Wildlife Populations: Red Knot* 1-2 (2020), https://www.nj.gov/dep/dsr/trends/wildlife-redknot.pdf.

[4] Sjoerd Duijns et al., *Body Condition Explains Migratory Performance of a Long-Distance Migrant*, 284 Proceedings of the Royal Society of London B 20171374, at 4-6 (2017).

[5] FWS, *Rufa Red Knot Background Information and Threats Assessment* 100 tbl. 12 (2014) (excluding 1984-1985, when the survey was not conducted).

[6] Pete Dunne, *Tales of a Low-Rent Birder* 10 (1986).

[7] *Id.* at 13-14.

[8] FWS, *Rufa Red Knot Background Information and Threats Assessment* 232 ("Evidence that commercial harvests caused horseshoe crab population declines in recent decades comes primarily from a strong temporal correlation between harvest levels . . . and population levels.").

[9] *Id.* at 100 tbl. 12 (for years 1981-2014); ASMFC, *Revision to the Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Inclusive of Red Knot Conservation (Draft for Board Review)* 155 tbl.

counts, the revised ARM Framework uses modeled estimates of the total number of red knots passing through Delaware Bay. While these modeled estimates face criticism for overrepresenting red knots' use of Delaware Bay, they have fallen as well, from as high as 152,900 in 1989, to an average of 77,000 per year for 1998-2001, to numbers in the 40,000s over the past several years.[10]

In 2015, FWS formally listed the red knot as a threatened species under the Endangered Species Act.[11] At the time of the listing, FWS cited several studies indicating that red knot abundance had declined, "probably sharply," since the 1980s.[12] FWS found that "[r]educed food availability in Delaware Bay due to commercial harvest of the horseshoe crab . . . is considered a primary causal factor in red knot population declines in the 2000s."[13] Reduced food availability is a particular threat for the Southern wintering population of red knots, which is disproportionately reliant on the Delaware Bay staging area and which FWS views as "a bellwether for the subspecies as a whole."[14] According to FWS, "[R]educed food availability at just one key migration stopover area (Delaware Bay) is considered the driving factor behind the sharp decline in the Southern wintering population in the 2000s."[15]

As FWS has stated, "Studies have shown red knot survival rates are influenced by the condition (weight) of birds leaving the Delaware Bay staging area in spring."[16] Research has also shown that, while red knots arriving relatively late to Delaware Bay were able to compensate by gaining weight at a higher rate, that was not the case in years with low horseshoe crab egg availability.[17]

Until now, the well-established link between horseshoe crabs and red knots has been the cornerstone of ASMFC's management of the horseshoe crab fishery at Delaware Bay. Addendum VIII would subvert that regime. While the proposed model nominally bases harvest quotas on red knot and horseshoe crab abundance estimates, it assigns an extremely weak correlation between the abundance of the two species. It thereby concludes that red knots would be essentially unaffected by the resumption of the female horseshoe crab bait harvest.

As explained below, Addendum VIII's baseline assumption—that increasing the horseshoe crab harvest would only marginally impact red knots at Delaware Bay—is unsupported. It relies on evaluating a limited dataset that omits years when the ecosystem flourished. (For example, its dataset about horseshoe crab abundance is drawn entirely from the last 20 years, after the crash

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12 (2021) ("ARM Report") (for years 2011-2020); Larry Niles, "2022 Delaware Bay Stopover Project Final Update-5 June 2, 2022," *A Rube with a View* (June 15, 2022), https://www.arubewithaview.com/2022/06/15/2022-delaware-bay-stopover-project-final-update-5-june-22022/ (for years 2021-2022).

[10] FWS, *Rufa Red Knot Background Information and Threats Assessment* 101 tbl. 13; ASMFC, *ARM Report* 155 tbl. 12.

[11] FWS, "Endangered and Threatened Wildlife and Plants; Final Threatened Status for the Rufa Red Knot," 79 Fed. Reg. 73,706 (Dec. 11, 2014). The listing became effective on January 12, 2015. *Id.* at 73,706.

[12] FWS, *Rufa Red Knot Background Information and Threats Assessment* 85. While FWS primarily analyzed red knot population trends within individual regions, it "note[d] a temporal correlation between declines at Tierra del Fuego and Delaware Bay." *Id.* at 84.

[13] 79 Fed. Reg. at 73,707.

[14] FWS, *Draft Recovery Plan for the Rufa Red Knot* 13 (May 2021).

[15] *Id.* at 14.

[16] *Id.* at 25; FWS, *Rufa Red Knot Background Information and Threats Assessment* 254.

[17] FWS, *Rufa Red Knot Background Information and Threats Assessment* 253.

of the horseshoe crab population and during a period when red knot abundance has been comparatively low.) And it suffers from modeling defects that, among other things, erroneously overstate the size and stability of the horseshoe crab population.

For these reasons and others detailed below, Addendum VIII is not a pathway for sustaining red knots, much less restoring a thriving ecosystem, nor does it honor the precautionary approach required when a threatened species is at stake. Instead, it risks a violation of ASMFC's legal obligations, including its obligation to avoid "take" of red knots under the ESA. The Board therefore should reject Addendum VIII and instead adopt adequate protections for horseshoe crabs and red knots at Delaware Bay.

II. NEW ANALYSIS REVEALS SIGNIFICANT TECHNICAL FLAWS THAT MAKE THE REVISED ARM FRAMEWORK UNSUITABLE FOR MANAGING THE HORSESHOE CRAB HARVEST.

As detailed in the following sections, the parties to this letter solicited independent expert reviews of the revised ARM Framework. These reviews reveal significant technical and methodological flaws that render the Framework unreliable for ASMFC management decisions.

For the first expert review, Dr. Kevin Shoemaker conducted an independent analysis of the horseshoe crab abundance and projection model that informs the revised ARM Framework. Dr. Shoemaker demonstrates that the Framework contains significant flaws that make it unsuitable for managing the horseshoe crab harvest. These flaws are especially alarming given the implications of the Framework for a threatened species such as the red knot. This section details many of Dr. Shoemaker's key findings, all of which are explained in more detail in the attached expert report.

At the outset, it is important to note that most of the components of the revised ARM Framework's model still have not been made available to the public. As a result, Dr. Shoemaker was unable to evaluate the components that link horseshoe crab abundance to red knot abundance or generate horseshoe crab harvest recommendations. Although Dr. Shoemaker was able to draw some conclusions about those aspects of the model, most of the analysis below necessarily focuses on the horseshoe crab model. As these comments proceed to discuss, the analysis that Dr. Shoemaker was able to conduct reveals severe issues concerning the reliability of the modeling. Nevertheless, Dr. Shoemaker's focus on the publicly available modeling information should not be interpreted to suggest that the unreleased components do not also contain significant flaws. To the contrary, given the flaws that are apparent in the information released to date, it is vital that *all* components of the model be subject to public evaluation before the Board takes any action to approve Addendum VIII.

A. <u>The revised ARM Framework Is an Inappropriate Tool for Helping to Reverse the Decline and Promote the Recovery of Red Knots.</u>

Considering that adaptive management is premised on the link between horseshoe crabs and red knots, the weakness of that link in the revised ARM Framework is breathtaking. By way of illustration:

- Dr. Shoemaker shows that, even if the horseshoe crab population in Delaware Bay completely collapsed to zero, the revised ARM Framework would predict that red knot abundance would remain stable or even increase over the next 50 years on average.[18]
    - Furthermore, "This simulation exercise makes it very clear that the REKN model used in the revised ARM would not be able to predict or explain the decline in the REKN population observed during the 1990s."[19] In other words, the model could not even have diagnosed the problem that it is supposed to solve.
- The data informing the revised ARM Framework actually show a negative correlation between female horseshoe crab abundance and red knot recruitment.[20] That is, according to the model, as female horseshoe crab abundance *increases*, red knot recruitment *decreases* on average.
- Due to the weak relationship between red knot and horseshoe crab abundance, it is not implausible that, with future updates to the revised ARM Framework, the relationship will disappear entirely or even become negative. Dr. Shoemaker observes that "[t]his outcome would pose an existential problem for the ARM framework . . . . There does not appear to be a contingency plan for this outcome."[21]
- Whatever weak signal the model has detected in historical data appears to be overwhelmed by random noise. As Dr. Shoemaker explains, it is highly likely that the model's "information about the HSC/REKN relationship would explain little if any of the variation in independent validation data."[22]

Due to the weak relationship between red knots and horseshoe crabs represented in the revised ARM Framework, it is unlikely that the model would outperform—much less significantly improve upon—a "null" model that entirely omits any effect of horseshoe crab abundance.[23] Yet it was impossible for Dr. Shoemaker to explore this key issue further because of the limitations on the materials made publicly available to date. Nevertheless, the concerns raised by the analysis that Dr. Shoemaker was able to perform are profound and call into question the revised ARM Framework's utility to guide any decision-making about the status or management of the affected species.

In sum, while the revised ARM Framework nominally recommends harvest quotas based on the relationship between horseshoe crabs and red knots, it effectively decouples the fates of the two species, unjustifiably transforming the methodology and philosophy that underlie the management of this fishery. This is an independently sufficient reason for the Board to reject Addendum VIII.

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18 Kevin Shoemaker, *Review of 2021 ASMFC ARM Revision* 6-9 & fig. 1 (Sept. 2022) ("*Shoemaker Expert Report*").
19 *Id.* at 8.
20 *Id.* at 9 fig. 2.
21 *Id.* at 10.
22 *Id.* at 26.
23 *Id.* at 25-26.

B. The Horseshoe Crab Population Simulation Model Does Not Properly Account for Uncertainty, Resulting in Artificially Stable Abundance Projections.

The revised ARM Framework profoundly underestimates uncertainty in the horseshoe crab recruitment rate, thereby calling into question its projections concerning the impact of harvest. As Dr. Shoemaker explains, the rate at which new recruits join the reproductive population "is the most consequential empirically fitted component of the HSC simulation model."[24] Other components of the model, such as natural and biomedical mortality, are fixed values, but the recruitment rate is calculated based on data.

Dr. Shoemaker shows[25] that the model errs by conflating two distinct types of uncertainty: (i) natural, year-over-year variation and (ii) the potential that the model incorporates incorrect parameters (most importantly, the mean horseshoe crab recruitment rate). The model treats both types of uncertainty as natural, year-over-year variation, with the consequence that the abundance estimates regress to a mean. In other words, the variations cancel each other out, making the projected population appear highly stable. But if evaluated properly, parameter uncertainty would likely compound over time, yielding a very different picture of the population. For example, if average recruitment is actually lower than the rate used in the model, that uncertainty would *not* cancel out over time. Instead, the horseshoe crab population could be headed for a one-way decline. Notably, the revised ARM Framework accounts for the two types of uncertainty separately in the *red knot* projection model, suggesting that the modelers recognized the importance of that approach, but nevertheless they did not implement it when projecting horseshoe crab abundance.

The consequences of this error are significant for estimates of the population's trajectory. Properly accounting for uncertainty, Dr. Shoemaker found that the horseshoe crab population faces a very real threat of declining well below levels acknowledged by the revised ARM Framework's projection model. Notably, he used the same estimates of uncertainty as the revised ARM Framework (as well as the same values for natural mortality, biomedical mortality, etc.). All that changed in his analysis was the method of evaluating uncertainty. Dr. Shoemaker's analysis[26] reveals that:

- Even under a scenario with *no* bait harvest, *no* biomedical mortality, and *no* discard mortality, the female horseshoe crab population has a 17.4% probability of declining below 4 million, and a 3.8% probability of declining below 3 million, over the next 50 years.
    - For comparison, 4 million is the lowest female abundance estimated for any year from 2003 to 2019 (the years upon which the model was based).
    - In contrast, by incorrectly accounting for uncertainty, the revised ARM Framework's model does not project female abundance values below 4 million within the 95% confidence interval under optimal harvest scenarios, *including* bait harvest, biomedical mortality, and discard mortality.[27]

[24] *Id.* at 12.
[25] The information in this paragraph is drawn from *Shoemaker Expert Report* 12-18 & figs. 3-4.
[26] Except where noted, these findings are presented in greater detail at *Shoemaker Expert Report* 15, 18 fig. 4.
[27] ASMFC, *Supplemental ARM Report* 35 fig. 15.

- Under a scenario in which horseshoe crabs are harvested for bait under the maximum quotas of 500,000 males and 210,000 females but are still *not* subject to biomedical or discard mortality, the female population has a 33% probability of declining below 4 million, an 11% probability of declining below 3 million, and a 2% probability of declining below 2 million, over the next 50 years.

Dr. Shoemaker concludes that, "if sources of error in the recruitment process are properly accounted for, the outlook for the HSC population in Delaware Bay is uncertain even in the absence of any harvest pressures."[28] If the Board approves Addendum VIII, it would increase harvest pressure through a model that fails to properly account for the risk of a declining horseshoe crab population.

C. <u>The Horseshoe Crab Projection Model's Recruitment Estimates Are Strongly Influenced by Nonsensical, Unverified Estimates from the Virginia Tech Gap Years.</u>

The revised ARM Framework's conclusions are further undermined by its reliance on fantastical recruitment projections to fill in a key gap in actual population-monitoring data for horseshoe crabs. Of the three trawl surveys that inform the catch multiple survey analysis ("CMSA") component of the framework, only the Virginia Tech survey measures primiparous (i.e., newly mature) females to provide an empirically based estimate of recruitment. Thus, the CMSA does not incorporate any direct measurement of recruitment during the 2013-2016 period when the Virginia Tech survey was not conducted. Instead, it indirectly estimates annual recruitment rates, but two of these estimates are many times higher than any estimate from years with direct observations. Since the average recruitment rate in the population projection model treats all of the estimates as equally valid—whether or not they were based on empirical observations or hypothetical estimates—the model's estimated annual recruitment rate is heavily influenced by the nonsensical estimates from the Virginia Tech gap years.

To understand the impact of the nonsensical gap year estimates, first consider the years with empirically derived recruitment estimates. The average annual estimated recruitment for 2003-2012 was 1.2 million primiparous females. The average annual estimated recruitment for 2017-2019 was 1.9 million. Now consider the non-empirically derived gap year estimates. In 2013, the estimate was *9.6 million*—roughly eight times larger than the average over the previous ten years, and four times larger than the maximum annual estimate from that period.[29] In 2014, the estimate dropped to only two primiparous females across all of Delaware Bay, but the estimate is so uncertain that the upper limit of the confidence interval approaches infinity.[30] All told, the *average* estimate for the four Virginia Tech gap years was 4.2 million primiparous females, which is nearly *2 million* higher than the *maximum* ever estimated for any year with empirical observations.[31]

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[28] *Shoemaker Expert Report* 17.
[29] ASMFC, *Supplemental Report to the 2021 Revision to the Adaptive Resource Management Framework* 16 tbl. 3 (2022) ("*Supplemental ARM Report*").
[30] *Id.* at 25 fig. 5.
[31] *Id.* at 16 tbl. 3.

The nonsensical estimates from the Virginia Tech gap years compromise the horseshoe crab projection model because they significantly affect its recruitment estimate. As Dr. Shoemaker shows,[32] in the original ARM report, the ARM Subcommittee based the recruitment rate exclusively on data from 2013 to 2019, which relied overwhelmingly on estimates from the gap years and generated an annual recruitment estimate of 3.1 million primiparous females. Following criticism from the Peer Review Panel, the Subcommittee expanded the dataset to include 2003-2019, which reduced the recruitment estimate to 1.67 million. But if the nonsensical data from the gap years were excluded, this estimate would fall to 1.26 million. Dr. Shoemaker illustrates how the difference in these estimates has huge implications for the model's projection of future horseshoe crab abundance.

Dr. Shoemaker concludes that "the inflated estimates of recruitment during the VT gap years are likely to be an artifact of the CMSA model specification (and the lack of data on recruitment for those years) and are unlikely to be reflective of true HSC recruitment rates. . . . [A] conservative (precautionary) approach would be to exclude the VT gap years when computing recruitment for the HSC population simulations."[33] Doing so would yield a substantially lower recruitment estimate with a commensurately lower capacity to withstand a resumption of female harvest.

D. The Horseshoe Crab Population Model Has a Poor Correlation to Existing Data.

The CMSA's usefulness is cast further into doubt by its failure to correlate with any source of data about horseshoe crab abundance. As Dr. Shoemaker shows from an analysis of female horseshoe crab abundance estimates, the model does not correlate even with the data sources upon which it was based, much less any independent validation data.

For the years 2003-2019, the CMSA's correlation with the Delaware Adult Trawl Survey is extremely weak, and any correlation that exists is entirely attributable to the model's apparent ability to predict that horseshoe crab populations rose during 2013-2016, when the Virginia Tech survey was not conducted.[34] For the years before and after the Virginia Tech gap—that is, for the vast majority of years evaluated—the coefficient of determination (R^2) between the CMSA model and the Delaware Survey was *negative*, meaning that the model performed worse than a null model. The CMSA performs almost as poorly against data from the New Jersey Ocean Trawl Survey, with a weak positive correlation for the years prior to the Virginia Tech gap and a negative R^2 for the years after. The CMSA's worst performance comes when measured against the Virginia Tech survey, with a negative R^2 across the full time series for which data are available. To test the CMSA against independent validation data, Dr. Shoemaker compared it to the results of Delaware Bay spawning surveys and found no detectable relationship whatsoever between the results.

As this summary makes clear, the CMSA's modeled outcomes bear little relationship to actual data on the Delaware Bay horseshoe crab population. For this reason, Dr. Shoemaker recommends comparing the CMSA's horseshoe crab estimates to a null model that omits all information about horseshoe crab harvest from the model fitting process. Given its poor fit to

[32] The data discussed in this paragraph can be found at *Shoemaker Expert Report* 22-24 & fig. 7.
[33] *Id.* at 23.
[34] The findings in this paragraph are presented in greater detail at *Shoemaker Expert Report* 19-22 & figs. 5-6.

existing data, the CMSA's horseshoe crab projection model is "unlikely to outperform" even a relatively simple null model.[35] Dr. Shoemaker concludes, "If the HSC simulation model fails to outperform a model in which population dynamics are driven by noise instead of harvest, it should prompt managers to acknowledge that our current understanding of the effects of harvest on HSC populations remains insufficient for robust forecasting."[36] Absent a sound basis for robust forecasting, adoption of Addendum VIII and its attendant resumption of the female harvest cannot be justified.

III. THE REVISED ARM FRAMEWORK'S RISK-PRONE ASSUMPTIONS AND DECISIONS ARE INAPPROPRIATE, ESPECIALLY WHEN A THREATENED SPECIES IS AT STAKE.

In addition to its technical flaws, the revised ARM Framework incorporates risk-prone assumptions and decisions that further render it unsuitable as a management tool. It neglects important variables related to horseshoe crab demography and egg density that cast doubt upon the recovery of horseshoe crabs and their ability to provide adequate food resources for red knots. It draws conclusions from data collected when both red knots and horseshoe crabs were already depleted and therefore does not understand how the species would interact in a healthy ecosystem. It also reverses precautionary decisions made by stakeholders in the original ARM Framework—without soliciting renewed stakeholder input—in order to eliminate protections against the female horseshoe crab harvest and utilize previously-rejected surveys that inflate horseshoe crab abundance estimates.

The findings in this section draw heavily from an independent analysis of the revised ARM Framework and related materials conducted by Dr. Romuald Lipcius, as well as the analysis of Dr. Shoemaker. Both expert reports are attached.

A. Demographic Trends Indicate that the Horseshoe Crab Population Is Not Recovering.

Despite the Subcommittee's assertion that horseshoe crab abundance is increasing in Delaware Bay, Dr. Lipcius has identified troubling indicators that are inconsistent with a recovering population. The revised ARM Framework ignores these trends and treats abundance estimates as a comprehensive indication of population health. That would be a risk-prone approach even if the abundance estimates were fully reliable (which they are not).

As shown in Dr. Lipcius's report, the mean size (prosomal width) of female horseshoe crabs has recently declined. In the most recent three years of available data (2018-2020), adult female horseshoe crabs recorded the lowest mean sizes of any year since data collection began in 2002.[37] The same is true for newly mature females over the most recent two years of available data.[38]

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[35] *Id.* at 25.
[36] *Id.*
[37] Romuald Lipcius, *Expert Report* 6 (Sept. 2022) ("*Lipcius Expert Report*").
[38] *Id.*

Dr. Lipcius explains that, given constant recruitment, a prohibition on female harvest would typically lead to an increase in size due to reduced harvest pressure on older, larger females.[39] The declining size of female horseshoe crabs is inconsistent with the premise that the female segment of the population has recovered.[40] It is further evidence that the revised ARM Framework does not properly account for the population dynamics of horseshoe crabs.

A female harvest prohibition would also be expected to decrease the ratio of males to females in the population. But the data indicate that the male-to-female ratio increased between 1999 and 2019, suggesting *fewer* females for every male.[41] This is another warning sign that the population has not recovered, and the harvest of female horseshoe crabs should not resume.[42] Resuming such harvest would only further deplete a critical component of the population that has failed to show expected signs of recovery even under the female harvest prohibition.

Abundance data for immature and newly mature females raise additional concerns about the recovery of the female population. In 2019 and 2020, the Virginia Tech survey estimated the lowest abundance of newly mature female horseshoe crabs since data collection began in 2002, "indicating low influx of young mature females into the spawning stock."[43] Moreover, abundances of immature females and males for 2016-2020 were similar to those before 2013, when there was no female harvest prohibition in place. That is again contrary to expectations, since a prohibition on harvesting females should correlate to an increase in younger individuals.[44]

Dr. Lipcius explains that estimates of abundance can be less sensitive to serious problems in a population than variables including female size, female size structure, spawning stock biomass, and sex ratio. But the revised ARM Framework relies on abundance estimates to the exclusion of these other important variables. That is a risk-prone strategy and is not suitable for protecting horseshoe crabs or the threatened red knots.

B. <u>The Revised ARM Framework Fails to Consider Horseshoe Crab Egg Density, the Most Direct Measure of Food Availability for Red Knots.</u>

Another critical omission in the revised ARM Framework is its exclusion of data about the most direct measure of the adequacy of food resources for red knots: the availability of horseshoe crab eggs on the beach. As explained above, for red knots arriving at Delaware Bay after flying thousands of miles, horseshoe crab eggs provide energy-rich, easily digestible nutrition as the birds prepare to complete their journey northward and breed in the Arctic Circle. Red knots flying from South America shrink their digestive organs for the journey, and no other food source can replace easily digestible horseshoe crab eggs in enabling red knots to quickly rebuild their organs and muscles.[45] When conditions permit, a red knot at Delaware Bay can double its

[39] *Id.*
[40] *Id.*
[41] *Id.* at 10.
[42] *Id.*
[43] *Id.* at 6, 7 fig. 1.
[44] *Id.*
[45] Niles et al., *Effects of Horseshoe Crab Harvest* 154.

body mass in as little as 12 days by feasting on horseshoe crab eggs.[46] Research indicates that the red knots that have flown the farthest, from Tierra del Fuego, are particularly dependent on the density of horseshoe crab eggs (i.e., the number of eggs per square meter of beach).[47] Nevertheless, the revised ARM Framework has failed to consider actual data on egg density in the Delaware Bay region. Whatever concerns may have existed about such data at the time the original ARM Framework was developed, egg density should now be considered in light of new scholarship (discussed below) and the importance of horseshoe crab eggs for red knots. The revised ARM Framework's failure to do so represents another key flaw.

1. Egg density is the most direct measure of food availability for red knots.

Scientific studies link food availability at Delaware Bay to red knot survival and fecundity. Under favorable conditions including abundant horseshoe crab eggs, red knots at Delaware Bay roughly double their body mass from 90-120 grams to 180-220 grams before departing for the Arctic.[48] Individual red knots can gain up to 15 grams per day, "probably when horseshoe crab eggs are superabundantly available," allowing even late-arriving red knots to gain adequate mass in a brief period.[49] Researchers have observed that red knots experience "striking fitness consequences . . . correlated with the amount of nutrient stores accumulated in Delaware Bay."[50] Specifically, research has found a positive correlation between the mass of birds leaving Delaware Bay in the spring and the speed at which they complete their migration to the Arctic, reproductive success, and survival to the autumn.[51]

A superabundance of horseshoe crab eggs is required to meet the nutrition needs of red knots, other shorebirds, and the many other species that rely on this unique resource. Horseshoe crabs lay eggs too deep in the sand for red knots to access. But as more horseshoe crabs spawn on the beach, they disturb the sand, churning some of the eggs closer to the surface.[52] It is this churning, as well as wave action, that makes horseshoe crab eggs accessible to red knots.[53] The system depends on the successive spawning of large numbers of horseshoe crabs.[54]

2. Egg Density Has Declined Dramatically in Recent Decades, Correlating with the Decline in Red Knots.

Research strongly demonstrates that the abundance of horseshoe crab eggs near the beach surface (where the eggs are accessible to red knots) used to be at least ten times greater than the

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[46] New Jersey Department of Environmental Protection, *Wildlife Populations: Red Knot* 1-2.
[47] FWS, *Species Status Assessment Report for the Rufa Red Knot* (Version 1.1) 9 (Sept. 2020) ("*Species Status Assessment Report*").
[48] Allan J. Baker et al., *Rapid Population Decline in Red Knots: Fitness Consequences of Decreased Refuelling Rates and Late Arrival in Delaware Bay*, 271 Proceedings of the Royal Society of London B 875, 876 (2004).
[49] *Id.* at 876.
[50] *Id.* at 881.
[51] Duijns et al., *Body Condition Explains Migratory Performance* 5-6.
[52] Niles et al., *Effects of Horseshoe Crab Harvest* 155.
[53] *Id.*
[54] *Id.*

abundance in recent years.[55] Measurements from 1985 to 1987 conservatively indicate that egg density averaged 156,000 eggs per square meter of beach. In recent years, egg density averaged only around 10,000 eggs per square meter of beach.[56]

This decline in egg density correlates with the dramatic decline of migratory shorebirds, especially red knots. The trends mirror each other over decades but also converge on smaller timescales. Among years when measurements were taken, the nadir for horseshoe crab egg density appears to have been the early 2000s, shortly after the unregulated overexploitation of horseshoe crabs in the 1990s.[57] This corresponds to a "changepoint" for red knots when the peak count dropped from more than 43,000 to fewer than 16,000.[58]

3. Horseshoe Crab Abundance Is Not an Adequate Proxy for Egg Availability.

Notwithstanding the research documenting a dramatic decline in the availability of horseshoe crab eggs, the revised ARM Framework posits that the abundance of female horseshoe crabs is increasing. That is a dubious claim, as explained in section III.A of these comments. But even assuming for the sake of argument that it were correct, it would not necessarily result in more eggs for horseshoe crabs. To the contrary, demographic trends suggest that the production of eggs per horseshoe crab is likely decreasing.

Dr. Lipcius describes how egg production is directly proportional to the weight of horseshoe crabs, such that heavier crabs produce more eggs.[59] Data from the Virginia Tech Horseshoe Crab Trawl Survey indicate that the average prosomal width of female horseshoe crabs has fallen considerably, with an especially marked drop in the largest crabs over the past few years (2018-2020). Weight is an exponential function of prosomal width, meaning that even a modest decline in crab width could signify a very significant decline in weight and therefore in egg production. The trend toward smaller female horseshoe crabs may partially explain the low egg density numbers in recent years. Dr. Lipcius concludes that "total reproductive (egg) output has likely not improved, which hampers recovery of the HSC and RK populations."[60]

4. The ARM Report Presents No Compelling Reason to Ignore Egg Density.

There is no defensible rationale for completely excluding from the revised ARM Framework any direct measure of the most direct indicator of the adequacy of the red knot food supply: egg density. None of the ARM Subcommittee's reasons for excluding data about food availability withstands scrutiny.

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[55] Joseph A.M. Smith et al., *Horseshoe Crab Egg Availability for Shorebirds in the Delaware Bay: Dramatic Reduction After Unregulated Horseshoe Crab Harvest and Limited Recovery After 20 Years of Management*, Aquatic Conservation: Marine and Freshwater Ecosystems (2022) (in press) ("*Horseshoe Crab Egg Availability*").
[56] *Id.*
[57] *Id.*
[58] *Id.*
[59] The information in this paragraph is drawn from *Lipcius Expert Report* 7-10 & figs. 2-6.
[60] *Id.* at 10.

First, the Subcommittee asserted that the protocol for measuring egg density over the years was too variable to provide reliable comparisons.[61] Even if that was previously a legitimate concern, scientists have now demonstrated a long-term reduction in the surface availability of horseshoe crab eggs based on multiple studies using similar methods and sampling from comparable or even identical locations.[62] More fundamentally, in the context of a threatened species, major warning signs should not be disregarded on the basis of uncertainty in the data, especially when the data that exist point strongly in the same troubling direction. As Dr. Lipcius explains, "Lack of use of HSC egg density data, as a proxy for RK food availability, amounts to a failure to incorporate all available scientific information into the analysis to guide management decisions in a risk-averse manner."[63]

The Subcommittee next asserted that habitat loss had not been "adequately rule[d] out" as the cause of declining egg density. This argument is equally misplaced. Recent research demonstrates that egg density has declined even where habitat continues to be suitable, such as where sand depth exceeds 40 centimeters.[64] Moreover, habitat loss does not provide a basis for disregarding the availability of horseshoe crab eggs for red knots. As Dr. Lipcius explains, while the Board does not have control over all sources of stress on horseshoe crabs, the existence of multiple stressors demands a *more* risk-averse approach with respect to factors such as harvest quotas that are fully within the Board's control.[65]

In addition, the Subcommittee denied the ability to link horseshoe crab egg abundance with red knot nutrition or survival.[66] However, as shown above, there is a strong correlation between declining egg density and declining red knot abundance.

Regardless of the Subcommittee's concerns that egg density data are not sufficiently conclusive, or that habitat loss is a contributing factor, multiple studies over several decades uniformly point in the same direction: egg density has declined to an alarming degree, as have the red knots that consume the eggs. At a minimum, the Commission must recognize that plentiful eggs are a necessary and critical element of red knot recovery and solicit formal stakeholder input on incorporating that principle into harvest decisions in light of recent research.

C. <u>The Revised ARM Framework Finds a Weak Relationship Largely Because It Relies on Data from Years When Both Red Knots and Horseshoe Crabs Were Already Depleted.</u>

In contrast to all of the scientific information discussed above demonstrating a critical connection between horseshoe crabs and red knots, the revised ARM Framework finds a weak link between these species partly because it is based entirely on data from after the ecosystem

[61] ARM Subcommittee, *Majority Response to Niles and Justification for Why Opinion Not Adopted* (in *ASMFC, ARM Report*) 105-06.
[62] Smith et al., *Horseshoe Crab Egg Availability*.
[63] *Lipcius Expert Report* 12.
[64] Smith et al., *Horseshoe Crab Egg Availability*.
[65] *Lipcius Expert Report* 13.
[66] ARM Subcommittee, *Majority Response to Niles* 104.

crashed in the late 1990s.[67] The most the model can do is interpret the interaction between two perilously depleted species, without any concept of how a healthy ecosystem would function. In defiance of historical and scientific evidence, the revised ARM Framework seems to assume that a supposedly minimal correlation between horseshoe crabs and red knots when both species are degraded is indicative of how the ecosystem would operate when both species are plentiful. Rather than viewing its finding of a weak link appropriately as a symptom of an ailing ecosystem, the revised ARM Framework leverages it to justify greater exploitation.

As one example of why recent data may not represent the historic relationship between the two species, consider the population of red knots migrating from southern South America. These birds travel the farthest to reach Delaware Bay and need to rebuild their digestive organs upon arrival, making them particularly dependent upon easily digestible horseshoe crab eggs.[68] Even more than other red knots, this Southern wintering population has suffered "sharp and well-documented declines" in recent decades due to reduced food availability at Delaware Bay.[69] As a result, the relatively small number of red knots that pass through Delaware Bay may be increasingly skewed toward birds that winter farther north, with fewer of the birds that most heavily depend upon horseshoe crab eggs. The revised ARM Framework would interpret these conditions to mean that red knot abundance is less affected by horseshoe crab abundance and that greater exploitation is acceptable. It would thus ignore the impact of egg scarcity on the most vulnerable population of red knots.

While the revised ARM Framework may necessarily be limited by the years from which data are available, it should not draw overbroad conclusions from a constrained dataset. As Dr. Shoemaker explains, these constraints give the model a "limited scope of historical variation . . . . Using these models to forecast system dynamics under conditions outside the range of values used to fit the model (e.g., lower HSC abundances, higher REKN abundances) therefore requires extrapolation, which can be highly uncertain (and often inaccurate)."[70] Based on Dr. Shoemaker's expert judgment, "[I]t does not seem prudent to implement management 'experiments' that could potentially imperil a threatened or endangered species (TES), even under the rubric of adaptive management."[71]

D. <u>The Revised ARM Framework Would Arbitrarily and Unjustifiably Remove Abundance Thresholds Below Which the Harvest of Female Horseshoe Crabs Is Prohibited.</u>

The revised ARM Framework would arbitrarily lift the protective abundance thresholds intended to preserve the availability of food for red knots. Specifically, under the existing Framework, the female harvest quota is zero until the estimated abundance of female horseshoe crabs exceeds 11.2 million or the estimated abundance of red knots exceeds 81,900 in Delaware Bay.[72] These

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[67] *E.g.*, *ARM Report* 156 tbl. 13 (illustrating that the catch multiple survey analysis for horseshoe crabs uses data starting from 2003). Compounding the chronological limitations on the data informing the model, the revised ARM Framework also imposes geographic constraints by including only data from Delaware Bay.
[68] FWS, *Species Status Assessment Report* 9.
[69] *Id.* at 28; FWS, *Draft Recovery Plan for the Rufa Red Knot* 14.
[70] *Shoemaker Expert Report* 11.
[71] *Id.*
[72] ASMFC, *ARM Report* 21.

thresholds reflect stakeholders' desire to take a precautionary approach to managing the delicate relationship between horseshoe crabs and red knots. Because neither species has reached its threshold since the original ARM Framework was implemented, the model has never recommended a female harvest. Under the revised ARM Framework, the model could (and likely would) recommend a significant female harvest even when neither red knot nor female horseshoe crab abundance has exceeded its protective threshold. Indeed, the Subcommittee's calculations show that the model would have recommended a female harvest of approximately 150,000 for 2017-2019, years when the original ARM Framework recommended a female harvest of zero.[73]

1. ASMFC Has Provided No Defensible Rationale for Removing the Protective Thresholds.

Removal of the protective thresholds received significant criticism in the minority opinions submitted by ARM Subcommittee members.[74] In rejecting these critiques, the Subcommittee relied on two primary arguments, neither of which is defensible.

First, the Subcommittee stated, "The presence of these threshold constraints in the utility function was criticized during this revision for not being consistent with adaptive management and optimization procedures and therefore they were removed from the utility functions."[75] But the Subcommittee's argument assumes that stakeholder values have no role in adaptive management, and that adaptive management is inconsistent with any constraint that arises from something other than an optimization model. This view squarely defies the adaptive management process as described in Addendum VII, which highly values stakeholder input, as explained in section IV.B of these comments. Moreover, the Subcommittee's view is internally inconsistent, as the revised ARM Framework appropriately maintains precautionary limits on the maximum harvest of male and female horseshoe crabs,[76] which represents a constraint on the model in deference to precautionary values. Thus, the revised ARM Framework is arbitrarily selective about its willingness to consider precautionary constraints.

Second, the Subcommittee described the thresholds as a "knife-edge utility function[]" and stated that, once the thresholds were exceeded, the existing ARM Framework would immediately recommend the maximum harvest package, with its female quota of 210,000.[77] According to the Subcommittee's calculations, the model is unlikely to ever select the interim harvest package, with a female quota of 140,000.[78]

The Subcommittee's argument misses the mark. The immediate issue is whether female harvest is allowed *below* the thresholds. The Subcommittee may have concerns about what

[73] ASMFC, *Supplemental ARM Report* 21 tbl. 11.
[74] *E.g.*, Wendy Walsh, *Walsh Minority Opinion* (in ASMFC, *ARM Report*) 113-14.
[75] ARM Subcommittee, *Majority Response to Niles* 107.
[76] ASMFC, *ARM Report* 81 ("[O]ne feature from the packages used in the original ARM version was retained: the maximum harvest for females was set to 210,000 and for males 500,000."). The Subcommittee pointed to these limits as an example of maintaining an "earlier decision[] made by stakeholders." ARM Subcommittee, *Majority Response to Walsh and Justification for Why Opinion Not Adopted* (in ASMFC, *ARM Report*) 125.
[77] ARM Subcommittee, *Majority Response to Walsh* 124.
[78] *Id.*

recommendations the current model would make in the unprecedented event that the thresholds were exceeded, but that is a separate question. In addition, if the current model would catapult over the interim harvest package and immediately recommend the maximum harvest package in the event that red knots or female horseshoe crabs met their abundance threshold, that would seem to indicate a defect in the existing model. A more reasonable correction would be to adjust the existing model to facilitate a gradual increase in female harvest recommendations once an abundance threshold is met. It is not at all clear why removing the thresholds altogether is a necessary or logical solution. Regardless, a potential defect in the current model's response to the achievement of protective thresholds for horseshoe crabs or red knots cannot offer any justification for eliminating the thresholds well before they are met. At the very least, the Subcommittee should have made its decision in consultation with stakeholders, not unilaterally.

2. The Elimination of the Protective Thresholds Illustrates the Improper Exclusion of Stakeholder Input.

In section IV.B, these comments detail why the exclusion of formal stakeholder input from the development of the revised ARM Framework was inappropriate and violated the requirements for adaptive management. This section explains why excluding stakeholders from decisions about the protective thresholds was particularly improper and contravened the views of the Commission's own experts and peer review panel.

During the Board's early consideration of developing Addendum VIII, the ARM Subcommittee Chair explained what process would be required to change (much less eliminate) the protective thresholds:

> [M]oving forward with this new Population Dynamics Model, where that threshold is at 11.2 million, you know that could change. It is a possibility to have a different utility function. *That is something that would have to be discussed amongst stakeholders* and among the ARM Workgroup members.[79]

Despite the Chair's acknowledgement that changing the female horseshoe crab threshold would require stakeholder input, the revised ARM Framework would eliminate the threshold even in the absence of stakeholder input.

The exclusion of stakeholders and elimination of the thresholds was criticized in the minority opinion of Subcommittee member (and Chair of the Delaware Bay Ecosystem Technical Committee) Dr. Wendy Walsh, the national lead for red knot recovery at FWS. Dr. Walsh meticulously detailed the role of stakeholder input in adaptive resource management and observed that the ARM Subcommittee had "failed to consult a broad array of stakeholders in the reinterpretation of previously agreed-upon objectives."[80] With respect to the abundance thresholds, Dr. Walsh explained:

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[79] Comments of John Sweka, ARM Subcommittee Chair, *Proceedings of the Atlantic States Marine Fisheries Commission Horseshoe Crab Management Board* 5 (Oct. 29, 2019) (emphasis added), https://www.asmfc.org/uploads/file/5fb2ea02HorseshoeCrabBoardProceedingsOct2019.pdf.

[80] *Walsh Minority Opinion* 113.

> These threshold values act as a constraint on female harvest, which was the express intent of the stakeholders. . . . [T]he formulation of these values as a constraint was an explicit and clear choice in the development of the existing framework. . . . [T]he high risk-aversion to female crab harvest by the stakeholders is clear, and thus it can be presumed that the new utility function . . . would be of considerable concern to those same stakeholders.[81]

The ASMFC-convened Peer Review Panel echoed these concerns. Recognizing that the Subcommittee had not convened stakeholders for this proceeding, the Panel tentatively stated that it "does not disagree" with the revised modeling functions, "as long as they truly reflect the objectives related to HSC harvest and REKN recovery and the risk associated with the HSC harvest."[82] The Panel reiterated its concern in its list of recommendations:

> The new utility and harvest functions are a representation of values, and the Panel understands that convening a group of stakeholders for this revision was not possible. Therefore, the Panel recommends the WG fully consider whether the new utility and harvest functions represent stakeholder values as articulated in 2009.[83]

The rejection of Dr. Walsh's minority opinion indicated a troubling misunderstanding of the Subcommittee's assignment. The Subcommittee wrote that retaining the threshold values "is more consistent with a simple harvest control rule" and "would not be adaptive management and would not require the Framework developed in this assessment."[84] By this statement, the Subcommittee revealed that it viewed stakeholder input as an impediment to adaptive management—an obstacle to the Framework the Subcommittee had already devised. But as explained in more detail below in section IV.B, stakeholder input has consistently been recognized as the foundational step of adaptive management. There is no adaptive management without stakeholder input, and the revised ARM Framework is therefore not an exercise in adaptive management.

E. The Horseshoe Crab Population Estimates Are Improperly Based, in Large Part, on Two Surveys that Stakeholders Have Rejected.

The omission of stakeholder input was particularly harmful because it obscured stakeholder objections to new survey data upon which the revised ARM Framework extensively relies. Since its inception, the ARM Framework has based horseshoe crab abundance estimates entirely on data from the Virginia Tech Horseshoe Crab Trawl Survey, which reflected the original stakeholders' greater confidence in that survey compared to other surveys of horseshoe crabs in Delaware Bay. The Virginia Tech survey is purpose-designed to count horseshoe crabs, as opposed to general surveys that count horseshoe crabs just incidentally, and FWS has called it

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[81] *Id.* at 113-14.
[82] ASMFC, *Horseshoe Crab Adaptive Resource Management Revision Peer Review Report* (in ASMFC, *ARM* Report) 10 (277 of PDF) ("*Peer Review Report*"). Significantly, the Peer Review Panel's tentative approval of the revised ARM Framework was uninformed by independent expert reviews such as those offered by Drs. Shoemaker and Lipcius in this comment process.
[83] *Id.* at 12.
[84] ARM Subcommittee, *Majority Response to Walsh* 122.

"the best benthic trawl survey to support the ARM."[85] Yet the revised ARM Framework would drastically downgrade the model's reliance on the Virginia Tech survey, rendering it one of three equally weighted surveys.[86] The two additional surveys that would comprise the abundance estimates—the New Jersey Ocean Trawl Survey and the Delaware Adult Trawl Survey—are general trawl surveys and not purpose-designed to count horseshoe crabs.

In her minority opinion, Dr. Walsh explained (as the Subcommittee acknowledged) that the revised approach would generate significantly higher abundance estimates,[87] which will lead to higher harvest recommendations for female horseshoe crabs. Dr. Walsh urged that, if the Subcommittee determined to rely upon all three surveys, it should at least accord greater weight to the Virginia Tech survey based on its "technical rigor and deliberate design" and "the high level of confidence that stakeholders have expressed in" it, among other reasons.[88] As Dr. Walsh noted, using all three surveys generates such high estimates that it would sometimes have resulted in female harvest recommendations even under the existing ARM Framework.[89]

The original decision to rely exclusively on the Virginia Tech survey reflected explicit stakeholder input. By introducing two additional surveys that stakeholders previously disfavored, and weighting all three surveys equally, the revised ARM Framework alters yet another stakeholder-driven component of the model without soliciting formal stakeholder input.

IV. ASMFC HAS REPEATEDLY EXCLUDED INPUT FROM STAKEHOLDERS AND THE BROADER PUBLIC.

The development of Draft Addendum VIII omitted input from stakeholders and the public throughout the process. The Atlantic Coastal Fisheries Cooperative Management Act of 1993 requires the Commission to "provide[] adequate opportunity for public participation in the [fishery management] plan preparation process."[90] ASMFC has violated legal requirements and its own guidelines by severely limiting public participation in this proceeding. Specifically, the Commission held a public comment period before essential information was publicly available, failed to solicit formal stakeholder input, and decided to artificially limit its range of options to adopting Addendum VIII or reverting to Addendum VI—both of which would lead to resuming the female horseshoe crab harvest—without any public input whatsoever.

[85] FWS, *Rufa Red Knot Background Information and Threats Assessment* 247.
[86] ASMFC, *ARM Report* 55.
[87] Walsh Minority Opinion 111; ARM Subcommittee, *Majority Response to Walsh* 123 ("[I]t was noted in the 2019 assessment that equally weighting the surveys resulted in higher population estimates and that characterization by Walsh is accurate."); ASMFC, *Supplemental ARM Report* 21 tbl. 11 (for a comparison of abundance estimates under the current and proposed methodologies).
[88] *Walsh Minority Opinion* 111.
[89] *Id.* at 111-12.
[90] 16 U.S.C. § 5104(a)(2)(B).

A. ASMFC Held the Public Comment Period Before the Revised ARM Framework's Core Model Was Publicly Available.

The public comment period for Addendum VIII occurred while crucial, material information was being withheld from the public. Specifically, the public still has not been allowed to see the model that generates bait harvest recommendations for horseshoe crabs in Delaware Bay.

New Jersey Audubon and Defenders of Wildlife requested the model on February 23, 2022, in FOIA requests submitted to the U.S. Geological Survey ("USGS") and FWS, as well as a record request submitted to ASMFC. While ASMFC provided certain components related to the horseshoe crab estimates, USGS controls the core component that links horseshoe crabs and red knots to generate harvest recommendations. In a letter prior to the Board's August 2022 meeting, New Jersey Audubon and Defenders of Wildlife explained that USGS had not yet released the model and urged the Board not to initiate the public comment period on Draft Addendum VIII until the public could access the model that underlies the revised ARM Framework.[91] At the Board meeting, several members expressed concern about the unavailability of the model, noted USGS's stated intent to release the model following internal review,[92] and asked to be kept apprised of developments in the public's access to the model.

As of September 30, 2022—the close of the public comment period on Draft Addendum VIII—USGS has still not released the model. As a result, the public's ability to submit substantive technical comments has been severely constrained. As this comment letter demonstrates, public evaluation is essential for identifying significant issues for the Board's consideration. Indeed, many of Dr. Shoemaker's critiques were enabled by the limited model components released by ASMFC. But the preponderance of the model underlying the revised ARM Framework still has not been subject to public evaluation. Dr. Shoemaker listed several questions that he could have investigated more thoroughly if that model were available,[93] including:

- Does the red knot projection model outperform a null model that excludes any effect of horseshoe crab abundance?
- How much variation in apparent survival in the red knot IPM model is explained by the horseshoe crab effect compared to random among-year variation?
- Would an index of horseshoe crab egg density explain more variation in red knot survival and fecundity than the CMSA-derived estimate of horseshoe crab abundance?

While the Board should resolve the issues that have already been raised before further considering Addendum VIII, it is impossible to anticipate all of the additional questions that will

[91] Letter from Benjamin Levitan, Earthjustice, to ASMFC Commissioners re *Consideration of Draft Addendum VIII on the Implementation of Recommended Changes from 2021 Adaptive Resource Management Revision and Peer Review Report for Public Comment* (July 26, 2022).
[92] In an email accompanying its denial of a Freedom of Information Act Request for the model, a U.S. Geological Survey representative wrote, "We have withheld the two USGS models, but they and their associated use publications will be published following the required USGS Fundamental Science Practices reviews." Email from Janis Wilson, USGS, to Benjamin Levitan, Earthjustice, re: *FOIA: DOI-USGS-2022-002312 – Response* (July 28, 2022). On August 15, 2022, New Jersey Audubon and Defenders of Wildlife administratively appealed the denial of access to the model, but USGS has not yet responded.
[93] *Shoemaker Expert Report* 26-27.

be identified once the model is released. New issues will inevitably arise. The proper time to address those questions is before the Board approves Addendum VIII. Enabling the public to identify additional questions only after the revised ARM Framework has been approved would subject red knots and horseshoe crabs to unacceptable risk and raise difficult administrative questions about how to limit the harm even as the Framework is in place.

B. The Subcommittee Violated ASMFC's Procedures by Failing to Solicit Formal Stakeholder Input.

The ARM Subcommittee's failure to solicit formal stakeholder input in this proceeding violated the principles and process of adaptive management. When the Board first approved the ARM Framework in Addendum VII more than a decade ago, stakeholder input was integral to the process. The *first sentence* of the "ARM Framework" section of Addendum VII was, "A goal of the ARM Framework is to transparently incorporate the views of stakeholders along with predictive modeling to assess the potential consequences of multiple, alternative management actions in the Delaware Bay Region."[94] The ARM Subcommittee expressed the same sentiment about the "ARM approach" in the current proceeding: "First, there is a great emphasis on complete elicitation of objectives and management actions from a full range of stakeholders."[95] The Subcommittee took that sentence verbatim from the Commission's Framework for Adaptive Management from 2009,[96] demonstrating how consistently stakeholder input has been acknowledged as the cornerstone of adaptive management.

The Board formalized the role of stakeholder input when it approved Addendum VII, which implemented an adaptive management framework for the Delaware Bay horseshoe crab fishery. Addendum VII required that the ARM Framework's "[i]mplementation *shall* be comprised of two cycles."[97] The *first step* of the "Longer Term Cycle," which was to occur "every 3 or 4 years," was to "[s]olicit formal stakeholder input on ARM Framework to be provided to the relevant technical committees."[98]

The ARM Subcommittee's failure to convene stakeholders in preparing Addendum VIII violated the Board's express requirements, as well as the principles underlying the adoption of adaptive management. And if the Board approves Addendum VIII, the exclusion of stakeholders is unlikely to be rectified anytime soon. Addendum VIII sets forth a default period of "every 9 or 10 years" for revising the ARM Framework, which "should incorporate" soliciting "formal stakeholder input."[99] Pursuant to that schedule, if the Board approves Addendum VIII in 2022—which it should not do—the ARM Framework will be due for a revision in the early 2030s. Assuming that stakeholders are formally consulted at that time (unlike this time), roughly *20*

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[94] ASMFC, *Addendum VII to the Interstate Fishery Management Plan for Horseshoe Crabs for Public Comment: Adaptive Resource Management Framework* 2 (2012), https://www.asmfc.org/uploads/file/hscAddendumVII_Feb2012.pdf ("*Addendum VIII*").
[95] ASMFC, *ARM Report* 21.
[96] ASMFC, *Stock Assessment Report No. 09-02 (Supplement B): A Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Constrained by Red Knot Conservation* 1 (2009), https://www.asmfc.org/uploads/file/2009DelawareBayARMReport.pdf.
[97] ASMFC, *Addendum VII* at 4 (emphasis added).
[98] *Id.*
[99] ASMFC, *Horseshoe Crab Draft Addendum VIII for Public Comment* 8 (Aug. 2022).

years will have elapsed between such consultations, a striking contrast to the "3 or 4 year[]" interval required by Addendum VII. That would also mean that stakeholders would not be formally consulted for roughly *17 years* after FWS's 2015 determination to list red knots under the Endangered Species Act. While it is impossible to know all the ways that soliciting stakeholder input would have affected the current proceeding, the revised ARM Framework's elimination of the protective abundance thresholds (described above in section III.D.2) demonstrates that this concern is not merely theoretical.

It bears repeating how significantly the revised ARM Framework departs from the paradigm that the stakeholders accepted in preparation for Addendum VII, which instituted harvest recommendations based on the relationship between horseshoe crabs and red knots. The revised Framework would weaken that relationship almost to the point of nonexistence and recommend quotas accordingly. While presented as a technical update, the revised ARM Framework cannot plausibly be considered a reflection of the stakeholders' articulated values. At the very least, stakeholders should have been involved in designing a revised approach. Failure to involve them represents another reason for rejecting the current proposal.

C. Even Before the Public Comment Period, ASMFC Purported to Limit Its Options to Those that Would Reinitiate the Female Horseshoe Crab Harvest.

In addition to the inaccessibility of crucial information and the exclusion of stakeholder input, there was no public notice or comment for arguably the most critical decision presented by Draft Addendum VIII, which ASMFC now presents as a foregone conclusion: designating a reversion to Addendum VI as the "No Action" alternative if the Board does not approve Addendum VIII.[100] Addendum VI would increase the Bay-wide horseshoe crab harvest quota and *allow for the resumption of the female harvest* in Maryland and Virginia. Thus, the Board has effectively foreclosed public comment on the pressing question of *whether* to resume female harvest for this fishery. Under the terms of draft Addendum VIII, whichever option the Board selects—and regardless of any information that might surface during the public comment period—that decision is preordained.

On the merits, selecting Addendum VI as the "No Action" alternative was arbitrary, unnecessary, and misleading. Addendum VI would completely transform the management framework. The transition from Addendum VI to Addendum VII was arguably the most significant event in ASMFC's management of the horseshoe crab fishery, and reverting to Addendum VI would be equally significant.

To justify the selection of Addendum VI, Draft Addendum VIII indicates that Addendum VII is unavailable as the "No Action" alternative because the model underlying it was built on obsolete software and can no longer be utilized.[101] Even if the software is obsolete, that does not back the Board into a corner with no option but to adopt an addendum with a female harvest. The current ARM Framework has generated the same harvest quota for ten consecutive years, and the legitimate "No Action" alternative would be to apply the same quota to the 2023 fishing season. In fact, Addendum VII contains two "fallback option[s]" for when the data required to run the

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[100] *Id.* at 5.
[101] *Id.*

ARM model are not available: use the quotas from Addendum VI *or* use the same quotas as the previous year.[102] It is unclear why the Board would have fewer options when the Addendum VII model cannot be run. The natural understanding of "No Action" would be to maintain the current status quo—i.e., the current addendum and current quotas—not to revert to an addendum and quotas that mark a major departure from the status quo.

At the August 2022 Board meeting, ASMFC staff explained that simply reusing last year's quotas is not appropriate because that would not qualify as "adaptive resource management."[103] Even if that were so, the solution should not be to reinstate the 12-year-old static quotas from Addendum VI. If the Board has authority to impose such a drastic change, then surely it has authority to continue relying on the most recent outputs of the current ARM Framework. It may be that neither option offers a satisfactory long-term solution, but the question now is what to do while questions about the revised ARM Framework are being addressed. The Board is not required to rush through a new (or old) addendum. It can temporarily maintain the current Framework to allow for thorough consideration of the appropriate next step, which clearly does not include accepting Addendum VIII as currently proposed.

V. THE FLAWS IN THE REVISED ARM FRAMEWORK MUST BE ADDRESSED NOW.

The Board's decision on Addendum VIII is highly consequential and could determine the course of the horseshoe crab fishery for many years to come. It is vital that the revised ARM Framework be subject to full vetting, and that foreseeable flaws be identified, prior to implementation by the Board. There will not be realistic opportunities to remedy defects in the revised ARM Framework in the future—at least not without imposing large burdens on both the Board and the public.

A. Flaws in the Revised ARM Framework Cannot Realistically Be Remedied at the Quota-Setting Stage.

At the Board's meeting in August 2022, some speakers observed that Addendum VIII will not, in itself, set binding quotas because the Board will retain discretion to deviate from the ARM Framework's harvest recommendations, and states will retain discretion to set quotas below those set by the Board.[104] But that is not a valid rationale for approving an addendum that has not been fully vetted and has been demonstrated to be flawed based on even the limited amount of information that has been made publicly available.

The purpose of the ARM process is to generate harvest recommendations based on rigorous science and sound policy.[105] As these comments detail, the revised ARM Framework incorporates many substantive and procedural flaws, and additional flaws are likely to emerge

[102] ASMFC, *Addendum VII* at 6.
[103] ASMFC, *Horseshoe Crab Management Board Proceedings Aug2022*, at 5:11, https://www.youtube.com/watch?v=OZvpdTTPj8c.
[104] *E.g.*, *id.* at 28:00, 1:12:57.
[105] 16 U.S.C. § 5104(a)(2)(B) (requirement in the Atlantic Coastal Fisheries Cooperative Management Act of 1993 for ASMFC to follow "standards and procedures to ensure that . . . [fishery management] plans promote the conservation of fish stocks throughout their ranges and are based on the best scientific information available.").

when the underlying model is released to, and evaluated by, the public. Regardless of the Board's or states' ability to deviate from those recommendations, the Board must ensure that the Framework represents the best available—and properly vetted—science and policy. To do otherwise would call into question the purpose of the ARM process and the harvest recommendations.

It would also not be practical for the Board or states to resolve the flaws in the revised ARM Framework at the quota-setting stage. If Addendum VIII were approved and the Board were unable to rely upon the Framework's flawed harvest recommendations, there would be no clear criteria or guidelines for establishing quotas, leading to a confusing, burdensome, and arbitrary quota-setting process. Similarly, if the Board approved Addendum VIII and adopted the revised ARM Framework's flawed harvest recommendations, states would need to determine the proper course in the absence of reliable information or direction from ASMFC. That would undermine the Horseshoe Crab Fishery Management Plan's purpose of creating "[a] coordinated and consistent management strategy."[106]

B. Flaws in the Revised ARM Framework Cannot Be Addressed Through Updates to the Model.

While the revised ARM Framework can be "updated based on the annual routine data collected in the region,"[107] updates will not remedy its flaws. Many of the defects identified in these comments cannot be addressed by new data but rather demand a deeper restructuring of the model. For example, the model's miscalculation of the uncertainty in horseshoe crab abundance projections will persist despite new data. The same is true for all of the variables that are omitted from the model but indicate an unstable horseshoe crab population: egg density, prosomal width, sex ratio, etc.

Other defects would theoretically be alleviated by new data, but not on any relevant timescale. For example, the effect of the nonsensical horseshoe crab recruitment rates from the Virginia Tech gap years will gradually be diluted as new data are added, but they will continue to have perilously high influence for many years—realistically, for as long as Addendum VIII will be in effect. And even if, for the sake of argument, the estimated recruitment rate will slowly become more accurate over the years, that does not justify neglecting to fix a clear defect before implementing the revised ARM Framework.

Finally, some defects may be compounded by the addition of more data. As explained above in section III.C, the model is based entirely on data from when both horseshoe crabs and red knots had already crashed. It does not reflect the dynamics of a properly functioning ecosystem. As more data from the post-crash years are added, the model may only grow more confident that the current state of the ecosystem represents the norm. As Dr. Shoemaker observes, additional data may even yield a negative relationship between the abundance of horseshoe crabs and red knots, which would pose an existential problem for the Framework.[108]

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[106] ASMFC, *Fishery Management Report No. 32 of the Atlantic States Marine Fisheries Commission: Interstate Fishery Management Plan for Horseshoe Crab* 1 (1998).
[107] ASMFC, *Draft Addendum VIII* at 8.
[108] *Shoemaker Expert Report* 10.

VI. APPROVING ADDENDUM VIII WOULD LIKELY LEAD TO A VIOLATION OF THE ENDANGERED SPECIES ACT BY ASMFC.

In addition to the other bases for rejecting Addendum VIII discussed above, the Endangered Species Act provides a powerful further reason: adopting Addendum VIII would threaten to violate the federal prohibition against "taking" a threatened species. The ESA prohibits any person from "tak[ing] any [endangered] species within the United States or the territorial sea of the United States."[109] Such prohibited "taking" includes actions that "harm" listed species, including "significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding or sheltering."[110] The ESA's "taking" prohibition extends to governmental authorization to take protected species that facilitates such harm by "solicit[ing]" or "caus[ing]" an offense.[111] By regulation, that prohibition extends to the taking of most threatened species, including the red knot.[112]

A. The Endangered Species Act Requires a Precautionary Approach.

In the Endangered Species Act, Congress adopted a precautionary approach. As the Supreme Court has stated, "Congress has spoken in the plainest of words, making it abundantly clear that the balance has been struck in favor of affording endangered species the highest of priorities, thereby adopting a policy which it described as 'institutionalized caution.'"[113] This principle is echoed in the ARM Framework's objective statement, which calls for "*ensur[ing]* that the abundance of horseshoe crabs is not limiting the red knot stopover population or slowing recovery."[114] Within the context of the ESA's legal framework, to ensure against such harms means taking a precautionary approach of "giv[ing] the benefit of the doubt to the species."[115] By setting ASMFC on a path to harm a threatened species whose population shows no sign of recovery, the revised ARM Framework would fall far short of ESA requirements and ASMFC's own objective.

As shown above, in many instances, Addendum VIII would enshrine a risk-prone approach instead of the risk-averse, precautionary approach required under the ESA. Even as it would allow the renewed harvest of female horseshoe crabs, Addendum VIII would utilize a model that, among other risky decisions:

- rejects the significant connection between horseshoe crabs and red knots,

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[109] 16 U.S.C. § 1538(a)(1)(B).
[110] 50 C.F.R. § 17.3.
[111] *Strahan v. Coxe*, 127 F.3d 155, 163 (1st Cir. 1997); 16 U.S.C. § 1538(g).
[112] 50 C.F.R. § 17.31(a) (applying the provisions of § 17.21 (addressing endangered species) to threatened species); *id.* § 17.21(a), (c) ("[I]t is unlawful . . . to solicit another to commit or to cause to be committed" the taking of an endangered species.).
[113] *Tenn. Valley Auth. v. Hill*, 437 U.S. 153, 194 (1978).
[114] ASMFC, *ARM Report* 25 (emphasis added).
[115] *See, e.g., Roosevelt Campobello Int'l Park Comm'n v. U.S. Envtl. Prot. Agency*, 684 F.2d 1041 (1st Cir. 1982) (quotations and citation omitted); *see also Defs. of Wildlife v. U.S. Dep't of the Interior*, 931 F.3d 339, 351 (4th Cir. 2019) (same regarding scientific determinations).

- neglects egg-density data, which provide the most direct measure of the adequacy of food for red knots,
- rejects protective populations thresholds that were essential to the only group of stakeholders that ASMFC ever formally consulted about this matter,
- assumes that horseshoe crabs are recovering despite negative demographic trends, and
- uses horseshoe crab projections that fail to account for uncertainty and are scarcely more accurate than a null model.

The exclusion of public input at multiple stages of this proceeding exacerbates the risk of an ESA violation because ASMFC has evaded the public scrutiny that would be appropriate for such a consequential proceeding. A risk-averse approach would be to welcome public input in order to identify and address weaknesses that create unacceptable risk for the red knot. But the Board has taken a different, risk-prone approach: hastening a vote on Addendum VIII even as the underlying model continues to be withheld, despite record requests submitted more than seven months ago. The Board will therefore make a decision without the benefit of crucial public input and the important considerations such input would raise.

Both ASMFC and FWS suggest that the model will be improved by future updates.[116] As shown above in section V.B, updates cannot remedy the flaws in the revised ARM Framework. But even if they could, relying on future updates is not appropriate when an ecosystem is dangerously degraded and a threatened species hangs in balance. Future updates are likely to come too late.

B. By Utilizing the Revised ARM Framework, ASMFC Would Harm Red Knots.

Like any other association or governmental entity, ASMFC is subject to the ESA taking prohibition.[117] Under the Atlantic Coast Fisheries Cooperative Management Act of 1993,[118] ASMFC's fishery management plans are legally binding upon affected states. Once the Commission issues a plan, states "shall implement and enforce the measures of such plan within the timeframe established in the plan."[119] Because ASMFC's quotas cannot be exceeded, states have been prohibited from authorizing female horseshoe crab bait harvest in Delaware Bay under the existing framework. States may authorize a female bait harvest only if ASMFC sets a non-zero female harvest quota.[120]

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[116] ASMFC, *Draft Addendum VIII* at 8; FWS, *U.S. Fish and Wildlife Service Evaluation of the Atlantic States Marine Fisheries Commission Horseshoe Crab/Red Knot Adaptive Resource Management Revision* at 3 of PDF (2022) ("*Evaluation*"), https://www.fws.gov/sites/default/files/documents/service-evaluation-of-atlantic-states-marine-fisheries-commission-horseshoe-crab-red-knot-adaptive-resource-management-revision.pdf.

[117] The ESA applies to any "person," which is broadly defined. 16 U.S.C. § 1532(13) ("The term 'person' means an individual, corporation, partnership, trust, association, or any other private entity; or any officer, employee, agent, department, or instrumentality of the Federal Government, of any State, municipality, or political subdivision of a State, or of any foreign government; any State, municipality, or political subdivision of a State; or any other entity subject to the jurisdiction of the United States.").

[118] Atlantic Coastal Fisheries Cooperative Management Act of 1993, Pub. L. 103-206, 107 Stat. 2419, Tit. VIII (codified at 16 U.S.C. § 5101 *et seq.*).

[119] *Id.* § 5104(b)(1).

[120] *Cf. Defs. of Wildlife v. U.S. Envtl. Prot. Agency*, 882 F.2d 1294, 1301 (8th Cir. 1989) (EPA's registration of pesticide effected a taking because the pesticide could not be used without such registration).

ASMFC's fishery management decisions therefore have a direct causal connection to the ultimate bait-harvesting actions that impact horseshoe crabs and red knots.[121] Indeed, the connection between the Board's management decisions and red knot demographics is the premise and intent of the ARM Framework's objective statement:

> Manage harvest of horseshoe crabs in the Delaware Bay to maximize harvest but also to maintain ecosystem integrity, provide adequate stopover habitat for migrating shorebirds, and ensure that the abundance of horseshoe crabs is not limiting the red knot stopover population or slowing recovery.[122]

Draft Addendum VIII shows that, if the revised ARM Framework had been utilized in 2017-2019, it would have allowed for the harvest of around 150,000 female horseshoe crabs each year,[123] compared to the actual quota of zero for each of those years. Going forward, allowing such an increase in the harvest of female horseshoe crabs, upon which egg abundance depends, threatens significant degradation and modification of red knot habitat at Delaware Bay that would kill or injure red knots by significantly impairing breeding and feeding activities that are essential to the continued existence of the species.[124]

As explained above, the revised ARM Framework raises serious questions that the Board has not answered or publicly considered. After 24 years of ASMFC management, including 10 years under an ARM Framework, neither red knots nor horseshoe crabs are on a trajectory to recover. There are serious reasons to doubt even the modest increase in the horseshoe crab population that ASMFC reports. ASMFC's red knot abundance estimates are essentially flat at low numbers, while other estimates based on direct counting have shown a dangerous decline in recent years.

Now, in the Board's first addendum since red knots were listed as threatened, Addendum VIII would result in the increased harvest of horseshoe crabs, including the resumed harvest of females, thus magnifying the factors imperiling red knots. This poses an enormous risk to the ecosystem, which is precisely the wrong response to a species being listed under the ESA.

C. FWS's "Evaluation" Does Not Offer Independent Support for Addendum VIII.

Recent statements from FWS do not bolster the credibility of the revised ARM Framework. When FWS listed red knots as threatened under the ESA, it stated, "[A]s long as the ARM is in place and functioning as intended, ongoing HSC bait harvests should not be a threat to the red knot."[125] In her minority opinion raising concerns about the revised ARM Framework, Dr. Walsh

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[121] *E.g.*, *Sierra Club v. Yeutter*, 926 F.2d 429, 438-39 (5th Cir. 1991) (holding that government agency violated ESA taking prohibition by authorizing logging that destroyed habitat and thereby impaired essential behavioral patterns of listed woodpecker species); *Loggerhead Turtle v. County Council of Volusia County*, 896 F. Supp. 1170, 1181-82 (M.D. Fla. 1995) (holding that county that regulates vehicular access to beaches is liable under ESA for taking of sea turtles caused by nighttime beach driving).
[122] ASMFC, *ARM Report* 25.
[123] ASMFC, *Draft Addendum VIII* at 12 app'x A tbl. 1 (showing annual female harvest quotas ranging from 144,803 to 154,483).
[124] 50 C.F.R. § 17.3 (defining "[h]arm").
[125] 79 Fed. Reg. at 73,709.

wrote that “[i]mmediate resumption of female harvest by the means described in the draft report may prompt the USFWS to reconsider if the ARM is functioning as intended.”[126]

In contrast to Dr. Walsh’s minority opinion, the document that FWS released on August 16, 2022, styled as an “evaluation” of the revised ARM Framework, did not offer any independent assessment of the revised ARM Framework. Rather, it repackaged the revised ARM Framework’s modeling with all of its flaws detailed above, at times appearing to copy and paste figures directly from the Subcommittee’s materials, and stated that the revision “poses negligible risk to red knot recovery and negligible risk of take under the Endangered Species Act.”[127] Nowhere did FWS question the validity of the revised ARM Framework or any of the underlying assumptions or decisions, including on any of the bases discussed in these comments and accompanying expert reports.

With its complete deference to ASMFC’s flawed modeling, assumptions, and conclusions, FWS unsurprisingly reached the same flawed result but did not bolster its validity. As these comments have shown, the revised ARM Framework incorporates numerous erroneous methodologies and assumptions. In its document, FWS propagated the same errors and replicated the same flaws as ASMFC. Moreover, since FWS relied on ASMFC’s non-public model, its assertions are effectively unverifiable. The revised ARM Framework is unreliable for the reasons demonstrated in these comments. The Framework also still needs a legitimate, thorough, independent review based on all underlying information—not just the information released publicly to date. FWS’s imprimatur does not resolve the defects of Addendum VIII.

VII. CONCLUSION

The window to save red knots is closing rapidly, especially for Southern wintering birds that fly the farthest and are most reliant upon horseshoe crab eggs at Delaware Bay. The revised ARM Framework would increase the pressure on this species, which is already vastly diminished on the beaches that once hosted its extraordinary migration. The Framework does not appreciate the importance of horseshoe crabs to red knots or the fragility of the horseshoe crab population itself. The weak relationship that it perceives between red knots and horseshoe crabs may well become a self-fulfilling prophecy, as the computer model continues to run while the ecosystem around it fades away.

The Horseshoe Crab Management Board has an obligation to restore red knots and horseshoe crabs at Delaware Bay. Just as importantly, it has a real—and maybe a final—opportunity to do so. For the reasons described above and in the attached expert reports, the Board should reject Addendum VIII.

[126] *Walsh Minority Opinion* 117.

[127] FWS, *Evaluation* at 3 of PDF. While the document is dated January 18, 2022, it was not released to the public until August 16. For an example of a copied figure, compare ASMFC, *Supplemental ARM Report* 30-31 figs. 10-11, with FWS, *Evaluation* at 5 of PDF fig. 1.

Review of 2021 ASMFC ARM revision

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September 2022

This is an expert review of the Adaptive Resource Management plan (ARM) proposed by ASMFC to guide management of the Horseshoe Crab fishery in Delaware Bay, performed by Kevin Shoemaker, Ph.D.

Dr. Shoemaker has a Ph.D. in Conservation Biology, a Master of Science degree in Conservation Biology, both from SUNY-ESF in Syracuse, NY, and a Bachelor of Science degree in Biology from Haverford College. He is a former Postdoctoral Fellow in the Department of Ecology and Evolution at Stony Brook University and a former Senior Scientist at Applied Biomathematics, an ecological research and development company located in Setauket, NY. Dr. Shoemaker is currently employed as an Associate Professor of Population Ecology at the University of Nevada, Reno. He has over 15 years of experience as a wildlife conservation scientist and has authored over 45 peer-reviewed scientific articles and book chapters on topics in wildlife ecology and conservation. He has expertise in Bayesian inference, machine learning, population ecology, and ecological modeling.

OVERVIEW

This report presents my review of the Adaptive Resource Management plan (ARM) proposed for use by the Atlantic States Marine Fisheries Commission (ASMFC) as a tool for guiding management of the horseshoe crab (HSC) fishery in Delaware Bay and protecting the Federally Threatened *Rufa* Red Knot (*Calidris canutus rufa*; REKN). Delaware Bay is a critical stopover site for REKN in their spring migration to breeding grounds in the high arctic from wintering grounds as far south as Tierra del Fuego (USFWS 2021). Specifically, HSC eggs deposited on coastal beaches provide a necessary high-calorie food resource for REKNs and other migrating shorebird species as they replenish fat reserves depleted from their long migration and prepare for breeding. At the heart of the proposed ARM framework is an optimization model that provides harvest recommendations for female and male HSC, conditional on current estimates of HSC and REKN abundance. These recommendations are calibrated to maximize HSC harvest while causing minimal risk to the REKN population. The optimization model is based on a linked two-species simulation model (comprising a HSC and a REKN simulation model) that incorporates a one-way biotic interaction in which annual REKN survival and recruitment depend on female HSC abundance in Delaware Bay (among other covariates). While the stated objectives of the revised ARM are sensible, my review identified several concerns that suggest the revised ARM framework is not an appropriate tool for managing risk to HSC or REKN populations. Specifically, this report identifies six main areas of concern:

(1) **The fitted relationship between HSC abundance and REKN vital rates (survival and fecundity) is of insufficient magnitude to forecast a decline in mean projected REKN population growth even under a total collapse of the HSC population**. The extremely weak REKN/HSC relationship used in the revised ARM is inconsistent with previous research documenting HSC eggs as a critical food resource for migrating REKN and with the documented decline of the REKN population over recent decades, which experts have linked to increases in HSC bait harvest during the 1990s (Niles et al. 2009; USFWS 2014). If the REKN population model is inconsistent with what has been observed in the recent past, it seems unlikely to yield robust forecasts of future risk to the REKN population (or recovery of this population) from which to base management decisions. The inclusion of a REKN population model within the ARM framework (both the initial and revised versions) presupposes that HSC harvest could put REKN populations at risk, at least under some scenarios. As it stands, the apparent inability of the revised ARM model to predict a decline of the REKN population even under a total collapse of the HSC population seems to violate this premise, and practically guarantees that the REKN population model will play an insignificant role in setting optimal HSC harvest rates.

(2) **The HSC population simulation model fails to correctly propagate uncertainty about mean recruitment rates**. In specifying the bivariate normal distribution used to generate

annual male and female HSC recruitment rates (the most consequential empirically fitted parameters of the HSC simulation model), the proposed ARM framework treats incertitude about annual recruitment rates as representative of temporal process variance (natural year-to-year fluctuations) rather than as a mixture of parameter uncertainty and process variance (Link and Nichols 1994; Regan et al. 2002; McGowan et al. 2011). This subtle but significant shortcoming will tend to manifest in simulation replicates that closely resemble one another, since key sources of uncertainty "regress to the mean" (good years cancel out bad years) instead of propagating over time. The importance of this distinction is magnified for long-lived iteroparous species like HSC, since these populations tend to be resilient to short-term fluctuations in reproduction or recruitment (Lovich et al. 2015). When this issue is corrected (using the same Bayesian approach used to treat process variation and uncertainty in the REKN simulation models in the revised ARM framework), preliminary simulation results suggest a highly uncertain outlook for the HSC population in Delaware Bay, especially when faced with harvest pressures. In sharp contrast to the ARM report and supplement, the population of HSCs in Delaware Bay appears to have a substantial (17.5%) probability of falling below the lowest previously estimated levels even in the absence of all direct anthropogenic sources of mortality (bait harvest, biomedical bleeding and discard mortality) over the next 50 years. Furthermore, a scenario in which HSCs are harvested annually at the current maximum allowable rates is accompanied by a severe risk of decline (33.45%) and disruption to the population age structure (lower multiparous/primiparous ratios than previously observed). Finally, an extreme harvest scenario in which two million male and female HSCs are harvested each year results in near-certain catastrophic population collapse over the 50-year time horizon, in contrast to the (original) ARM report, which suggests a relatively stable HSC population even under this extreme scenario (which greatly exceeds current maximum allowable rates).

(3) **The Catch Multiple Survey Analysis (CMSA) exhibits poor fit to training and independent data, raising concerns about its use in projecting future HSC abundance**. Aside from being able to explain the apparent difference in mean HSC abundance before and after the "VT gap years" (see below; higher HSC abundance is both predicted and observed after the

period 2013-2016), the CMSA model explains very little, if any, of the observed variation in the primary data sources (three trawl surveys conducted in and around Delaware Bay). The CMSA results exhibit relatively good fit ($R^2 > 0.5$) to the recruitment data (primiparous abundance); however, this is unsurprising since there is only one source of data (VT swept area surveys) for estimating annual primiparous abundance versus three sources for estimating adult (multiparous) and total abundance. Given the overall lack of fit to training data, the HSC simulation model is unlikely to perform well for predicting independent validation data (data not used to fit the model). Indeed, when the CMSA results are challenged against the HSC spawning surveys – an independent estimate of HSC abundance for this region – there is no detectable relationship between these two independent estimates of HSC abundance. This lack of fit to both training and validation data raises concerns about the utility of the CMSA model, which informs all aspects of the proposed ARM, including the REKN IPM (where it represents the abundance of female HSC each year), the HSC projection model, and the annual harvest recommendation.

(4) **The "gap years" in the VT trawl survey data raise concerns about HSC recruitment estimates from the Catch Multiple Survey Analysis (CMSA)**. As noted above, the CMSA is fundamental to all aspects of the proposed ARM framework. For the HSC population simulation models, the primary role of the CMSA is to parameterize HSC recruitment rates (which are the most consequential empirically derived inputs for the HSC simulation model). Unfortunately, of the three trawl surveys used to fit the CMSA models, the only survey that provides information for estimating recruitment – the Virginia Tech (VT) trawl surveys – was not conducted during a critical four-year period from 2013 to 2016 (hereafter referred to as the "VT gap", during which no direct information was available for estimating annual HSC recruitment rates). The CMSA results suggest that the HSC population underwent a substantial state transition during the VT gap years in which the population was small but stable prior to the gap, and larger and more variable after the gap. More concerningly, the CMSA predicts much higher average recruitment rates during the VT gap (for which no data are available for estimating recruitment) than at any single year before or after. The inflated average recruitment rates during the VT gap period are subsequently used for estimating

mean HSC recruitment rate for the HSC simulation models (thereby increasing estimated population resilience to harvest) – but unfortunately these high recruitment rates cannot be verified empirically. If average recruitment rates were computed from only those years in which recruitment could be verified empirically (i.e., excluding estimates from the VT gap years) the expected resilience of the HSC population to harvest would be substantially reduced.

(5) **The proposed ARM framework lacks 'null model' benchmarks and independent performance validation**. Null models are simplified representations of a system that lack many or all the proposed mechanisms that may help to explain the system dynamics; the typical null model in statistics assumes all observed variation is the result of a single random error process. By comparing complex models such as those used in the revised ARM with one or more null-model benchmark(s), researchers can determine whether the more complex models represent useful learned knowledge about a system (Koons et al. 2022). If a complex model fails to outperform a null model in terms of bias or precision (typically using independent validation data), the complex model is likely to be improperly specified or "overfitted" (whereby parameters are fitted to "noise" rather than true signal; Radosavljevic and Anderson 2014) and therefore not useful for prediction. The CMSA model fails to outperform even the simplest statistical null model (single intercept term with sampling error) for at least one data source (the VT swept-area estimate of female multiparous abundance). For the REKN component of the revised ARM, it would be informative to compare the performance of the REKN simulation model against a null model that omits any effect of female HSC abundance. It was recently demonstrated (Koons et al. 2022) that the ARM framework for guiding North American mallard harvest was unable to outperform a null model, and it would be instructive to pose a similar challenge to the REKN simulation model. If either model fails to outperform a null model, it should prompt managers to acknowledge that our current understanding of the effects of harvest on HSC populations remains insufficient for robust forecasting (Dietze 2017), and that a more precautionary approach may be warranted.

(6) **Lack of transparency**. The public still has no access to the data and code used for estimating

REKN population parameters, simulating REKN and HSC population dynamics, and running optimization routines (the CMSA code and data were made available). Without this data and code, it is difficult to fully assess the proposed ARM framework and to run scenario tests. If granted access to the code and data, there are a number of important null model tests (see above) and scenario tests that can be run, including (1) developing and testing the HSC and REKN models against a "null model" benchmark, (2) determining the 'optimal' female HSC harvest rates from the "canonical" versions of the HSC and REKN models in the absence of defined harvest limits, and (3) running the REKN simulation model under a scenario representing near-total collapse of the HSC population. The concerns identified above, which arise from analysis of the limited data and code made available to date, demonstrate, at a minimum, that such further testing is warranted. It seems prudent to delay implementation of the new ARM framework until the public and outside experts have had adequate time to scrutinize the statistical and simulation models that play such a central role in this proposed decision-making framework.

SUPPORTING EVIDENCE AND ANALYSES

The remainder of this report provides additional supporting details for the six major areas of concern identified above, including results and figures from re-analyses of the data presented in the ARM report.

1. The fitted relationship between HSC abundance and REKN vital rates (survival and fecundity) is of insufficient magnitude to forecast a decline in mean projected REKN population growth even under a total collapse of the HSC population

Including a model of REKN population dynamics as part of the previous and revised versions of the ARM framework implicitly acknowledges that reduction of the HSC population could, under some circumstances, have a negative impact on REKN populations. This assumption has a strong empirical basis, as multiple lines of evidence suggest that HSC eggs are an extremely important resource for migrating REKNs during their spring migration (e.g., Karpanty et al. 2006; Niles et al. 2009; USFWS 2014; USFWS 2021). Therefore, it is surprising that the fitted relationship between HSC abundance and REKN survival used in the revised ARM is very weak and appears to be overwhelmed by random among-year variation (Fig. 47 from ARM Report; Fig. 9 from Supplemental Report; hereafter, I will use the notation 'ARM Fig. 47/9'). In fact, it appears from the ARM report that estimated REKN survival rates have generally decreased weakly over time despite an estimated increase in HSC abundance (ARM Fig. 44/7). Years with the lowest HSC abundance in the study period (at or near the lowest HSC abundances ever recorded in Delaware Bay) are coincident with the highest estimated REKN survival rates (ARM Fig. 47/9). Given this weak fitted relationship, simulated REKN abundance based on this model seems unlikely to be very sensitive to changes in HSC abundance. Indeed, a 'back of the envelope' calculation based on the REKN vital rates presented in the ARM report (and the slightly modified numbers presented in the Supplement) shows that the mean population growth rate (Lambda) of the REKN population is likely to remain at or above replacement levels (Lambda ≥ 1) even at HSC population size equal to zero (Fig. 1). This calculation was produced by using the mean survival from Supplemental Table 8, mean recruitment estimated from Supplemental Fig. 7b, and the standardized logistic regression coefficients from Supplemental Table 9 (effect size = 0.37 for survival and -0.14 for recruitment) to model REKN survival and recruitment as a function of HSC abundance. As a brief aside, the regression coefficients presented in the ARM report (e.g., effect of HSC on survival) are standardized and are on the logit (log-odds) scale, making them difficult to interpret. A quick example may help to aid interpretation of the effect size of this relationship: given a coefficient of 0.37 (the mean regression coefficient for the relationship between HSC abundance and REKN survival from the ARM Supplement, Table 8), a loss of 1 million female horseshoe crabs from Delaware Bay would result in REKN survival rate declining by only 0.004 (from 0.93 to 0.926). This is consistent with visual inspection of ARM Fig. 47/9.

Although I did not have access to the code and data used to fit the relationships between HSC abundance and REKN survival and recruitment, the relationships I used to generate Fig. 1 closely match the relationships presented in ARM Fig. 46/8 (Fig. 2). Interestingly, the value for mean recruitment provided in Supplemental Table 8 (ρ_{mean} = 0.063) yields a declining REKN population (Lambda = 0.99) even under average conditions from 2005 to 2017. Since this result is inconsistent with the reported Lambda of 1.04 during that same period from ARM Table 25 (and the generally increasing population trajectories indicated in ARM Fig. 58/15), I chose to use the mean annual recruitment estimated from Supplemental Fig. 7b, which I calculated to be 0.109 (or geometric mean of 0.099). Using these mean recruitment values resulted in a Lambda of 1.035 (for arithmetic mean) or 1.027 (for geometric mean), more closely resembling but still below the reported baseline Lambda of 1.04 from the ARM report; setting baseline Lambda to 1.04 would only make a stronger case that REKN populations would not be expected to decline under an HSC population collapse (Fig. 1). This simulation exercise makes it very clear that the REKN model used in the revised ARM would not be able to predict or explain the decline in the REKN population observed during the 1990s, which has been attributed to unregulated harvest of HSCs in Delaware Bay (Niles et al. 2009; USFWS 2014). If this framework is unable to explain the decline of the REKN population in the first place, it does not appear to be an appropriate tool for helping to reverse the decline and promoting the recovery of this threatened subspecies.

Note that the population vital rates used to generate Fig. 1 represent point estimates. Because there was uncertainty associated with the estimate of Lambda (CI from 1.00 to 1.06; ARM Table 25), and with the effect size of HSC abundance on survival rate (CI from 0.12 to 0.63; ARM supplemental Table 9), some simulation runs (i.e., those with small Lambda and larger effect size sampled randomly from the joint posterior distribution) are likely to indicate REKN population decline at low HSC abundances. It is likely that these (probably rare) simulations drive the shape of the REKN “harvest function” yielded by the approximate dynamic programming algorithm. However, without access to the IPM and simulation code, I am not able to formally test the behavior of the REKN simulation model under scenarios of HSC population decline or collapse.

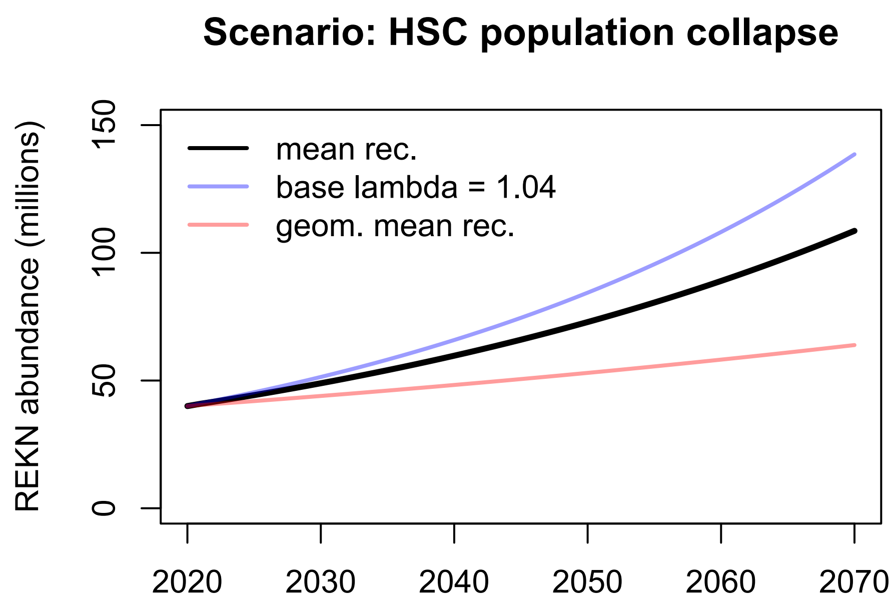

Figure 1*. Results from a 'back of the envelope' calculation of REKN population growth under a scenario with depleted HSC population (female HSC abundance = 0 based on numbers presented in the ARM report. Mean recruitment rate was computed in three ways: arithmetic mean of values from ARM Supplemental Fig. 7b ("mean rec"), the geometric mean of these same values ("geom. mean rec."), and a value fitted to ensure a population growth rate (Lambda) of 1.04, as indicated in the ARM report. Although somewhat simplistic, this figure illustrates that the reduction in REKN survival due to the collapse of HSCs in Delaware Bay appears to be insufficient to induce a meaningful REKN population decline. This figure is based on a simple age-structured population model and does not incorporate a density-dependence mechanism (the revised ARM includes a density ceiling that prevents the REKN population from growing above ~150k).*

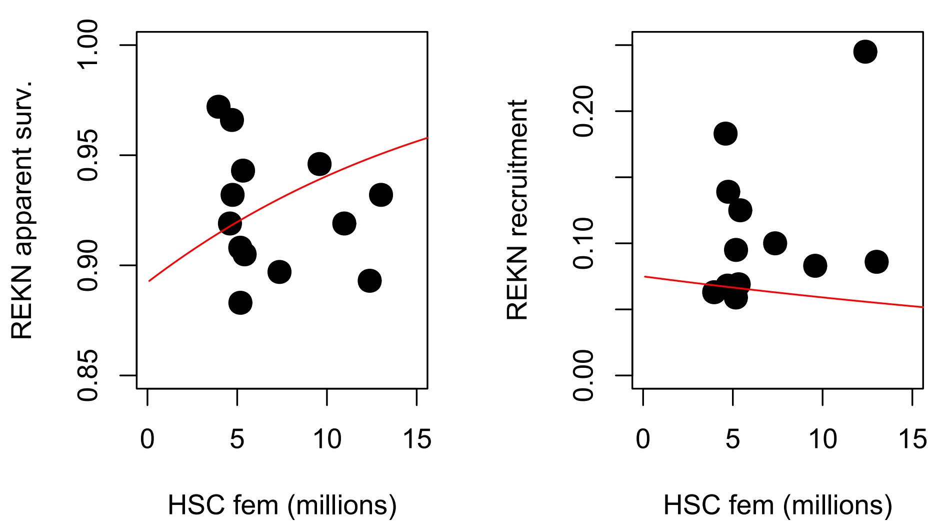

Figure 2*. Relationships between female HSC abundance and REKN survival (left panel) and recruitment (right panel), recreated from information in the ARM supplemental report for the purpose of calculating the expected REKN population response to changes in the HSC population. Solid black dots represent annual vital rates estimated from ARM Supplement Fig. 9, and the red lines represent the fitted relationships presented in ARM Supplement Table 9.*

Due to the weakness of the HSC/REKN relationship used in the revised ARM, and due to the complexity of the Integrated Population Model (IPM) framework used to represent the REKN population in the revised ARM, the relationship between HSC abundance and REKN population vital rates are likely to be unstable (sensitive to new data and alternative model specifications). Therefore, it is not implausible that the fitted relationship may disappear (become "non-significant") – or even flip sign to become a negative relationship – when the IPM is fitted to additional observations. This outcome would pose an existential problem for the ARM framework, decoupling the two-species framework and rendering the REKN model unusable in the context of management. There does not appear to be a contingency plan for this outcome. More generally, the REKN IPM appears to have gone through several distinct versions before researchers settled on a final set of decisions to incorporate into the final model (there are several important differences between an earlier version of the IPM presented in Tucker [2019] and the ARM report). Ideally, the results from alternative representations of the REKN system should be considered in aggregate to better represent structural uncertainty about this system (Williams 2011).

The linked two-species modeling framework in the revised ARM assumes the relationship between REKN and HSC is independent of REKN densities (i.e., it assumes a prey-dependent functional response). Under this assumption, larger REKN populations do not require larger abundances of HSC females (i.e., more HSC eggs deposited) to support adequate per-capita weight gain; in other words, the ARM model assumes that a REKN population of 40k would experience the same per-capita survival and fecundity as a population of 400k for a given abundance of female HSC. Implicitly, this assumes a lack of interference among REKN individuals, and no decline in the mean quality or accessibility of HSC egg resources at elevated REKN abundances (Karpanty et al. 2011). Some researchers have argued convincingly that a ratio-dependent functional response – in which per-capita prey consumption depends on the ratio between prey and predator abundances – is likely to be more realistic for simulation models with discrete time steps that span the entire reproductive periods of predator and prey (Abrams and Ginzburg 2000), such as the linked two-species model used in the revised ARM.

The previous ARM framework used data gathered from multiple sources of data outside

Delaware Bay to parameterize the simulation models. The revised ARM attempts to use Delaware Bay data sources wherever possible – which is a significant advance in many ways, as the revised ARM is "fine-tuned" for the system and can be updated relatively easily as new data are collected. However, this modeling decision also limits the analyses to a small geographic area over a short period of time, potentially ignoring relevant evidence from other regions and/or time periods. Furthermore, the time frame over which data are available for fitting the population models used in the revised ARM represents a limited scope of historical variation during which populations of REKN and HSC were relatively small in comparison with earlier estimates. Using these models to forecast system dynamics under conditions outside the range of values used to fit the model (e.g., lower HSC abundances, higher REKN abundances) therefore requires extrapolation, which can be highly uncertain (and often inaccurate). Since both the HSC and REKN simulation models tend to produce forecasts that differ from current conditions (e.g., larger numbers of both species), and because the optimization routine relies on these simulated results, the management recommendations emerging from the revised ARM rely on highly uncertain extrapolations about HSC and REKN population dynamics and about how these two species may interact (analogous to extrapolations of species and community distributions under climate change; Araujo and Rahbek 2009). On one hand, the ARM framework is designed to be able to refine management policies as new data become available and as sources of uncertainty are reduced (Nichols et al. 2007). On the other hand, it does not seem prudent to implement management "experiments" that could potentially imperil a threatened or endangered species (TES), even under the rubric of adaptive management.

In summary, the relationship between HSC abundance and REKN survival appears to be too weak to induce a decline in REKN abundance (Fig. 1). If all HSCs in Delaware Bay disappeared today, the model would continue to predict a generally stable or increasing population of REKN over the next 50 years. Therefore, the revised ARM model would be unable to predict the decline of REKNs that was observed in recent decades, and which has been attributed in part to the decline in the HSC population (Niles et al. 2009; USFWS 2014). This lack of consistency between the revised ARM model and recent historical observations raises significant doubts about the ability of this model to accurately reflect future risks to the REKN population or to guide HSC harvest decisions in a way that promotes REKN survival and recovery. Furthermore, the decision to include a REKN population model as part of the ARM framework (in both the original and revised versions) presupposes that HSC harvest could result in risk to the REKN population; the apparent inability of the ARM model to predict a decline in REKN abundance under a total HSC population collapse violates this premise and undermines the apparent purpose of the model.

2. The HSC population simulation model fails to propagate uncertainty about mean recruitment rates

The HSC recruitment process is the most consequential empirically fitted component of the HSC simulation model. Other elements of the HSC simulation model are not fitted to data – for example, natural mortality rate, the biomedical mortality rate, and bait harvest rates are fixed by the modelers. In the revised ARM, the recruitment process is fitted to data indirectly via the CMSA model; annual male and female recruitment estimates were used to fit a bivariate log-normal distribution (defined by a mean and standard deviation for each sex, along with a covariance between sexes – all on a logarithmic scale), which was then used to represent annual recruitment in the simulation model. The only other parameter fitted in the CMSA model – initial abundance – is not directly used in the simulation model. Recruitment is critical for any assessment of population resilience to harvest, since (in the absence of immigration, which is not included in the revised ARM), it is the only process that enables the population to overcome sources of mortality. Therefore, it is not surprising that the HSC simulation model is highly sensitive to changes in mean (log) fecundity (ARM Fig. 33; note that when I omit any reference to the supplemental report, I am referring to the primary ARM report). Given the high sensitivity of the HSC simulation model to the (log) mean HSC recruitment for males and females, it is critical that uncertainty about these parameters is properly represented in simulation models. However, the revised ARM framework incorrectly treats incertitude about annual recruitment rates as representative of temporal process variance (natural year-to-year fluctuations) rather than as a mixture of parameter uncertainty and process variance (Link and Nichols 1994; Regan et al. 2002; McGowan et al. 2011). This is a subtle but consequential error, as sources of uncertainty will tend to “regress to the mean” (with good years cancelling bad years) instead of propagating over time.

To estimate the parameters for the log-normal recruitment process in the revised ARM, the following steps were taken: (1) log-normal distributions were separately fitted to each estimate of primiparous abundance (separately for each year and sex), based on estimates of parameter uncertainty (95% confidence intervals) derived from the CMSA results, (2) this collection of lognormal distributions (representing parameter uncertainty) was used to simulate annual male and female primiparous abundance for the years represented in the CMSA model (confusing parameter uncertainty with temporal process variation), and then (3) data from these simulations were used to fit a bivariate lognormal distribution (via maximum likelihood) for representing annual HSC recruitment in the ARM model. In general, parameter uncertainty should be represented in simulation models by drawing a single sample per replicate from a distribution of values representing parameter uncertainty (or by running replicates with "worst-case" and "best case" values for key parameters). However, the "canonical" version of the HSC projection model fails to address parameter uncertainty – most notably, uncertainty about the mean HSC recruitment rate, to which the HSC projection model is highly sensitive (ARM Fig. 33). Therefore, there is more uncertainty about the future of the HSC population in Delaware Bay than the revised ARM acknowledges. It is important to note that a sensitivity analysis was run in which expected recruitment was allowed to vary across simulation replicates within ca. 5% or 10% of the median recruitment value. This sensitivity test demonstrates an appropriate method for modeling parameter uncertainty; however, this test fails to represent the extent of uncertainty about the median HSC recruitment, which extends far beyond 10% of the mean estimated value (Fig. 3). Furthermore, this treatment of uncertainty was only run as a scenario test and was omitted from the 'canonical' version of the ARM that is proposed for use in managing the HSC harvest in Delaware Bay.

Interestingly, the REKN projection model in the revised ARM appears to represent parameter uncertainty appropriately. The key parameters of the REKN model were estimated using an Integrated Population Model (IPM), which were fitted in a Bayesian framework. In this framework, parameter uncertainty is represented by a joint posterior distribution that embodies the set of values that are consistent with the observed data. Furthermore, temporal process variation in the REKN population model is treated by explicitly modeling annual variability in key vital rates (survival and recruitment) via annual random effects fitted with hyperparameters (Kery and Schaub 2011). This Bayesian hierarchical approach enables parameter uncertainty and process variation to be interpreted and modeled separately in a straightforward and intuitive manner. Specifically, parameter uncertainty is incorporated by running multiple replicates with different values drawn from the joint posterior distribution, and temporal process variation is included by sampling from the hyperparameters across years within each replicate (Goodman 2002).

To enable sensible propagation of parameter uncertainty in the HSC simulation model (analogous to the REKN model in the ARM), I constructed and fitted a hierarchical Bayesian version of the CMSA model. This model was fitted using the same data and model structure as the CMSA model included in the revised ARM. However, instead of estimating annual recruitment separately for each year and sex, the Bayesian CMSA model included an explicit representation of temporal process variance in recruitment (i.e., a "random effect" describing inter-annual variation in recruitment). This temporal process model was specified using a bivariate lognormal distribution exactly analogous to the HSC simulation model included in the ARM model, which included "hyperparameters" for male and female (log) mean recruitment, male and female (log) standard deviation, and a correlation term. By estimating temporal process variation directly, the Bayesian CMSA closely mirrors the HSC simulation model (analogous to the direct relationship between the IPM and the REKN simulation model), circumventing the multi-step process used in the ARM to generate the bivariate lognormal distribution from the CMSA results, and (most importantly) enabling the parameters of the bivariate lognormal distribution to be estimated directly from the data. To simulate HSC abundance over time, parameters for each replicate were drawn from the joint posterior distribution (representing parameter uncertainty), and temporal process variation within each replicate was simulated by sampling from the bivariate lognormal distribution. For the simulations, I incorporated the same restrictions in the stock-recruitment relationships indicated in the ARM report (driven by abundance and sex ratios for the years in which recruits were expected to have hatched).

Results from the Bayesian CMSA model indicate substantial uncertainty around mean HSC recruitment rates for both males and females (Fig. 3). Simulations (50 year time horizon) from this model in the absence of any direct anthropogenic sources of mortality (no bait harvest, biomedical mortality or discard mortality) indicate that the future of the HSC population in Delaware Bay is uncertain; the population has a 17.4% chance of declining below 4 million females (combined multiparous and primiparous abundance) at least once in the next 50 years, equivalent to the lowest abundances estimated from 2003 – 2019 (period for which the CMSA model was fitted) (Fig. 4). This no-harvest scenario also had a 3.8% probability of falling below 3 million females over the 50-year simulation, well below any estimate from the VT swept area surveys. In contrast, the HSC projection model in the revised ARM indicates a large and sustainable HSC population under a scenario with no bait harvest but including other anthropogenic sources of mortality including biomedical harvest and discard mortality (ARM Fig. 30; note that this figure does not reflect changes in mean HSC recruitment following peer review—the Supplement does not update this figure but contains other figures indicating a sustainable HSC abundance even with a bait harvest; Supplemental Fig. 15). Simulations from the Bayesian CMSA also indicate a much higher probability of decline under a scenario in which males and females are harvested at their respective maximum allowable rates (but are not subject to biomedical and discard mortality); this scenario had a 33% probability of declining below 4 million females over the next 50 years, 11% probability of declining below 3 million females, and a 2% probability of declining below 2 million females (Fig. 4). This scenario also appeared to disrupt the age structure in many simulations, resulting in fewer multiparous adults than primiparous adults. In contrast, the HSC simulation model in the revised ARM suggests a stable or increasing HSC population even under maximum allowable harvest scenarios that also include biomedical and discard mortality (ARM Fig. 31; see above caveat). Finally, a scenario in which both female and male HSCs were harvested at a rate of 2 million per year (much higher than the current maximum rate) results in a high probability of decline or even extirpation over the 50-year simulation; there was a >99% probability of declining to below 3 million females, a 92% probability of declining below 1 million females, and a 12% chance of falling below 10k females (Fig. 4). In contrast, the HSC simulation model in the revised ARM predicted a relatively sustainable population of HSC even under this extreme scenario, with no risk of population collapse (ARM Fig. 32; note that the HSC simulation model in the supplemental report may not sustain this level of harvest due to the reduced mean recruitment rate relative to the model used to generate ARM Fig. 32).

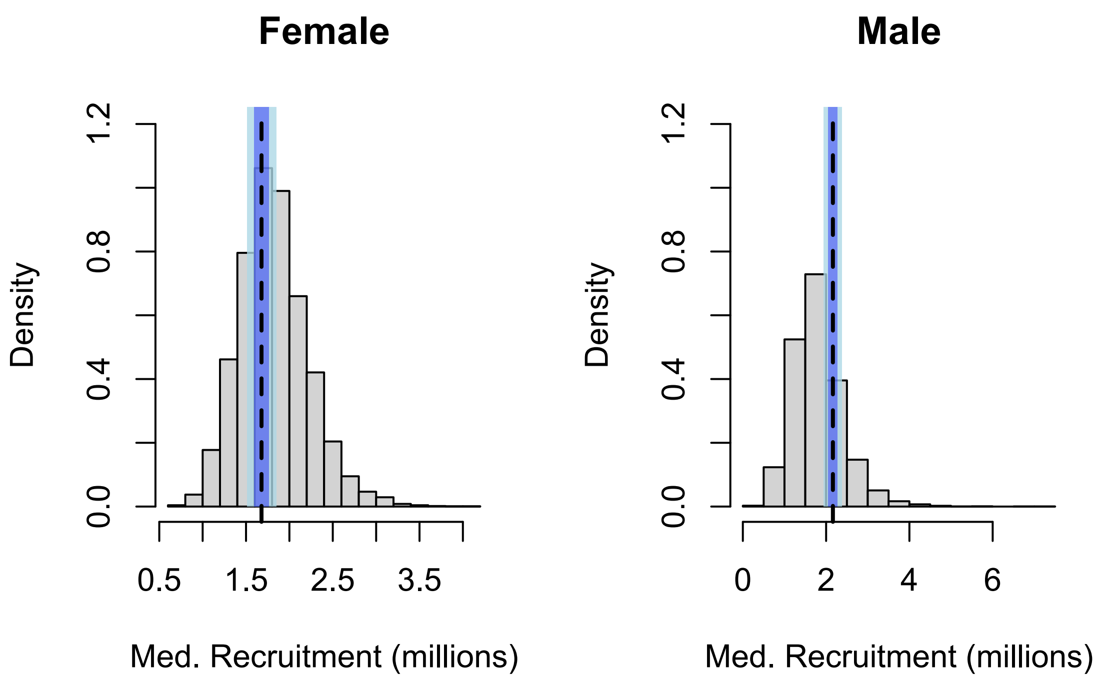

Figure 3*. Posterior distributions representing parameter uncertainty for median female and male HSC recruitment rates, fitted using a Bayesian reanalysis of the CMSA model from the revised ARM (same data and model structure used to fit the CMSA model). Vertical dashed lines denote the median HSC recruitment values used in the base HSC projection model in the revised ARM. Light and darker blue shaded polygons represent the "added variation in expected recruitment" sensitivity tests from the ARM report (e.g., Fig. 69, 70). Note that the true range of parameter uncertainty falls well beyond the bounds of these sensitivity tests.*

This critique is focused primarily on uncertainty about the annual HSC recruitment (primiparous abundance) parameters since they represent the ultimate source of projected resilience (or non-resilience) to harvest pressures and are therefore the most consequential fitted parameters in the CMSA simulation model. However, there are several other sources of uncertainty that should be accounted for in the HSC simulations. For example, natural mortality of HSC is set at exactly 0.3 (30%) across all sexes and age classes (primiparous and multiparous) in the revised ARM model, whereas there is substantial uncertainty about this parameter. The value of 0.3 was based on tag recovery data (assuming negligible harvest), but other lines of evidence seem to suggest natural mortality may be closer to 20% or even lower (as noted in the ARM report). Lower estimates of mortality (higher survival and greater longevity) could imply lower resilience to harvest of adults (Midwood et al. 2015). Interestingly, natural mortality is an estimable parameter in the CMSA model; when modeled as a free parameter in the Bayesian CMSA, the model suggests that natural mortality is lower than 30%, but higher for females than males (note that Figs 3 and 4 are based on a model with natural mortality set at 30%, to match the ARM models). Other sources of uncertainty in the HSC population model include discard mortality (where 5% mortality was assumed for trawl and dredge surveys, while 12% mortality applied for gill nets) and biomedical mortality (assumed to be 15%). Although the ARM report documents a limited set of sensitivity analyses that were designed to test the degree to which key results changed under alternative parameter values (including mortality; ARM Table 18, 19), the relatively small set of sensitivity tests does not appear to comprehensively address these sources of uncertainty and seem inadequate for characterizing uncertainty about this system. Furthermore, uncertainty about these processes is not propagated through the HSC projection models.

In summary, if sources of error in the recruitment process are properly accounted for, the outlook for the HSC population in Delaware Bay is uncertain even in the absence of any harvest pressures. Based on a reanalysis of the existing data (using the same model specification used in the CMSA and HSC projection model), I found that harvest at the current maximum allowable rates has a high risk (11%) of causing the female HSC population to decline below the lowest levels ever recorded (3 million females). The HSC population models presented in the ARM report and supplement are not useful because they mis-characterize the risk of harvest pressures to the HSC population in Delaware Bay.

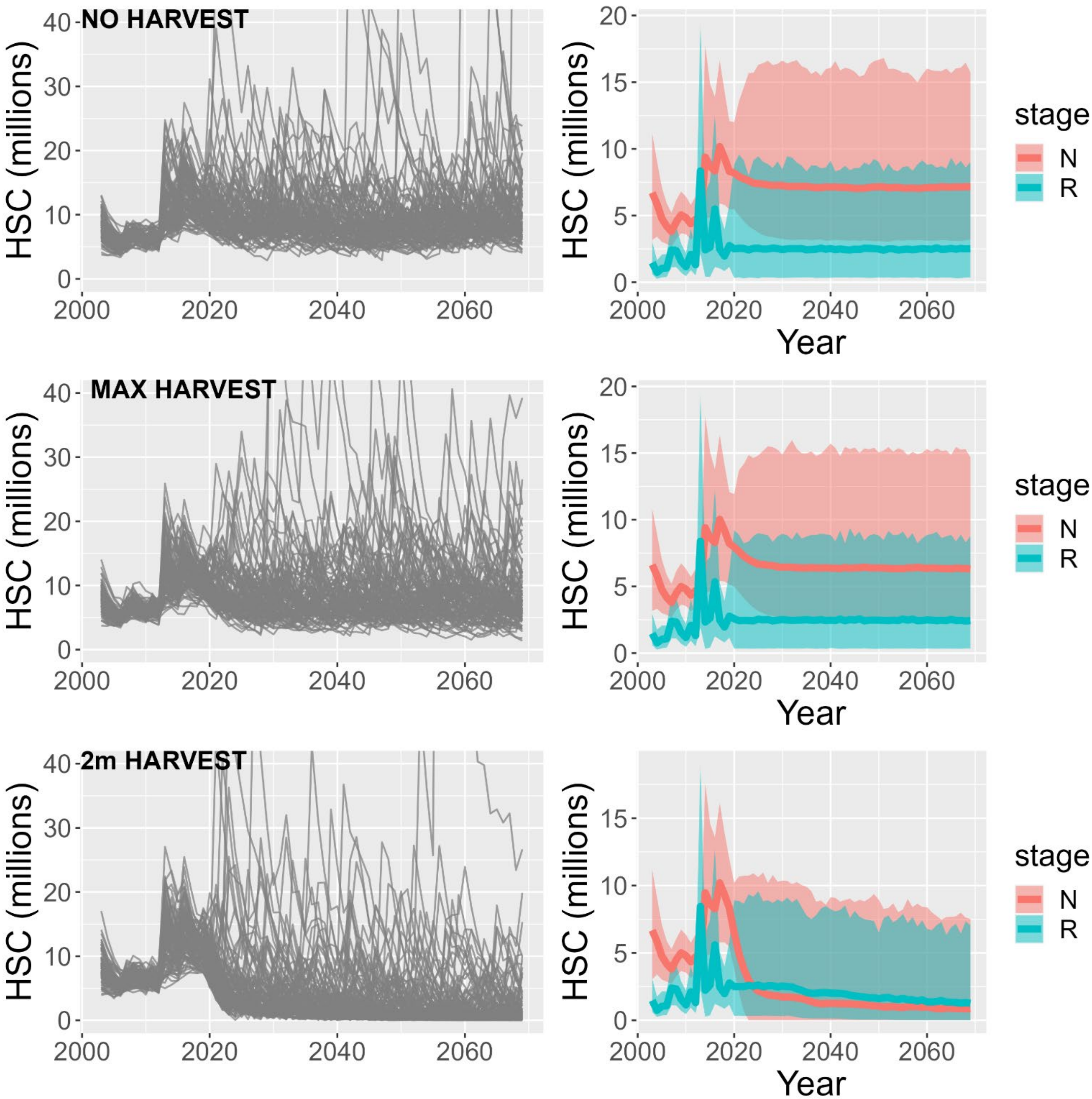

Figure 4*. Female HSC population simulations run using fitted parameters (joint posterior distribution) from a Bayesian CMSA model, with uncertainty propagation performed in a manner analogous to the REKN projection model. The top row depicts simulations run under a no exploitation scenario (no bait harvest nor biomedical/discard mortality), the middle row depicts maximum allowable harvest rates (but also without biomedical and discard mortality), and the bottom row depicts an extreme harvest scenario (2 million females, 2 million males harvested annually). The left-hand panels depict trajectories of total abundance (primiparous and multiparous) for individual simulation replicates. Right-hand panels depict the 95% credible intervals for primiparous abundance (R) and multiparous abundance (N). None of these scenarios include biomedical or discard mortality.*

3. The Catch Multiple Survey Analysis (CMSA) appears to exhibit poor fit to both training and independent data, raising concerns about its use in projecting future HSC abundance

The CMSA model explains little (and, in at least one case, none) of the variation in the data sources used to train this model (comprising three different trawl surveys conducted in and around Delaware Bay; here I present results for the female CMSA only) (Fig. 5). Notably, the CMSA performs worse than a statistical null model (all variation is assumed to be random "noise") for predicting the multiparous female abundance estimated from the VT trawl surveys, with R^2 of -0.42 for the full time series (negative R-squared value indicates the CMSA model performs worse than the null model). In contrast, the CMSA results appear to exhibit relatively good fit ($R^2 > 0.5$) to the recruitment data (primiparous abundance) from the VT trawl surveys (Fig. 5; ARM Fig. 21). However, this is not a fair test; with only one source of data for estimating annual primiparous abundance (the VT trawl surveys) – and with a separate recruitment parameter fitted for each year – the CMSA recruitment results are practically guaranteed to resemble the observed recruitment data.

For the remainder of the datasets used to train the CMSA (DE and NJ trawls), it is instructive to note that the majority of the observed variance 'explained' can be attributed to the apparent difference in mean HSC abundance before and after the period 2013-2016 (during which the Virginia Tech trawl surveys were not conducted and therefore no estimates of recruitment were available; hereafter, "VT gap", see below). Indeed, for the DE surveys the R-squared value drops to negative values for the periods before (R^2 = -0.07) and after (R^2 = -0.03) the VT gap period (versus R^2 = 0.14 for the full time series). Similarly, for the NJ trawl survey, the R-squared value drops to 0.11 for the period before the gap and falls below zero for the period after the VT gap (R^2 = -0.05; compared to R^2 = 0.57 for the full time series). More concerningly, the CMSA can "explain" the apparent increase in the HSC population after the VT gap period only by estimating extremely high recruitment during the VT gap period (during which no recruitment information was available; see below for more details). Because no data were available for fitting recruitment (primiparous abundance) during the VT gap, the CMSA model was free to "fill in" whatever recruitment estimates produced the best match to available data (DE and NJ surveys were the only available data sources during this period)—even if these recruitment estimates were unrealistically high or low (with no data available for comparison, there was no penalty for producing unrealistic estimates). If the CMSA is only able to fit the training data via unrealistic estimates of recruitment (see below), this strongly suggests a poorly specified model and raises serious doubts about using the CMSA results to represent and forecast the HSC population in Delaware Bay.

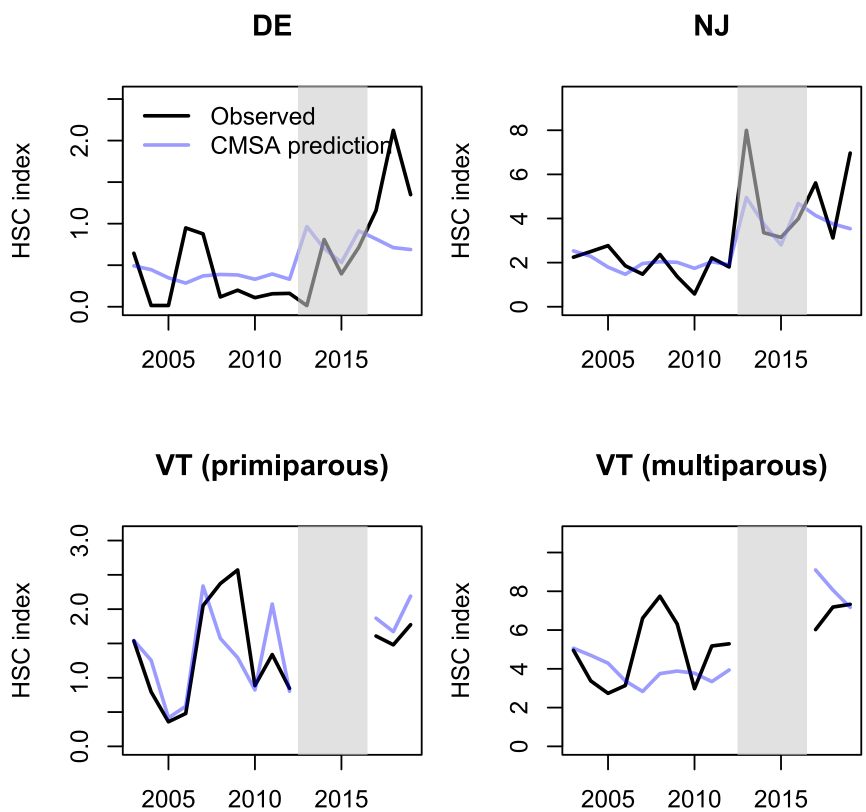

***Figure 5**. Illustration of the fit of the CMSA model to data on female HSC abundance derived from three trawl surveys: DE, NJ, and VT (the same sources of data that were used to fit the CMSA model). This figure presents the same information as ARM Fig. 21/4. The CMSA model performs well in predicting primiparous abundance (bottom left) but exhibits poorer performance for predicting adult (multiparous) abundance (bottom right) or total abundance (top row). The CMSA predicts little to no variation in adult/total abundance besides the difference in apparent mean abundance before and after the "VT gap years" (gray regions).*

Given the lack of fit to training data, the HSC simulation model is unlikely to perform well when predicting to independent validation data (data not used to fit the model). Indeed, when the CMSA results are challenged against the Delaware Bay HSC Spawning Surveys (e.g., Zimmerman et al. 2020; https://www.delawarebayhscsurvey.org/), which provides an independent estimate of relative HSC abundance for this region, there is no detectable relationship between these two independent estimates of HSC abundance (Fig. 6). This lack of fit to both training and validation data raises doubt about the utility of the CMSA results, which are central to all aspects of the proposed ARM, from fitting the HSC/REKN relationship to forecasting HSC abundance, to guiding annual decisions about HSC bait harvest.

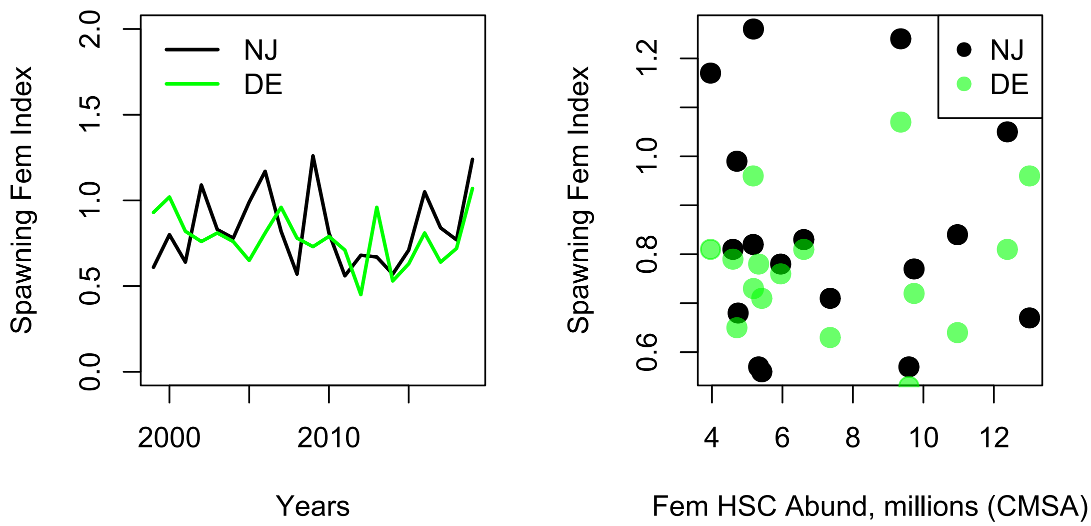

Figure 6*. Comparisons of standardized HSC spawning female counts from DE and NJ beaches (an index of relative female HSC abundance analogous to trawl surveys) with (left) each other and (right) with the CMSA estimates of female HSC abundance in Delaware Bay (in millions). The two spawning surveys exhibit very little correlation between the NJ and DE sides of Delaware Bay from 1999 to 2018 (left panel; correlation = 0.25). In addition, there is no detectable relationship between spawning counts (on either the NJ or DE sides) and CMSA estimates of female HSC abundance (right panel).*

In summary, the CMSA model does not perform well when predicting to the training data (the three sources of data used to fit the model). Although the model can explain some of the apparent difference in mean HSC abundance before and after the 'VT gap years', this 'ability' is driven by inflated recruitment rate estimates during the VT gap years that cannot be verified empirically (see below). Furthermore, the CMSA model explains virtually none of the observed variation in HSC spawning abundance from the same period, which represents an independent index of HSC population size. The poor performance of the CMSA model in predicting observed variations in HSC abundance in Delaware Bay calls into question the utility of this model – which is central to all aspects of the ARM model – as a robust system for characterizing and predicting the HSC population in Delaware Bay.

4. The "gap years" in the VT trawl survey data raise concerns about HSC recruitment estimates from the Catch Multiple Survey Analysis (CMSA)

As noted previously, the CMSA is fundamental to the proposed ARM framework. For the HSC population simulation models, the primary role of the CMSA is to parameterize HSC recruitment rates (which are the most consequential empirically derived inputs for the HSC simulation model). Unfortunately, of the three trawl surveys used to fit the CMSA models, the only survey that provides information for estimating recruitment – the Virginia Tech (VT) trawl surveys – was not conducted during a critical four-year period from 2013 to 2016 (referred to in this report as the "VT gap", during which no direct information was available for estimating annual HSC recruitment; note that the missing survey years were actually 2012-2015, but the VT results were lagged forward within the CMSA to ensure comparability with the DE and VT trawls). The lack of information on primiparous abundance during the VT gap years leads to several nonsensical results in the CMSA model. For example, in one year (2013; the first VT gap year) the estimated number of new female recruits is near 10 million – approximately 8 times larger than the average estimated recruitment rate from the 10-year period from 2003 to 2012 and 4 times larger than the maximum estimate during this 10-year time frame (ARM Supplemental Table 3). The following year (2014), the point estimate for primiparous abundance goes down to 2, i.e., 2 primiparous female individuals across Delaware Bay. Furthermore, the standard error estimates for primiparous abundance during the VT gap years are very large – in fact, the upper bound on the confidence intervals approaches infinity for one year (2014).

The CMSA results suggest that the HSC population underwent a substantial state transition during the VT gap years in which the population was small but stable prior to the gap, and larger and more variable after the gap. In the fitted CMSA model, this state transition appears to be driven by extremely high recruitment rates during the VT gap years. Concerningly, the CMSA model (including the Bayesian version of the CMSA model described above) predicts much higher mean annual recruitment rates during the VT gap (for which no data are available for estimating recruitment) than at any single year before or after (Fig. 7). Specifically, mean annual recruitment during the VT gap years was estimated at 4.2 million (using the arithmetic mean, per the ARM report), versus 1.2 million before the gap and 1.9 million after the gap (using the geometric mean to represent the median of a lognormally distributed sample, per the ARM report). The inflated mean recruitment rates during the VT gap period are subsequently used for estimating the average HSC recruitment rate for the HSC simulation models (thereby increasing estimated population resilience to harvest) – but unfortunately these high recruitment rates cannot be verified empirically.

In summary, the CMSA model estimates abnormally high annual recruitment rates during the VT gap years (Fig. 7). These very high estimates are unverifiable, as no data on HSC recruitment was collected during these years. In the original ARM report, the average annual recruitment used in the HSC simulation model relied heavily on the inflated estimates of recruitment during the VT gap years, discounting the pre-gap years entirely. After peer-review, the ARM was altered to consider all years instead of discarding lower estimates from the pre-gap years. Nonetheless, the revised ARM model continues to treat the mean recruitment rate during the VT gap as reliable, allowing these inflated estimates to contribute to the estimate of average annual HSC recruitment used for the HSC simulation models (which are highly sensitive to the estimate of average recruitment; ARM Fig. 33). If the extremely high recruitment estimates during the VT gap years were to be excluded from this estimation process out of precaution, the average annual HSC recruitment rate would drop substantially (Fig. 7), further reducing the expected resilience of this population to harvest pressures. Ultimately, the inflated estimates of recruitment during the VT gap years are likely to be an artifact of the CMSA model specification (and the lack of data on recruitment for those years) and are unlikely to be reflective of true HSC recruitment rates. However, there remains no way to verify HSC recruitment rates during this period. Given this uncertainty, a conservative (precautionary) approach would be to exclude the VT gap years when computing recruitment for the HSC population simulations (Fig. 7).

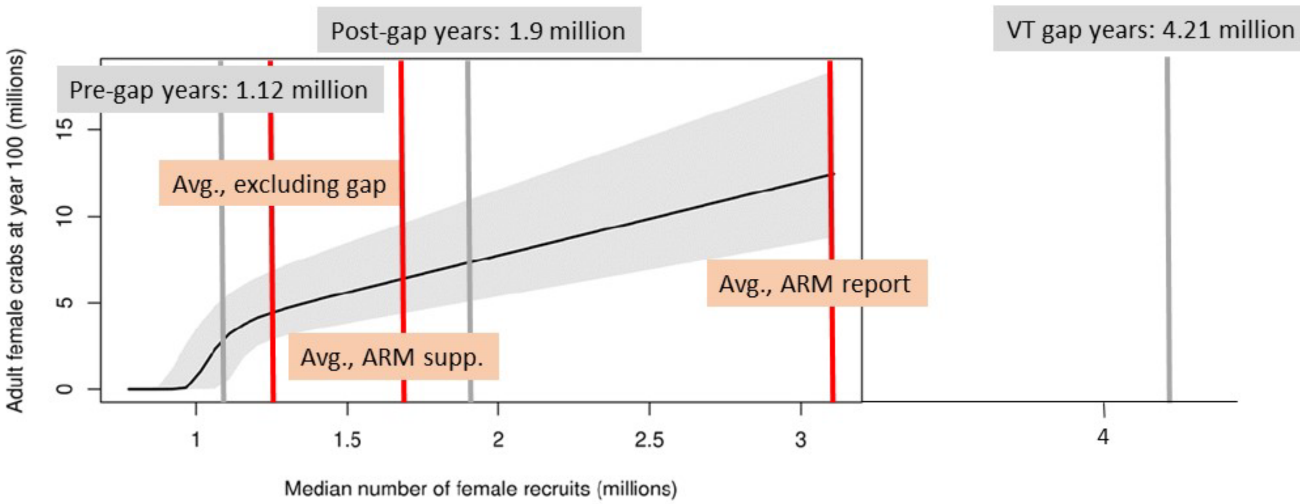

Figure 7*. Annotated version of ARM Fig. 33, which (in its original form) illustrates the sensitivity of HSC simulation results to changes in average HSC recruitment rates. Annotations reflect the average female recruitment before, after and during the VT gap years (in gray), the average recruitment value used in the original 2021 ARM report (red, far right), the value used in the supplemental report produced after peer-review (red, middle) and the analogous estimate computed by excluding the VT gap years (red, left). Average recruitment estimated for the VT gap years (arithmetic mean of 4.21 million based on the latest CMSA results) falls well outside the range of estimates during years for which recruitment was an observable process (and well outside the range of the x-axis of the original figure). The ARM report ignored recruitment estimates from the pre-gap years, giving very high weight to the inflated estimates during the VT gap years. Based on the peer-review, which suggested that the pre-gap years should not be excluded from the estimation of average recruitment rates, the current proposed value (described in the ARM supplement) is much lower than the value used in the ARM report (1.67 million vs. 3.1 million). However, the new proposed value continues to include unverifiable estimates from the VT gap years. If the VT estimates were excluded out of precaution, the average annual HSC recruitment would drop to 1.26 million, perilously close to the sustainability threshold identified in this figure (i.e., ARM Fig. 33).*

5. The proposed ARM framework lacks 'null model' benchmarks and independent performance validation

Null models are simplified representations of a system that lack many or all the explanatory mechanisms hypothesized to operate in the system. In statistics (e.g., linear regression analysis) the typical null model assumes all system variation is a result of unexplained variance in the form of random noise (often a single random error process). In other contexts, null models may include additional processes/mechanisms but omit a key focal mechanism, enabling researchers to test whether that focal mechanism contributes usefully to predictive performance. In the context of adaptive harvest management, a null model would at least omit consideration of the impacts of harvest processes on system dynamics, which ultimately informs management decisions (Koons et al. 2022). By comparing complex models such as those used in the revised ARM with one or more null-model benchmark(s), researchers can determine whether the more complex models represent useful learned knowledge about a system (Koons et al. 2022). If a complex model fails to outperform a null model in terms of bias or precision (typically using independent validation data), the complex model is likely to be improperly specified or "overfitted" (whereby parameters are fitted to "noise" rather than true signal; Radosavljevic and Anderson 2014) and therefore not useful for prediction.

In the context of the HSC fishery in Delaware Bay, it would be informative to compare the performance of the HSC simulation model against a null model that omits all information about HSC harvest from the model fitting process; this would enable assessment of our current understanding of how estimated rates of harvest affect the HSC population. Given the poor fit of the HSC simulation model to training and validation data (see above), the HSC simulation is unlikely to outperform simpler null models. In fact, the CMSA model fails to outperform the simplest standard null model (single intercept term with sampling error) for at least one data source (the VT swept-area estimate of female multiparous abundance) despite its complexity (~20 parameters for the CMSA vs 1 parameter for describing expected abundance each year). If the HSC simulation model fails to outperform a model in which population dynamics are driven by noise instead of harvest, it should prompt managers to acknowledge that our current understanding of the effects of harvest on HSC populations remains insufficient for robust forecasting (Dietze 2017).

For the REKN component of the revised ARM, it would be informative to compare the performance of the REKN simulation model against a null model that omits any effect of female HSC abundance. It was recently demonstrated (Koons et al. 2022) that the ARM framework for guiding North American mallard harvest was unable to outperform a null model, and it would be instructive to pose a similar challenge to the REKN simulation model. Given that all the deterministic processes (fixed effects) included in the IPM model were very weak (i.e., the HSC effect on survival and fecundity; see above) or "non-significant", it is already apparent that random noise overwhelms most signal in the training data regarding how the HSC population affects REKN population dynamics. Therefore, it is likely that information about the HSC/REKN relationship would explain little if any of the variation in independent validation data. Furthermore, the lack of a relationship between the HSC model (CMSA) and the number of spawning females observed on coastal beaches (see above) makes it even more unlikely that the current REKN population model would outperform a null model that excludes any effect of HSC abundance (since the HSC/REKN relationship is based on the consumption by REKNs of HSC eggs deposited by spawning females).

In summary, null model benchmarks should be incorporated into the ARM framework to ensure that effective learning is occurring and that managers acknowledge uncertainty about how their decisions affect the populations they are charged with managing (Koons et al. 2022). If one or both simulation models that form the core of the revised ARM framework fail to outperform null models, it would strongly suggest that the ARM framework's current level of understanding about how management decisions are likely to affect the HSC and REKN populations is insufficient for robust forecasting of population-level risk to either species from HSC harvest. Although the ARM process is designed to treat management actions as opportunities for learning – updating harvest recommendations as new data become available (Nichols et al. 2007) – the fact that one of these species is federally threatened (USFWS 2014) justifies a more precautionary approach for risk management.

6. Lack of transparency

The public still has no access to the data and code used for (1) estimating REKN population parameters via a Bayesian integrated population model (IPM), (2) simulating REKN and HSC population dynamics, and (3) running the optimization routines via approximate dynamic programming (ADP). The CMSA code and data were made available, which enabled me to re-analyze the HSC survey data and run informative scenario tests (see above). Without the data and code for other components of the ARM model, it is not possible to re-analyze the data, test key assumptions, or simulate population dynamics under different hypothetical scenarios. Given the substantial concerns generated by the data and code that has been made publicly available to date (discussed above), such further re-analysis, testing, and simulation is warranted. If granted access to the code and data, there are several important questions that could be addressed more thoroughly, including but not limited to:

1) How would HSC abundance projections change – and how would harvest functions change – under the lower mean recruitment estimate produced by excluding anomalous estimates from the VT gap years?
2) What would happen to the REKN population projections if female HSC abundance were set to zero?
3) Does the REKN projection model outperform a null model that excludes any effect of HSC abundance?
4) In the REKN IPM, does the effect of HSC abundance disappear (or flip sign to become a negative relationship) under alternative plausible model specifications?
5) What proportion of variation in apparent survival in the REKN IPM model is explained by the HSC effect vs. random among-year variation?
6) Does an index of HSC spawning or HSC egg densities explain more variation in REKN survival and fecundity than the CMSA-derived estimate of HSC abundance?

CONCLUSION

In this report I have outlined six major concerns about the revised ARM. First, the modeled relationship between REKN vital rates and HSC abundance does not appear to be strong enough to induce an expected decline in the REKN population even under a catastrophic collapse of the HSC population. The apparent inability of the model to predict a major population response of REKNs to the depletion of the Delaware Bay HSC stock invalidates the premise of including a REKN population model within the ARM framework, which implicitly assumes that (1) HSC eggs are a critical resource for REKN populations and (2) HSC harvest could inhibit or slow the recovery of the REKN population, at least under some circumstances. The apparent inability of the ARM model to show a strong population-level effect of HSC harvest on REKN populations is inconsistent with the observed decline of the REKN population in recent decades, which many researchers have attributed to increased HSC harvest rates in the 1990s. Therefore, the REKN model included as part of the revised ARM does not appear to be a useful tool for assessing and managing risks to the REKN population from HSC harvest – or for promoting recovery of the REKN population.

In addition, I have identified several concerns about the HSC data analysis and simulation models. First, the HSC model in the revised ARM does not appropriately address key sources of uncertainty – particularly with respect to HSC fecundity (the source of potential harvest resilience). When these sources of uncertainty are addressed, the outlook for the HSC population is more uncertain than indicated in the ARM report. My analyses indicate that harvest at the maximum allowable levels could put the population in jeopardy (~11% risk) of decline below 3 million females – well below the minimum level previously recorded – within the next 50 years. In addition, the Catch Multiple Survey Analysis (CMSA), which is central to all aspects of the ARM, appears to exhibit poor fit to both training and independent data. I was unable to detect any correlation between the CMSA estimate of female HSC abundance and the estimated number of spawning females on coastal beaches in Delaware Bay. Finally, the estimate of HSC recruitment (which determines harvest resilience in the projection models) used in the revised ARM incorporates questionable (and highly inflated) estimates from a four-year period during which direct information on HSC recruitment was not available. Taken together, the above concerns strongly suggest the ARM model is not a valid tool for managing risk to the HSC population in Delaware Bay.

My final concerns are more general. First, I suggest that both the REKN and HSC models should be subjected to more rigorous evaluation, including tests for whether these models are able to outperform "null model" benchmarks that assume no useful learned knowledge about population dynamics and population response to harvest and harvest management. Ecological null models provide a useful benchmark for gauging the degree to which knowledge is accrued through the adaptive management process, and a mechanism for keeping modelers and managers "honest" by acknowledging an incomplete or inadequate understanding of the systems they are charged with managing. My analysis demonstrates that the CMSA model fails to outperform the simplest statistical null model for at least one data source. Finally, I was not provided access with much of the data and code used to generate the models used in the revised ARM (except for the CMSA code and data). Given the concerns that are apparent based on analysis of the limited code and data made available to date, it seems prudent to, at a minimum, delay implementation of this framework until the public and outside experts have had adequate time to scrutinize the statistical and simulation models that play such a central role in this proposed decision-making framework.

Despite the lack of transparency, I was able to run several informative re-analyses and scenario tests with the information provided in the ARM report and supplement, and with the CMSA code and data. Based on my analysis, there is sufficient evidence to conclude that the ARM framework is not useful for assessing the resilience of the HSC population to harvest pressures, nor for managing risk to the REKN population due to HSC harvest.

Referenced literature:

Abrams, P. A., & Ginzburg, L. R. (2000). The nature of predation: prey dependent, ratio dependent or neither?. Trends in Ecology & Evolution, 15(8), 337-341.

Araújo, M. B., & Rahbek, C. (2006). How does climate change affect biodiversity?. Science, 313(5792), 1396-1397.

Atlantic States Marine Fisheries Commission (ASMFC). 2021. Revision to the Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Inclusive of Red Knot Conservation and Peer Review Report. Arlington, VA. 302 pp. http://www.asmfc.org/species/horseshoe-crab

Dietze, M. C. (2017). Ecological forecasting. Princeton University Press.

Goodman, D. (2002). Predictive Bayesian population viability analysis: a logic for listing criteria, delisting criteria, and recovery plans. Population viability analysis, 447, 454.

Karpanty, S. M., Fraser, J. D., Berkson, J., Niles, L. J., Dey, A., & Smith, E. P. (2006). Horseshoe crab eggs determine red knot distribution in Delaware Bay. The Journal of wildlife management, 70(6), 1704-1710.

Karpanty, S. M., Cohen, J., Fraser, J. D., & Berkson, J. (2011). Sufficiency of horseshoe crab eggs for red knots during spring migration stopover in Delaware Bay USA. The Journal of wildlife management, 75(5), 984-994.

Kéry, M., & Schaub, M. (2011). Bayesian population analysis using WinBUGS: a hierarchical perspective. Academic Press.

Koons, D. N., Riecke, T. V., Boomer, G. S., Sedinger, B. S., Sedinger, J. S., Williams, P. J., & Arnold, T. W. (2022). A niche for null models in adaptive resource management. Ecology and evolution, 12(1), e8541.

Link, W. A., & Nichols, J. D. (1994). On the importance of sampling variance to investigations of temporal variation in animal population size. Oikos, 539-544.

Lovich, J. E., Ennen, J. R., Yackulic, C. B., Meyer-Wilkins, K., Agha, M., Loughran, C., ... & Madrak, S. (2015). Not putting all their eggs in one basket: bet-hedging despite extraordinary annual reproductive output of desert tortoises. Biological Journal of the Linnean Society, 115(2), 399-410.

McGowan, C. P., Runge, M. C., & Larson, M. A. (2011). Incorporating parametric uncertainty into population viability analysis models. Biological Conservation, 144(5), 1400-1408.

Midwood, J. D., Cairns, N. A., Stoot, L. J., Cooke, S. J., & Blouin-Demers, G. (2015). Bycatch mortality can cause extirpation in four freshwater turtle species. Aquatic Conservation: Marine and Freshwater Ecosystems, 25(1), 71-80.

Nichols, J. D., Runge, M. C., Johnson, F. A., & Williams, B. K. (2007). Adaptive harvest management of North American waterfowl populations: a brief history and future prospects. Journal of Ornithology, 148(2), 343-349.

Niles, L. J., Bart, J., Sitters, H. P., Dey, A. D., Clark, K. E., Atkinson, P. W., ... & Veitch, C. R. (2009). Effects of horseshoe crab harvest in Delaware Bay on red knots: are harvest restrictions working?. BioScience, 59(2), 153-164.

Radosavljevic, A., & Anderson, R. P. (2014). Making better Maxent models of species distributions: complexity, overfitting and evaluation. Journal of biogeography, 41(4), 629-643.

Regan, H. M., Colyvan, M., & Burgman, M. A. (2002). A taxonomy and treatment of uncertainty for ecology and conservation biology. Ecological applications, 12(2), 618-628.

Riecke, T. V., Williams, P. J., Behnke, T. L., Gibson, D., Leach, A. G., Sedinger, B. S., ... & Sedinger, J. S. (2019). Integrated population models: model assumptions and inference. Methods in Ecology and Evolution, 10(7), 1072-1082.

Simmons, J. P., Nelson, L. D., & Simonsohn, U. (2016). False-positive psychology: undisclosed flexibility in data collection and analysis allows presenting anything as significant.

Tucker, A. (2019). Stopover ecology and population dynamics of migratory shorebirds. Dissertation. Auburn University.

Tucker, A. M., McGowan, C. P., Lyons, J. E., DeRose-Wilson, A., & Clark, N. A. (2021). Species-specific demographic and behavioral responses to food availability during migratory stopover. Population Ecology, 64(1), 19-34.

USFWS 2014. Endangered and Threatened Wildlife and Plants; Threatened Species Status for the Rufa Red Knot. Federal Register / Vol. 79, No. 238

USFWS 2021. Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for Rufa Red Knot (*Calidris canutus rufa*). Federal Register / Vol. 86, No. 133

Williams, B. K. (2011). Resolving structural uncertainty in natural resources management using POMDP approaches. Ecological Modelling, 222(5), 1092-1102.

EXPERT REPORT

Romuald N. Lipcius, Ph.D.

29 September 2022

Contents

1 Scope of Work

I was asked by representatives of EARTHJUSTICE to evaluate the Atlantic States Marine Fisheries Commission's Report and Supplemental Report to the 2021 Revision to the Adaptive Resource Management (ARM) Framework dealing with horseshoe crab (*Limulus polyphemus*) fishery management and implications for red knot (*Calidris canutus*) conservation. The red knot (RK hereafter) has been listed as "threatened" under the Endangered Species Act, and relies on horseshoe crab eggs buried along beaches of Delaware Bay to feed as it migrates along North and South America. The conclusions in the ARM report relate to an amendment proposed through the Atlantic States Marine Fisheries Commission (ASMFC) that would likely allow female horseshoe crab (HSC hereafter) harvest in Delaware Bay for the first time since 2012 and thereby potentially reduce food provisions (HSC eggs) needed by migrating RK. My primary goal is to evaluate the evidence in favor of the amendment objectively and determine if the amendment is justified.

In forming my opinions, I reviewed and considered various data sources regarding the HSC fishery and RK conservation along the Mid-Atlantic coast, with emphasis on Delaware Bay. My opinions are also based on my extensive experience conducting research and providing technical advice on fishery management and conservation of various marine species (see Section 8). My compensation is not contingent upon the conclusions or outcome of my review.

2 Summary Opinion

Based on my analysis and my expertise in conservation, fisheries and fishery management, I conclude to a reasonable degree of scientific certainty that:

The proposed amendment that would allow harvest of female horseshoe crabs is not justified by the available scientific evidence, due to various *risk-prone* decisions and assumptions that underlie the Adaptive Resource Management framework and model. The proposed amendment thereby poses a significant risk both to the Horseshoe Crab population and Red Knot recovery.

3 Abbreviations and Definitions

ARM: Adaptive Resource Management framework
HSC: Horseshoe Crab (*Limulus polyphemus*)
RK: Red Knot (*Calidris canutus*)
VTS: Virginia Tech HSC survey
DES: Delaware HSC survey
NJS: New Jersey HSC survey
Risk-prone: Conservation or management actions based on overly optimistic assumptions about the status of a population. The assumptions may be about data sources, observations or data, and often involve ignoring information to the contrary of optimistic conclusions about population status. For endangered or threatened species, a risk-averse, rather than risk-prone, strategy based on the precautionary principle is critical for population recovery, population conservation, and sustainable resource management.

4 Opinions

The following specific opinions describe various lines of evidence indicating that the HSC population is not in a healthy state and has not fully recovered despite a prohibition on female harvest since 2012. The different lines of evidence are effectively "red flags" leading to the conclusion that the current and proposed management strategies are risk-prone, such that harvest restrictions should not be relaxed at present. To the contrary, further management actions or improvements to the current management plan are necessary to stimulate HSC recovery. Furthermore, due to the lack of *substantial* improvement of the HSC spawning stock (i.e. mature females), the existing HSC management strategy has not significantly enhanced food availability for the threatened RK and therefore its recovery. A shift to risk-averse management based on the precautionary principle is essential for HSC and RK recovery.

4.1 Low Newly Mature Female, Recruit and Spawning HSC Abundance

An expectation from the female harvest prohibition is a rebound in young mature females and recruitment of immature males and females into the HSC population. In 2019 and 2020, abundance of newly mature females was at an all-time low; recruitment of immature females and males was extremely low and unchanged since before the prohibition; and female abundance in the spawning survey dropped sharply in 2019. These are warning signs that the HSC population has not fully recovered and may even be declining. Thus, female harvest should not be raised.

4.2 Smaller Body Size of Mature Female HSC

An expectation of the female harvest prohibition is that female body size would increase, given constant recruitment, which is a typical response in fisheries worldwide when harvest pressure on older, larger females is reduced. On the contrary, mean size of mature female HSC was smallest in the last 3 years (2018 to 2020) and of newly mature females in the last 2 years of the time series from 2002 to 2020, despite the prohibition on female harvest since 2012. These data are inconsistent with the previous expectation and the premise that the female segment of the HSC population has rebounded.

4.3 Loss of Large Mature Female HSC and Lower Egg Production

Population egg production is a function of spawning stock (= mature females) biomass (i.e. weight). Hence, changes in size distribution of mature females will affect total egg production, particularly the loss of large HSC females which contribute disproportionately to total egg production. Consequently, using only HSC abundance to estimate reproductive output and egg production is ignoring main biological drivers of population egg production–size structure and biomass–of the HSC spawning stock. Size distribution of mature females has shifted to smaller females. Abundance of females larger than 300 mm prosomal width (i.e. females with the highest egg production) has dropped recently, particularly from 2018 to 2020. Recent low recruitment means that smaller mature females are not compensating for the loss of larger mature females. Consequently, total reproductive (egg) output has likely not improved, which hampers recovery of the HSC and RK populations.

4.4 HSC Sex Ratio

When HSC harvest has been restricted to males, the ratio of males to females should have decreased. In contrast, male:female sex ratios have actually increased from 1999 to 2019. This represents another warning sign that the current management strategy has not been effective, that population dynamics are not well understood, and that harvest of females should not be increased.

4.5 High Mature Female HSC Mortality

The combination of discard mortality and bait harvest mortality for females has increased substantially in recent years and is comparable to levels before the prohibition. Assuming that the prohibition has worked is therefore risk-prone. The collective bait harvest and discard mortality is not being controlled effectively and inhibits HSC recovery.

4.6 Reliance on HSC Density as the Indicator of HSC Population Status

Female density (catch per unit area) is a primary variable used in HSC surveys and the ARM framework model. Reliance solely on HSC density or abundance ignores other variables that commonly produce warning signs about the status of a stock, such as female size, female size-frequency distribution, spawning stock biomass and female:male sex ratio. These variables are often more sensitive indicators of problems in a population, meaning that they can detect problems more effectively than abundance estimates. Hence, the current management strategy is risk-prone by ignoring these more sensitive indicators.

4.7 Low HSC Egg Density

Recent data indicate that HSC egg densities in HSC spawning habitats and RK feeding grounds remain an order of magnitude below densities when RK and HSC were relatively abundant. The ARM process has decided to ignore patterns in HSC egg density because of methodological "uncertainty" in the data. Under conditions where a population is not in danger, this may be acceptable, but absolutely not when it represents a potential warning sign about a population in danger, such as the RK. Thus, lack of use of HSC egg density data, as a proxy for RK food availability, amounts to a failure to incorporate all available scientific information into the analysis to guide management decisions in a risk-averse manner.

4.8 Lack of Correlation of HSC Surveys

Data from the DES and NJS of HSC in Delaware Bay are assumed to be correlated with the VTS and used to fill in survey gaps in the VTS. Survey data when all three surveys were conducted are not correlated, and data from the DES and NJS were relatively higher than that from VTS. These results lead to an overestimation of HSC abundance during VTS gap years, which is indicative of a risk-prone assumption.

4.9 Degraded HSC Spawning Habitat and RK Feeding Grounds

Spawning habitat (e.g. beaches) for HSC and feeding grounds for RK have been lost throughout the stopover range of RK in the Mid-Atlantic. Loss of habitat is an additional stress that demands risk-averse management of mortality sources (e.g. fishing) which management can control. There may be variables that are beyond ASMFC's control, but that means they should be more precautionary with variables they can control, and it's certainly not a valid basis for ignoring warning signs like reduced HSC egg density and abundance.

5 Evidence for Opinions

The VTS is based on robust experimental design principles, and is the only spatially widespread survey that includes the coastal zone along Delaware and New Jersey, as well as Delaware Bay. In addition, the VTS collects much more comprehensive demographic data, which enables more types of analysis. Thus, the VTS serves as a robust and independent measure of HSC population status. The remainder of the analysis therefore focuses on data from the VTS and other published information on horseshoe crabs and the red knot. All analyses were conducted using the statistical software package R, version 4.1.2 (2021).

5.1 Low Newly Mature Female, Recruit and Spawning HSC Abundance

An expectation from the female harvest prohibition is a rebound in young mature females and recruitment of immature males and females into the HSC population. In 2019 and 2020, abundance of newly mature females was at an all-time low; recruitment of immature females and males was extremely low and unchanged since before the prohibition; and female abundance in the spawning survey dropped sharply in 2019. These are warning signs that the HSC population has not fully recovered and that female harvest should not be raised.

Data from the VTS on abundance of newly mature female HSC in 2019 and 2020 were at the lowest levels in the time series since 2002, indicating low influx of young mature females into the spawning stock (Figure 1). Similarly, abundance of immature female and male HSC, representing future recruitment to the adult segment and spawning stock of the population, were at extremely low levels and unchanged from those before 2013 (Figure 1). Moreover, female abundance in the Delaware Bay Horseshoe Crab Spawning Survey dropped sharply in 2019 (Figure 2), despite the prohibition of female harvest since 2012.

5.2 Smaller Body Size of Mature Female HSC

An expectation of the female harvest prohibition is that female body size would increase, given constant recruitment, which is a typical response in fisheries worldwide when harvest pressure on older, larger females is reduced (Beverton and Holt, 1956; Gedamke and Hoenig, 2006). On the contrary, mean size of mature female HSC was smallest in the last 3 years (2018 to 2020) and of newly mature females in the last 2 years of the time series from 2002 to 2020, despite the prohibition on female harvest since 2012. These data are inconsistent with the previous expectation and the premise that the female segment of the HSC population has rebounded.

VTS data were examined in two ways (mean and mode of size-frequency histograms) to evaluate this expectation. First, the time series of mean size in the VTS (Figure 3) indicated that mean sizes of mature female HSC and of newly mature females from 2016 to 2020 were the smallest in the time series from 2002 to 2020, despite the prohibition of female harvest since 2012.

Given that the mean of a sample can be influenced by outliers, the size data were also examined using a non-parametric statistic, the mode. The median could not be calculated because the raw data were unavailable for this analysis. The mode for each year was visually estimated from the size-frequency histograms of mature females (Appendix Figures 10 and 11). As with the mean, modal sizes of mature females from 2018 to 2020 were the lowest in the time series (Figure 4). In contrast, modal sizes of mature males were relatively unchanged (Figure 4).

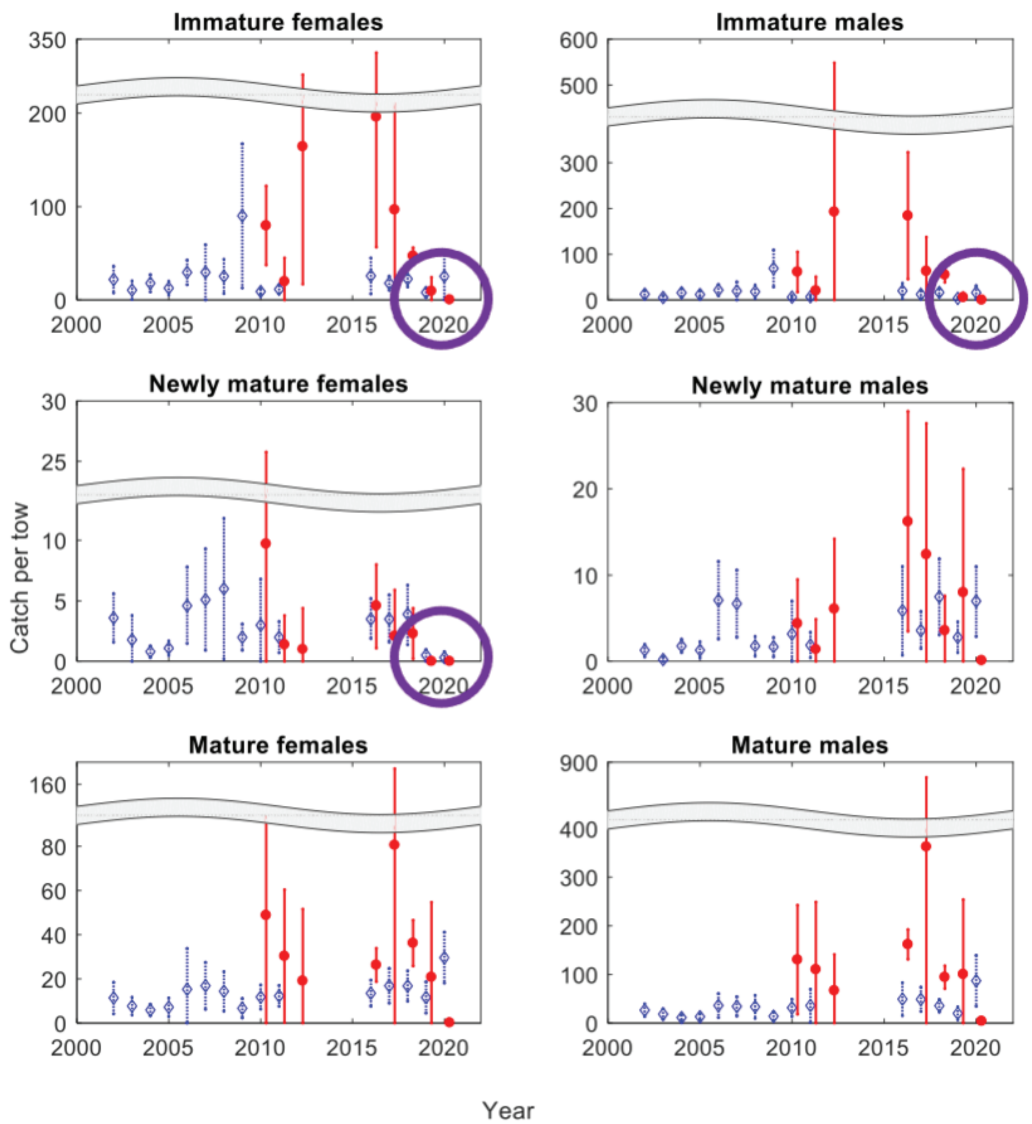

Figure 1: Densities of HSC males and females from Figure 3 of the VTS report (Hallerman and Jiao, 2021). Purple circles have been added to highlight the warning signs that the HSC population has not fully recovered.

Mean body size of spawning females could decrease over time if there was high recruitment of smaller, newly mature females shifting down the average size. However, the opposite (weak recruitment) appears to be the case, as described in section 5.1.

5.3 Loss of Large Mature Female HSC and Lower Egg Production

Population egg production is a function of spawning stock (= mature females) biomass (i.e. weight). Hence, changes in size distribution of mature females will affect total egg production, particularly large HSC females which contribute disproportionately to total egg production. Consequently, using only HSC abundance to estimate reproductive output and egg production is ignoring the main biological drivers of population egg production–size structure and biomass–of the HSC spawning stock. Size distribution of mature females has shifted to smaller females. Abundance of females larger than 300 mm prosomal width (i.e. females with the highest egg production) has dropped recently,

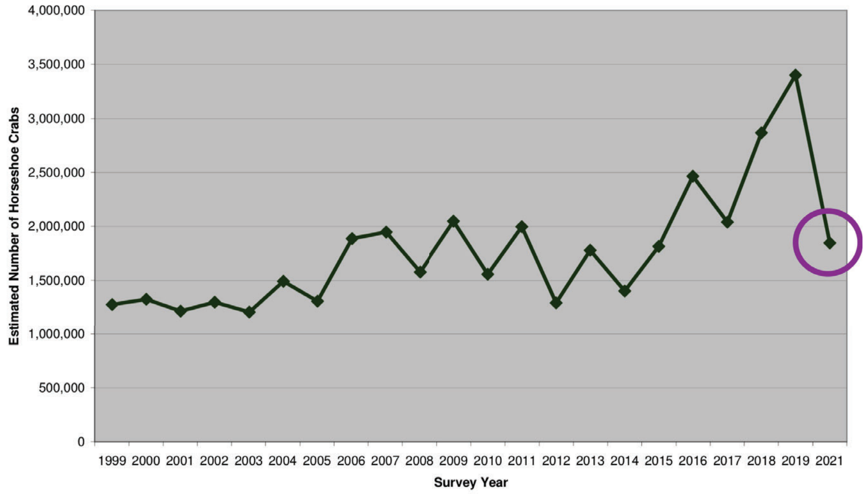

Figure 2: Spawning horseshoe crab survey data, highlighting low abundance of spawning horseshoe crabs in 2021 Swann and Hall (2019).

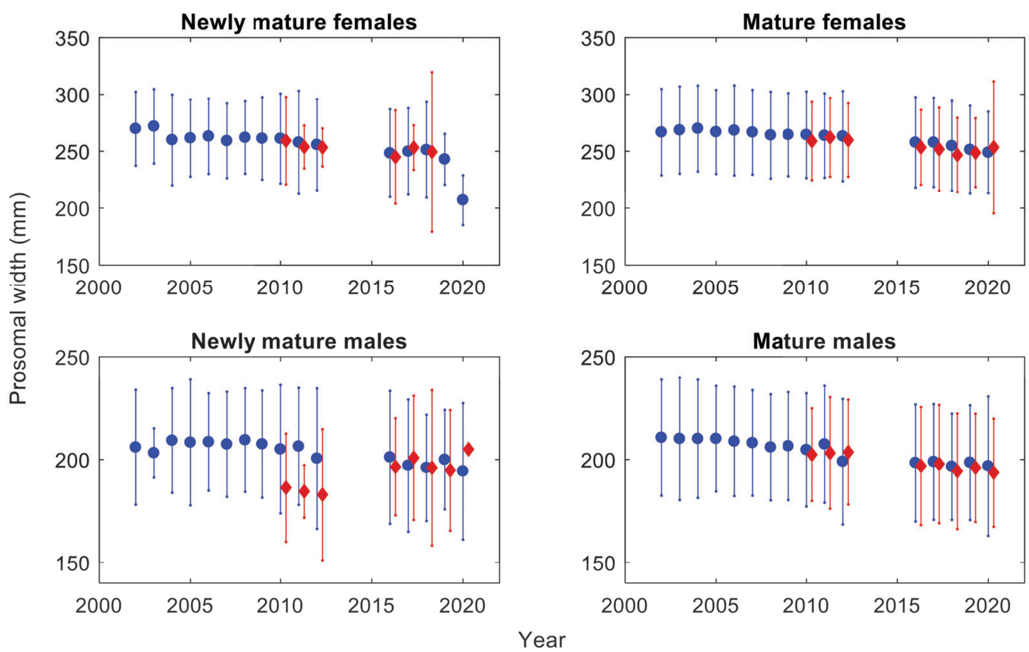

Figure 3: Mean sizes of newly mature and mature female and male horseshoe crabs over 2010 to 2020, with gap years from 2012 to 2015, from the VT survey in the coastal Delaware Bay area (Hallerman and Jiao, 2021).

particularly from 2018 to 2020. Recent low recruitment means that smaller mature females are not compensating for the loss of larger mature females. Consequently, total reproductive (egg) output has likely not improved, which hampers recovery of the HSC and RK populations.

For an individual HSC female, her egg production is directly proportional to individual weight, which is an exponential (not linear) function of prosomal width (Figure 5), as in other species of horseshoe crabs (Chatterji, 1995) and marine species in general (Barneche et al., 2018).

Changes in size distribution of mature females, particularly large HSC females which contribute disproportionately to total egg production due to the exponential increase in weight with size (Figure 6), will reduce population egg production. This was validated for an HSC population by

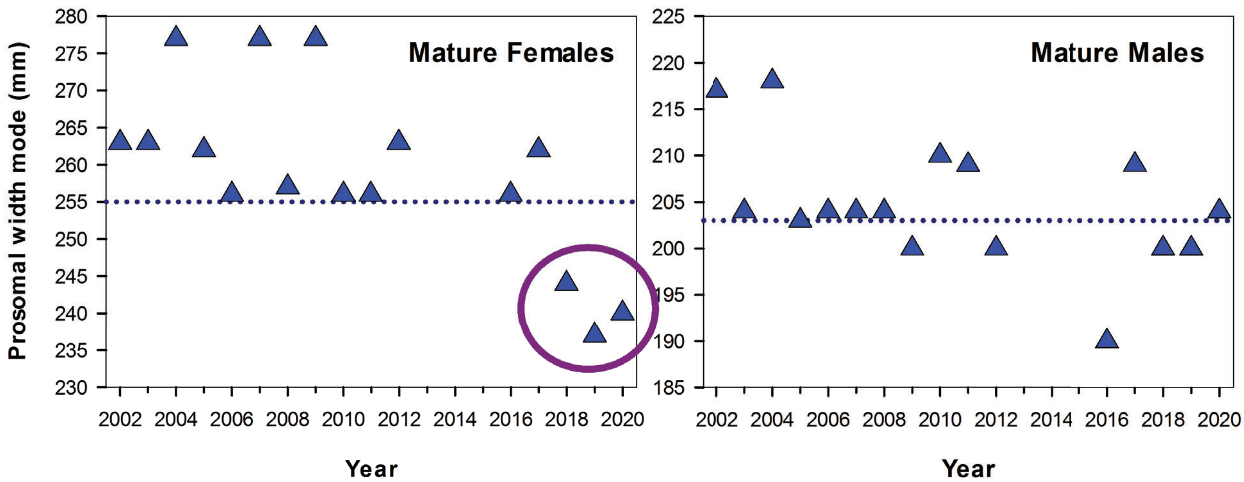

Figure 4: Size modes of mature female and male horseshoe crabs over 2002 to 2020 (gap years from 2013 to 2015) from the VTS in the coastal Delaware Bay area. Mode sizes were estimated from Figures 10 and 11.

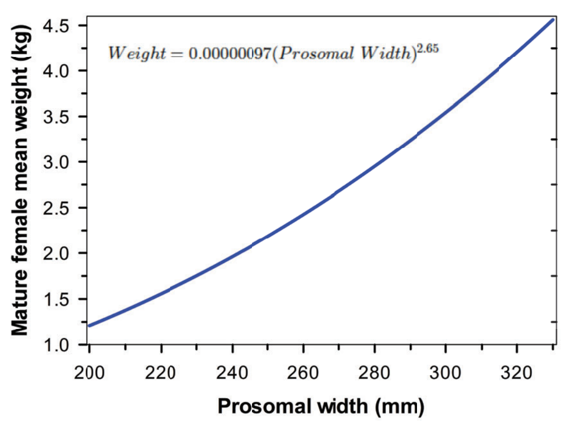

Figure 5: Exponential relationship between mature female HSC weight (kg) and prosomal width (mm) derived from Table 3 in Graham et al. (2009).

Leschen et al. (2006), who concluded that "larger females held a larger number of eggs (63,500) than smaller females (14,500) [and] laid a higher percentage of the eggs they contained. Thus they not only contain more eggs, but are more effective at laying them as well."

Using only HSC abundance to estimate reproductive output and egg production is ignoring the main biological drivers of population egg production–size structure and biomass (weight)–of the HSC spawning stock. Abundance is a reliable proxy of HSC egg production only if size structure of the spawning stock is unchanged over time, which is not the situation with the HSC spawning stock. Size distribution of mature females has shifted to smaller females (Figures 3 and 4), and recruitment does not account for the recent shift in size distribution because abundance of newly mature and immature females in the past few years has been well below average (Figure 1).

Abundance of females larger than 300 mm prosomal width (i.e. females with the highest egg production) has dropped recently, particularly from 2018 to 2020 (Appendix Figures 10 and 11), which has substantially reduced egg production. Note in Figures 10 and 11 that females larger than 300 mm prosomal width were apparent in 6 of 8 years from 2002 to 2009 (Figure 10), but only in 1 of 8 years from 2010 to 2020 (Figure 11). Moreover, the recent low recruitment means that

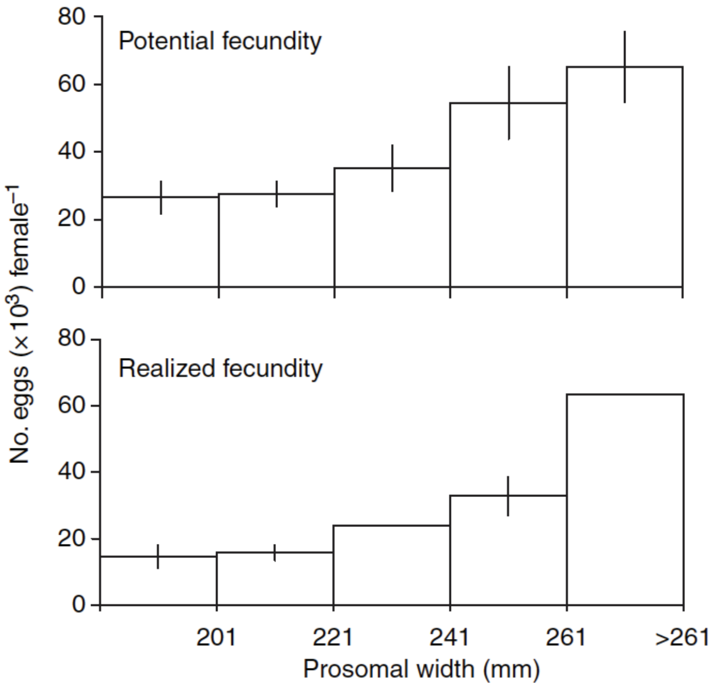

Figure 6: Positive relationship between HSC female fecundity and prosomal width (Leschen et al., 2006).

smaller mature females are not compensating for the loss of larger mature females. Consequently, total reproductive (egg) output has likely not improved, which hampers recovery of the HSC and RK populations.

5.4 HSC Sex Ratio

When HSC harvest has been restricted to males during the prohibition, the ratio of males to females should have decreased. In contrast, male:female sex ratios have actually increased from 1999 to 2019. This represents another warning sign that the current management strategy has not been effective, and that harvest of females should not be increased.

To assess HSC sex ratio over time, particularly since the prohibition on female harvest, I examined sex ratio data from the 2019 Delaware Bay Horseshoe Crab Spawning Survey, Table 5 (Figure 7). The time series shows an initial drop in the ratio of males to females during 2013, shortly after the prohibition on female harvest began. However, the ratio of males to females has increased since 2014 and even reached the highest ratios in the time series during 2018 and 2019.

5.5 High Mature Female HSC Mortality

The combination of discard mortality and bait harvest mortality for females has increased substantially in recent years and is comparable to levels before the prohibition. Assuming that the prohibition has worked is therefore risk-prone. The collective bait harvest and discard mortality is not being controlled effectively and inhibits HSC recovery.

Total mortality of females due to the bait fishery and its discards has increased substantially in recent years and is comparable to levels before the prohibition (Figure 8). Note that there is still a small amount of direct mortality due to the bait fishery (Figure 8), possibly due to inaccurate identification of female HSC by fishers. Thus, the prohibition on female harvest has not been

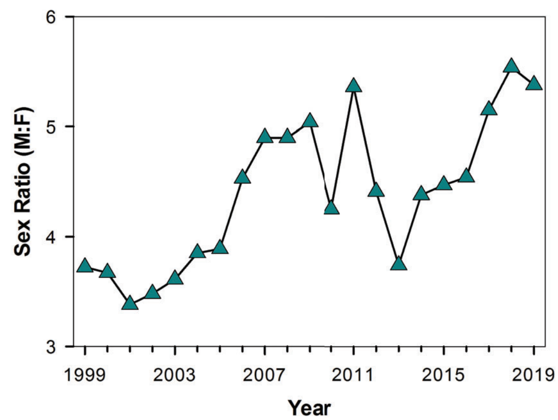

Figure 7: Sex ratio from the Delaware Bay Horseshoe Crab Spawning Survey Swann and Hall (2019).

effective in reducing female HSC mortality, and any further increase in female harvest is risk-prone and a danger to the HSC population and RK recovery.

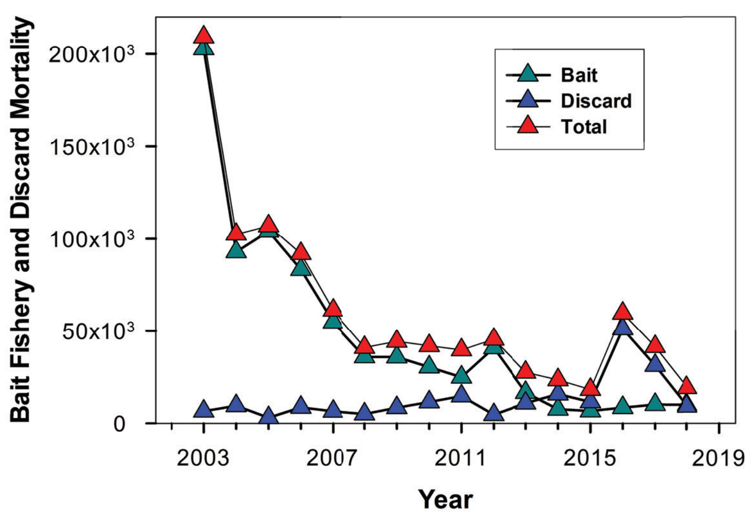

Figure 8: HSC mortality due to the bait fishery and discards (Adaptive Resource Management Subcommittee, 2022).

5.6 Reliance on HSC Density as the Indicator of HSC Population Status

Female density (catch per unit area) is a primary variable used in HSC surveys and the ARM framework model. Reliance solely on HSC density or abundance ignores other variables that commonly produce warning signs about the status of a stock, such as female size, female size-frequency distribution, spawning stock biomass and female:male sex ratio (Free et al., 2020; Punt et al., 2020). These variables are often more sensitive indicators of problems in a population, meaning that they can detect problems more effectively than abundance estimates alone. Hence, the current management strategy is risk-prone by ignoring these more sensitive indicators.

5.7 Low HSC Egg Density

Recent data indicate that HSC egg densities in HSC spawning habitats and RK feeding grounds remain an order of magnitude below densities when RK and HSC were relatively abundant. The ARM process has decided to ignore patterns in HSC egg density because of methodological "uncertainty" in the data. Under conditions where a population is not in danger, this may be acceptable, but absolutely not when it represents a potential warning sign about a population in danger, such as the RK. Thus, lack of use of HSC egg density data, as a proxy for RK food availability, amounts to a failure to incorporate all available scientific information into the analysis to guide management decisions in a risk-averse manner.

To assess changes in HSC egg density over time, I compared data for egg density before the peak of HSC harvest during 1985, 1986, 1988 and 1990 with data after the peak of HSC harvest from 1999 to 2021 (Smith et al., 2022). While the time series from 1999 to 2021 shows egg density increasing from an average of about 3,000 eggs per m^2 in 2000 to 9,000 eggs per m^2 in 2021 (Figure 6), egg density remains over an order of magnitude lower than that before the peak of HSC harvest during 1985 to 1990 (Figure 6).

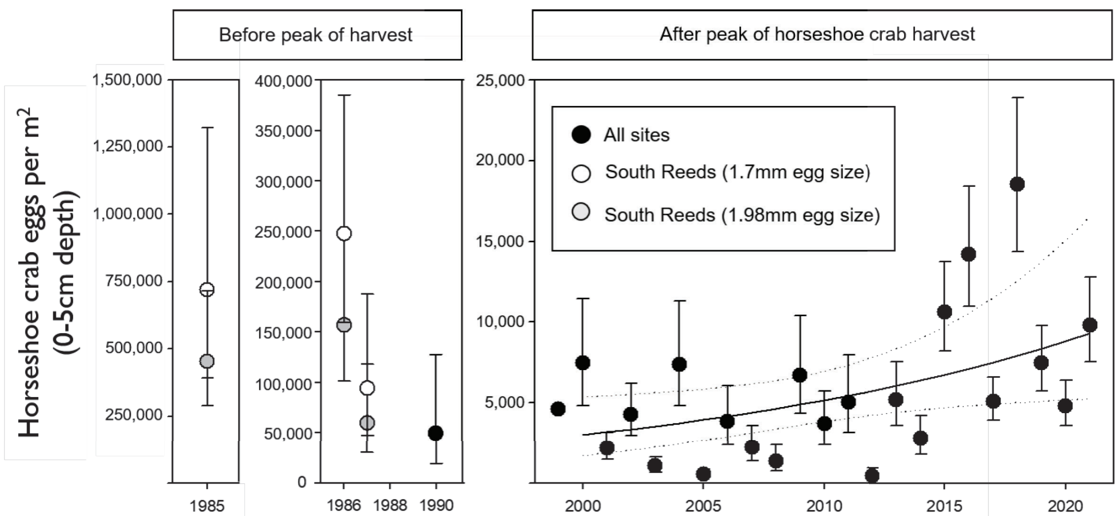

Figure 9: HSC egg density from spawning beaches, emphasizing the order of magnitude lower egg densities in recent years relative to historical levels in the spawning beaches. Note the different range of values in the left and right graphs. Figure from Smith et al. (2022).

5.8 Lack of Correlation of HSC Surveys

Data from the DES and NJS of HSC in Delaware Bay are assumed to be correlated with the VTS and used to fill in survey gaps in the VTS. Survey data when all three surveys were conducted are not correlated, and data from the DES and NJS were relatively higher than that from VTS. These results lead to an overestimation of HSC abundance during VTS gap years, which is indicative of a risk-prone assumption.

To evaluate the assumption of coherence between the three surveys, and justification for use of the DES and NJS in the four years when VTS data were unavailable, correlation between the three surveys was investigated. Data used in the analysis are those in Tables 1 and 2 from Adaptive Resource Management Subcommittee (2022) for indices VTS Multiparous Females, DES Adult and

NJS Ocean Trawl from 2003 to 2012, when indices were available for all three surveys prior to the 2012 prohibition.

Data for female and male HSC abundance from the three surveys were not correlated (Table 1), such that the use of data from two surveys (NJS and DES) to estimate data from the VTS survey during gap years when the VTS did not collect data is invalid. Furthermore, the NJS and DES produced data that were relatively higher than data from the VTS (positive intercepts in Table 1), indicating that the replacement data for the VTS using DES and NJS overestimate HSC abundance from the VTS.

Table 1: Correlation analysis for mature female HSC from VTS, NJS and DES.

Parameter	Estimate	Standard Error	t value	P
Females				
DES as a function of VTS: $r^2 = 0.01$				
Intercept	0.23	0.37	0.61	0.56
Slope	0.02	0.07	0.28	0.79
NJS as a function of VTS: $r^2 = 0.001$				
Intercept	1.96	0.67	2.91	0.02
Slope	-0.01	0.13	-0.07	0.95
Males				
DES as a function of VTS: $r^2 = 0.12$				
Intercept	0.03	0.23	0.12	0.91
Slope	0.02	0.02	1.03	0.34
NJS as a function of VTS: $r^2 = 0.03$				
Intercept	2.25	0.71	3.15	0.02
Slope	-0.03	0.06	-0.52	0.62

5.9 Degraded HSC Spawning Habitat and RK Feeding Grounds

Spawning habitat (e.g. beaches) for HSC and feeding grounds for RK have been lost throughout the stopover range of RK in the Mid-Atlantic. Loss of habitat is an additional stress that demands risk-averse management of mortality sources (e.g. fishing) which management can control. There may be variables that are beyond ASMFC's control, but that means they should be more precautionary with variables they can control, and it's certainly not a valid basis for ignoring warning signs like reduced HSC egg density.

A major threat to horseshoe crab population involves habitat degradation and loss, and is expected to worsen in the future due to sea level rise (Botton et al., 2022). Spawning habitat loss has been significant due to various factors such as shoreline management (e.g. bulkheading), coastal disturbances and sea-level rise (Smith et al., 2017, 2020). In some cases, whole beaches have been lost (Smith et al., 2017). Given that habitat loss is not under control by ASMFC, precautionary management demands consideration of such stressors to the population by control of fishery harvest to compensate for external stressors.

5.10 Appendix Figures

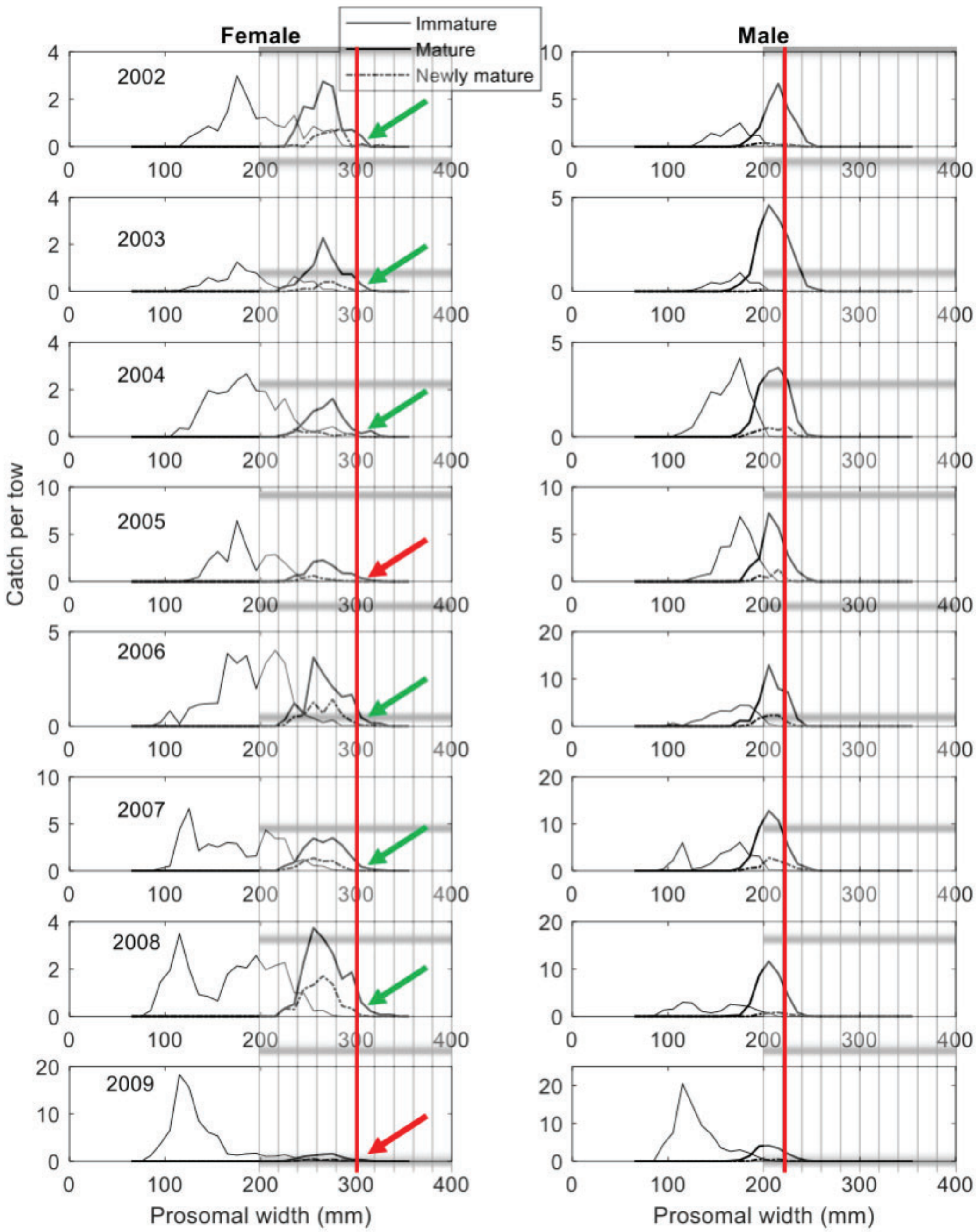

Figure 10: Size frequencies of mature female and male horseshoe crabs over 2002 to 2009 from the VT survey in the coastal Delaware Bay area (Hallerman and Jiao, 2021). Vertical red lines and grid cells were added for reference. Green arrows indicate years when mature females larger than 300 mm prosomal width were apparent, and red arrows when not.

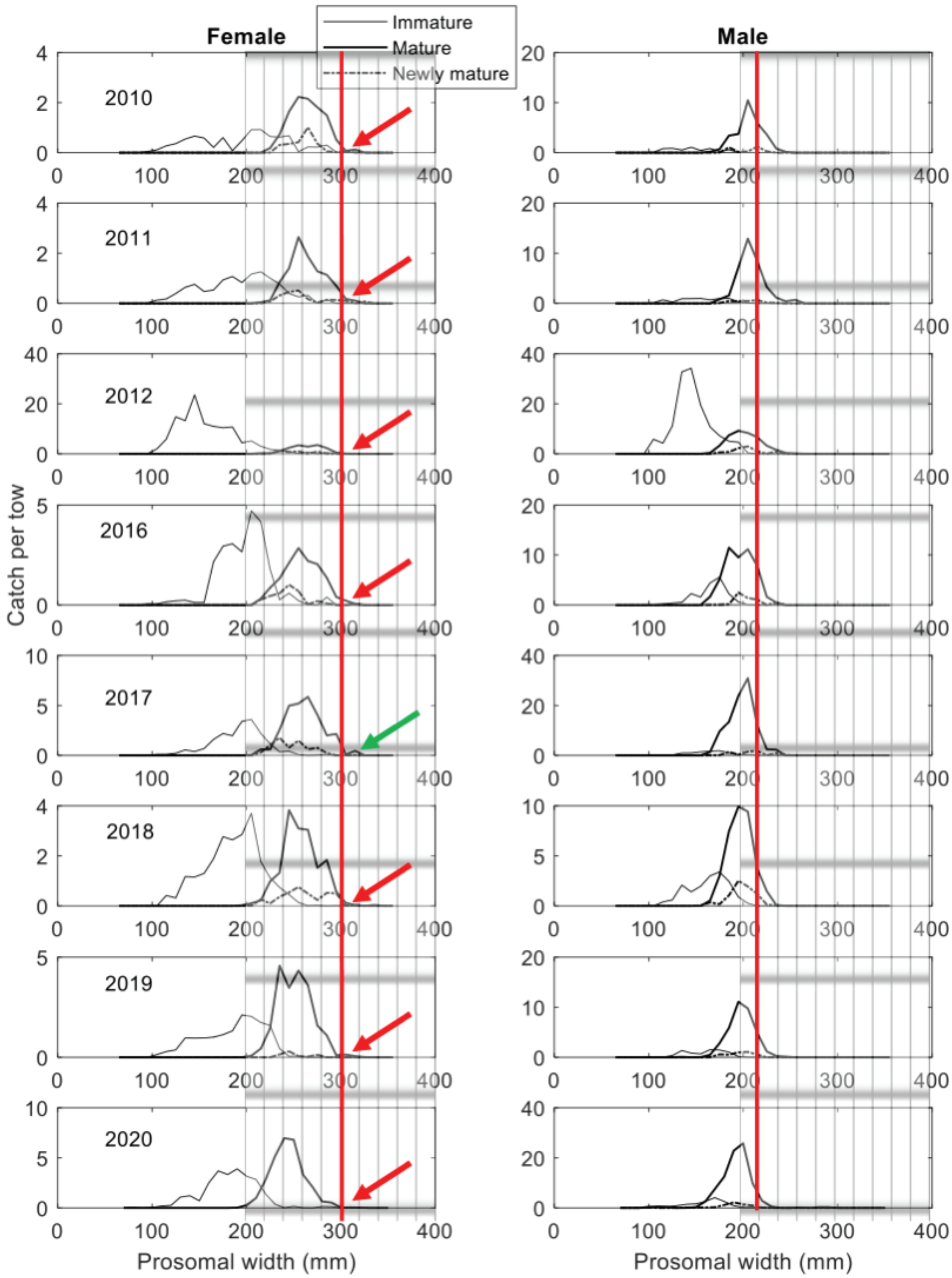

Figure 11: Size frequencies of mature female and male horseshoe crabs over 2010 to 2020, with gap years from 2013 to 2015, from the VT survey in the coastal Delaware Bay area (Hallerman and Jiao, 2021). Vertical red lines and grid cells were added for reference. Green arrows indicate years when mature females larger than 300 mm prosomal width were apparent, and red arrows when not.

6 Acknowledgements

I am extremely grateful to Dr. John Hoenig for his ideas and comments which greatly improved this report.

7 Literature Cited

Adaptive Resource Management Subcommittee (2022). 2021 revision to the adaptive resource management framework and peer review report. Technical report, Atlantic States Marine Fisheries Commission.

Barneche, D. R., Robertson, D. R., White, C. R., and Marshall, D. J. (2018). Fish reproductive-energy output increases disproportionately with body size. Science, 360(6389):642–645.

Beverton, R. and Holt, S. (1956). A review of methods for estimating mortality rate of exploited populations, with special reference to source of bias in catch sampling. Rapp. P.-V. Reun. Cons. Int. Explor. Mer., 140 (1): 67, 140:67–83.

Botton, M. L., Loveland, R. E., Munroe, D., Bushek, D., and Cooper, J. F. (2022). Identifying the major threats to American horseshoe crab populations, with emphasis on Delaware Bay. International Horseshoe Crab Conservation and Research Efforts: 2007-2020: Conservation of Horseshoe Crabs Species Globally, page 315.

Chatterji, A. (1995). Fecundity of the Indian horseshoe crab, *Tachypleus gigas* (Muller) from Balramgari (Orissa). Pakistan Journal of Marine Sciences, 4(2):127–131.

Free, C. M., Jensen, O. P., Anderson, S. C., Gutierrez, N. L., Kleisner, K. M., Longo, C., Minto, C., Osio, G. C., and Walsh, J. C. (2020). Blood from a stone: performance of catch-only methods in estimating stock biomass status. Fisheries Research, 223:105452.

Gedamke, T. and Hoenig, J. M. (2006). Estimating mortality from mean length data in nonequilibrium situations, with application to the assessment of goosefish. Transactions of the American Fisheries Society, 135(2):476–487.

Graham, L. J., Botton, M. L., Hata, D., Loveland, R. E., and Murphy, B. R. (2009). Prosomal-width-to-weight relationships in American horseshoe crabs (*Limulus polyphemus*): examining conversion factors used to estimate landings. Fishery Bulletin, 107(2):235–244.

Hallerman, E. and Jiao, Y. (2021). Results of the 2020 horseshoe crab trawl survey: Supplemental report to the 2021 revision to the adaptive resource management framework. Technical report, Virginia Polytechnic Institute and State University.

Leschen, A. S., Grady, S. P., and Valiela, I. (2006). Fecundity and spawning of the Atlantic horseshoe crab, *Limulus polyphemus*, in Pleasant Bay, Cape Cod, Massachusetts, USA. Marine Ecology, 27(1):54–65.

Punt, A. E., Tuck, G. N., Day, J., Canales, C. M., Cope, J. M., de Moor, C. L., De Oliveira, J. A., Dickey-Collas, M., Elvarsson, B. ., Haltuch, M. A., et al. (2020). When are model-based stock assessments rejected for use in management and what happens then? Fisheries Research, 224:105465.

Smith, D., Brockmann, H., Beekey, M., King, T., Millard, M., and Zaldivar-Rae, J. (2017). Conservation status of the American horseshoe crab, (*Limulus polyphemus*): a regional assessment. Rev Fish Biol Fisheries, 27:135–175.

Smith, J., Niles, L., Hafner, S., Modjeski, A., and Dillingham, T. (2020). Beach restoration improves habitat quality for American horseshoe crabs and shorebirds in the Delaware Bay, USA. Marine Ecology Progress Series, 645:91–107.

Smith, J. A. M., Dey, A., Williams, K., Diehl, T., Feigin, S., and Niles, L. J. (2022). Horseshoe crab egg availability for shorebirds in the Delaware Bay: dramatic reduction after unregulated horseshoe crab harvest and limited recovery after 20 years of management. Aquatic Conservation: Marine and Freshwater Ecosystems, in press.

Swann, B. L. and Hall, W. (2019). The 2019 Delaware Bay horseshoe crab spawning survey. Technical report, `https://www.delawarebayhscsurvey.org/survey`.

8 Qualifications & Credentials

The qualifications, experience and scientific recognition that allow me to provide an informed, expert opinion on this matter are described below. My academic and professional credentials include: Professor (2000-present), Associate Professor (1993-2000), and Assistant Professor (1986-1993) of Marine Science, Virginia Institute of Marine Science, William & Mary, Department of Fisheries Science; Senior Postdoctoral Fellow, Smithsonian Institution (1997-1999); Postdoctoral Fellow, U.S. National Research Council (1985-1986); Adjunct Professor, Anne Arundel Community College (1984-1985); Postdoctoral Fellow, Smithsonian Institution (1984-1985); and Assistant Professor, Florida A & M University (1981-1984; while Ph.D. student at FSU). I received my Ph.D. from Florida State University in 1984 (major: Biological Science; minor: Statistics).

My scientific expertise and research specialties include Marine Conservation Ecology, Fisheries Management, Mathematical Biology, Ecological Statistics, and Ecology and Management of Crustaceans and Molluscs. Over the span of my career, I have 121 publications in peer-reviewed scientific journals, numerous technical reports, and 80 research grants totaling over $20 million from agencies including the National Science Foundation, National Oceanic and Atmospheric Administration, U.S. Army Corps of Engineers, National Undersea Research Program, Department of Defense, and various others.

I have 45 years of experience with eastern oyster, blue crab, Caribbean spiny lobster, queen conch, Nassau grouper and various marine bivalves; 36 years experience as the Commonwealth of Virginia's expert on blue crab ecology and fishery management; provision of formal opinions to Virginia Marine Resources Commission, Chesapeake Bay Commission, Chesapeake Bay Stock Assessment Committee, and Chesapeake Bay Program Fisheries Goal Implementation Team; 18 years experience as scientific advisor on oyster restoration to U.S. Army Corps of Engineers, NOAA Chesapeake Bay Office, and Chesapeake Bay Program Fisheries Goal Implementation Team; 33 years as Chief Scientist of the Blue Crab Winter Dredge Survey; Co-Principal Investigator of the Blue Crab Stock Assessment in Chesapeake Bay; and member of technical teams for Gulf of Mexico and Chesapeake Bay oyster and blue crab stock assessment, conservation and restoration.

Scientific honors, recognition and awards include: (i) Coastal America Partnership Award from the Executive Office of the President of the U.S., (ii) Kavli Fellowship from U.S. National Academy of Sciences, (iii) Aldo Leopold Leadership Fellow Award, (iv) Outstanding Faculty Award for Advisory Service, Virginia Institute of Marine Science, and (v) Outstanding Faculty Award for Research, Virginia Institute of Marine Science.

From: Robert E. Rutkowski
To: info; Comments
Cc: Keith Abouchar
Subject: [External] Expert Analysis Reveals Fatally Flawed Horseshoe Crab Model Threatens Red Knots in Delaware Bay
Date: Tuesday, September 26, 2023 11:26:55 AM

Horseshoe Crab Management Board
ASMFC
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Re: Expert Analysis Reveals Fatally Flawed Horseshoe Crab Model Threatens Red Knots in Delaware Bay

Dear Members of the Horseshoe Crab Management Board:

A new technical analysis from University of Nevada, Reno Associate Professor Dr. Kevin Shoemaker finds that a computer model used by the Atlantic States Marine Fisheries Commission does not accurately represent the impacts of a horseshoe crab bait harvest in Delaware Bay. As a result of the model's intrinsic flaws, relying on it to justify management decisions would further imperil the rufa red knot, a shorebird listed as threatened under the Endangered Species Act. Citing this analysis, Earthjustice sent comments to the ASMFC on behalf of New Jersey Audubon and Defenders of Wildlife, urging it to exercise precaution when setting bait harvest quotas and to maintain the prohibition on harvesting female horseshoe crabs from Delaware Bay. At its annual meeting in October, the ASMFC will set the Delaware Bay horseshoe crab bait harvest quota for 2024.

This new analysis makes it abundantly clear that red knots remain at risk in Delaware Bay. While the ASMFC did not authorize a female crab harvest for 2023 in response to overwhelming public concern, it also approved a fatally flawed computer model that is nearly certain to recommend a substantial female harvest in future years, which could have devastating impacts. Implementing the model's recommendations would pose a profound risk of violating the Endangered Species Act.

The full adaptive resource management model was withheld from the public until the evening before the ASMFC's horseshoe crab management board approved it in November 2022. Dr. Shoemaker has since reviewed the full model, finding irremediable flaws intrinsic to its core structure and functionality. Among other deficiencies, the model fails to acknowledge the correlation between the abundance of horseshoe crabs and red knots. Despite the historical role horseshoe crab overharvest has played in the decline of red knots, the model predicts red knot abundance would increase even if all horseshoe crabs vanished from Delaware Bay. The model does not account for the number of horseshoe crab eggs on the beach—a critical food source metric that is necessary for red knot survival.

Dr. Shoemaker's review and reanalysis of the ASMFC's adaptive resource management framework makes it clear that the models used by this agency to manage horseshoe crabs must be revamped. The ASMFC's stated responsibility is to manage horseshoe crabs populations to ensure the long-term viability of red knot populations. The premise put forward by the ARM model outputs suggesting that the relationship between horseshoe crab and red knot populations are weak is an outcome of using the wrong metric to measure the relationship. Clearly, horseshoe crab eggs, which have been ignored by the ASMFC since the inception of the ARM framework, have the greatest influence on the trajectory of red knot populations.

The ASMFC has prohibited the bait harvest of female horseshoe crabs in Delaware Bay for more than a decade, but the status of both horseshoe crabs and red knots remains precarious. Instead of delivering much-needed additional protections, the ARM model's recommended harvest quotas would increase pressure on these species.

Management decisions for public resources such as horseshoe crabs must be based on verifiable science, not inaccurate assumptions only loosely tethered to reality. The ASMFC is charged with conserving Atlantic coastal fishery resources based on the best scientific information available. The ARM model, however, is too fundamentally flawed to conserve depleted horseshoe crabs and protect threatened red knots that depend on horseshoe crab eggs to survive their epic migration and successfully reproduce.

Conservation groups have repeatedly sounded the alarm over the potential of an Endangered Species Act violation on impacts to red knots if the ASMFC moves forward with a female horseshoe crab bait harvest. Red knots make one of the most epic migrations in the animal kingdom, which begins as far south as Tierra del Fuego and journeys more than 9,000 miles to their breeding grounds in the Arctic Circle. For most red knots, Delaware Bay is a critical resting point to replenish and renourish with horseshoe crab eggs that enable a rapid doubling of their body mass before they complete their journeys.

Letter:
https://earthjustice.org/wp-content/uploads/2023/09/nj-audubon-defenders-of-wildlife-2023-comments-to-hsc-board.pdf

Yours sincerely,
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Delaware Bay Horseshoe Crab Management Stakeholder Survey Report

October 2023

Sustainable and Cooperative Management of Atlantic Coastal Fisheries

Delaware Bay Management Objectives Work Group

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EXECUTIVE SUMMARY

The Atlantic States Marine Fisheries Commission (Commission) has maintained primary management authority for horseshoe crabs in state and federal waters since it adopted the Interstate Fishery Management Plan for Horseshoe Crabs (FMP) in 1998. The Delaware Bay population of horseshoe crabs has been managed under the Adaptive Resource Management (ARM) Framework since 2012. The ARM Framework considers the abundance levels of horseshoe crabs and shorebirds in determining the optimal harvest level for the Delaware Bay states of New Jersey, Delaware, Maryland, and Virginia (east of the COLREGS). Since 2013 the Horseshoe Crab Management Board (Board) has set bait harvest limits for the Delaware Bay region based on the ARM Framework recommendations.

In 2023 the Board undertook an effort to better understand stakeholder values regarding horseshoe crab management in the Delaware Bay region. This initiative was in response to widespread public concern about the adoption of the 2021 ARM Revision, which updated the ARM model to include additional data on shorebirds and horseshoe crabs and advancements in modeling software and techniques. In large part this public concern was focused on the potential for female horseshoe crab harvest under the Revised ARM and its impact on the rufa red knot, which is listed as threatened under the Endangered Species Act, and depends on horseshoe crab eggs as a major food source in the Delaware Bay during its migration.

A survey was developed by a work group of Board members from the Delaware Bay states and distributed to Delaware Bay stakeholders, including bait harvesters and dealers, fishermen who use horseshoe crab as bait, biomedical fishery and industry participants, environmental conservation groups, and researchers. The survey results reflect diverging values across stakeholder groups. Commercial industry participants indicated they still value the harvest of female horseshoe crabs, though it has not been permitted in the region since 2012. Researchers and environmental groups tended to value the protection of female horseshoe crabs and the ecological role of horseshoe crabs as a food source for shorebirds over the fishery.

The survey results will be considered by the Board to provide guidance on whether to consider future changes to horseshoe management for the Delaware Bay region.

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1. INTRODUCTION

The Delaware Bay population of horseshoe crabs has been managed under the Adaptive Resource Management (ARM) Framework since 2012 in recognition of public concern regarding the horseshoe crab population and its ecological role of horseshoe crabs in the Delaware Bay. The Framework considers the abundance levels of horseshoe crabs and shorebirds in determining the optimal harvest level for the Delaware Bay states of New Jersey, Delaware, Maryland, and Virginia (east of the COLREGS). Since 2013, the Board has annually reviewed recommended harvest levels from the ARM model, and specified harvest levels for the following year in New Jersey, Delaware, Maryland, and Virginia.

In 2021, a revision to the ARM Framework was completed. The revision updated the ARM model with an additional decade of data on shorebirds and horseshoe crabs in the Delaware Bay region, and advancements in modeling software and techniques. Changes to the ARM Framework are described in detail in the 2021 Revision to the Adaptive Resource Management Framework and Peer Review Report, and include:

- Catch multiple survey analysis (CMSA) to estimate male and female horseshoe crab population estimates using all quantifiable sources of mortality (i.e., natural mortality, bait harvest, coastwide biomedical mortality, and commercial dead discards) and several abundance indices from the Delaware Bay Region
- Integrated population model (IPM) to quantify the effects of horseshoe crab abundance on red knot survival and recruitment based on data collected in the Delaware Bay
- Transition to new modeling approach which can be implemented through readily available R software and incorporates uncertainty on all life history parameters for both horseshoe crabs and red knots
- Harvest recommendations based on a continuous scale rather than discrete harvest packages as in the previous Framework
- Female harvest decoupled from the harvest of males

Following the recommendations of the ARM Revision independent peer review panel that endorsed the ARM Revision as the best and most current scientific information for the management of Delaware Bay horseshoe crabs, the Horseshoe Crab Management Board (Board) reviewed and accepted the ARM Framework Revision in January 2022. The Board adopted use of the ARM Revision for management under Addendum VIII, approved in November 2022. During the public comment period on Addendum VIII, there was significant public concern about the status of the red knot population in the Delaware Bay. Over 30,000 comments were submitted by the public opposing the adoption of the ARM Revision, in large part due to the fact that the revised model allowed for a limited amount of female horseshoe crab harvest by the bait fishery. In response to the widespread public concern, the Board elected to implement a zero female horseshoe crab harvest for the 2023 season, despite the 2022 ARM model run recommending a female harvest limit of 125,000 horseshoe crabs for the 2023 season.

The Board expressed interest in evaluating the current goals and objectives for the Delaware Bay horseshoe crab fishery and ecosystem, given the apparent differences in stakeholder opinions on female harvest. After reviewing information on available resources and possible approaches, in May of 2023 the Board agreed to form a work group to develop a survey that would be distributed to stakeholders including bait harvesters and dealers, biomedical fishery and industry participants, and environmental groups. The goal of the survey is to provide insight into stakeholder perspectives to help inform the Board on whether to consider future changes to horseshoe management for the Delaware Bay region.

2. METHODS

Survey Development

The Delaware Bay Management Objectives Work Group (DBMO WG) met via webinar four times between June and September 2023 to develop the survey questionnaire. The WG members identified the following overarching research questions:

- Is there demand for harvest of female horseshoe crabs?
- Under what conditions would stakeholders be comfortable allowing female harvest?
- What management goals for the Delaware Bay region are important to stakeholders?
- Should the Board consider changes to the management program for setting Delaware Bay bait harvest specifications?

A survey questionnaire was developed to provide insight into these research questions. The questionnaire was reviewed by an external social science researcher to identify potential sources of bias and recommend changes. The final survey was created using online SurveyMonkey software. Survey logic was incorporated into the survey design to present certain questions to a respondent based on a previous response. Specifically, one set of questions was only administered to those who indicated their field of work was commercial fisheries. A copy of the final survey questionnaire is provided in Appendix A.

Survey Dissemination

This survey effort was aimed at better understanding stakeholder values regarding the Delaware Bay horseshoe crab fishery and population; therefore, the survey participants were limited to stakeholders from the Delaware Bay region. The DBMO WG aimed to survey individuals from various stakeholder groups with an interest in horseshoe crab management, including environmental conservation groups, commercial fishermen and dealers, biomedical industry, academics and researchers, and coastal community members.

The WG members identified specific individuals from New Jersey, Delaware, Maryland, and Virginia to participate in the survey representing the various stakeholder groups. Contacts were also collected from organizations that submitted public comments to the Management Board on Addendum VIII. A total of 107 individuals with available contact information were identified to receive the survey. Table 1 details the number of contacts provided by each state, and by stakeholder group.

Table 1. Survey contacts provided by states and stakeholder groups.

Group	Harvesters	Dealers	Other Fishermen	Environmental NGO	Biomedical	Towns	Other
#	26	4	39	25	4	3	6
State	**NJ**	**DE**	**MD**	**VA**			
#	53	15	18	17			

Using SurveyMonkey, the survey was disseminated via email to the recipients on August 22, 2023 and two reminder emails were sent to those that had not completed the survey (September 11 and 18, 2023). Each survey recipient was informed their responses would be anonymous.

3. RESULTS

Response Rate

Of the 106 individuals who received the survey invitation, 83 opened the survey (78.3%), 17 did not open the survey (16.0%), and 4 email invitations bounced (3.8%). A total of 40 responses to the survey were received, resulting in a 38% response rate.

The following sections provide the results of the survey, grouped by sets of related questions. Open-ended responses are provided in Appendix B, and additional figures are provided in Appendix C.

3.1 Questions 1-2. State of Residence and Occupation

The first two questions of the survey asked the respondents to indicate which state they lived in, and their primary field of work. The majority of respondents identified New Jersey as their state of residence (22 of 40, 55%), followed by Delaware (7, 18%), Virginia (6, 15%), and Maryland (3, 8%). One respondent each answered New York and Pennsylvania.

Of 11 possible multiple-choice options, the 40 respondents represented five occupational groups. The groups in descending order by number of respondents are: Commercial fisheries (harvesters and dealers) (21, 53%), Environmental conservation (8, 20%), Biomedical industry (4, 10%), Academia or research (4, 10%), and Unemployed or retired (3, 8%).

3.2 Questions for Harvesters and Dealers

Questions 3-7 in the survey was only administered to respondents who answered that their primary field of work is “Commercial fisheries (harvesters and dealers).” These questions were targeted at the fishing industry to better understand the makeup of the fishery and value of horseshoe crabs by sex. A total of 19 individuals responded to these questions.

Question 3. What are the horseshoe crabs that you harvest or sell used for?

The possible responses to this question were: bait, biomedical, both bait and biomedical, I do not know, and I do not harvest horseshoe crabs. Ten respondents harvest or sell horseshoe crabs for bait, five for both bait and biomedical, three do not harvest horseshoe crabs, and one does not know what the horseshoe crabs are used for. No respondents indicated that they only harvest or sell horseshoe crabs for biomedical purposes.

Question 4. Have you ever harvested or sold female horseshoe crabs for bait in the past?
The majority of respondents to this question indicated that they have harvested or sold female horseshoe crabs in the past (74%). Five responded that they have not (26%).

Question 5. How important is it to you to be able to harvest/sell female horseshoe crabs for bait in the future?
The possible responses to this question included: Not Important at All, Of Little Importance Of Average Importance, Very Important, and Absolutely Essential. Respectively, these responses were selected by 1, 1, 6, 7, and 4 individuals. The most common responses were "Very Important" (37%), "Of Average Importance (32%), and "Absolutely Essential" (21%) (Figure 1). By applying a numeric value to each of the above responses from one to five (1=Not Important at All, 5=Absolutely Essential) the average response across the 19 respondents is equal to 3.63. This indicates that on average, more commercial fishermen and dealers do think it is important to harvest/sell female horseshoe in the future than do not.

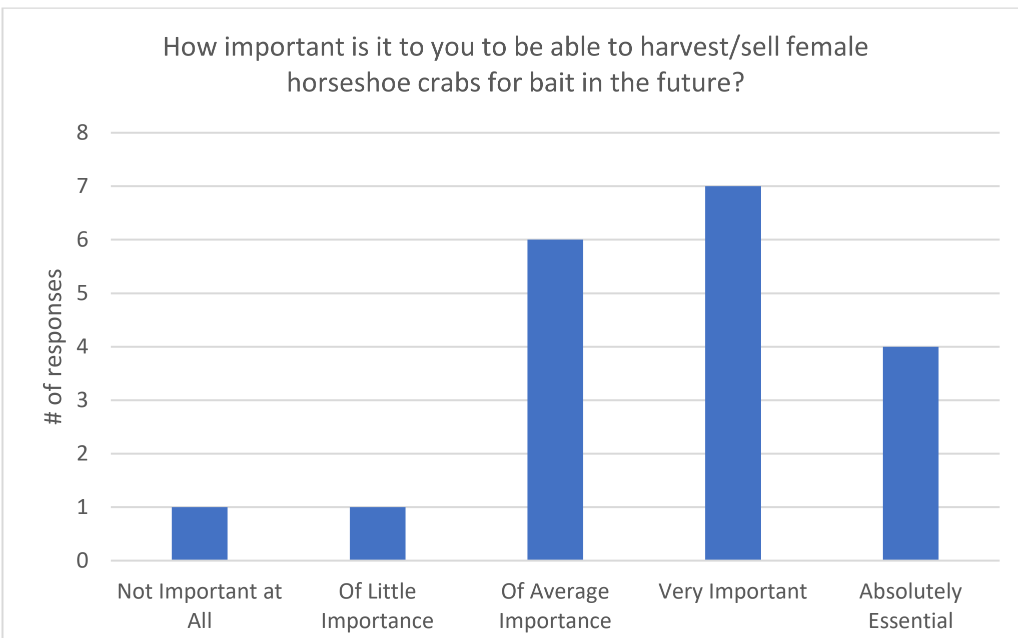

Figure 1. Importance of future female harvest.

Question 6. Value and demand for female horseshoe crabs
Question 6 asked respondents to express their level of agreement to two separate statements: "Female horseshoe crabs are worth more money than male horseshoe crabs" and "There is no market demand for female horseshoe crabs." Responses were given on a scale of 1 to 5, where 1 is "strongly agree" and 5 is "strongly disagree." The responses to each statement were significantly skewed, with the large majority in agreement that female horseshoe crabs are worth more money than males, and in disagreement that there is no market demand for female

horseshoe crabs (Figure 2). A single respondent disagreed with the first statement, and one respondent agreed with the second statement.

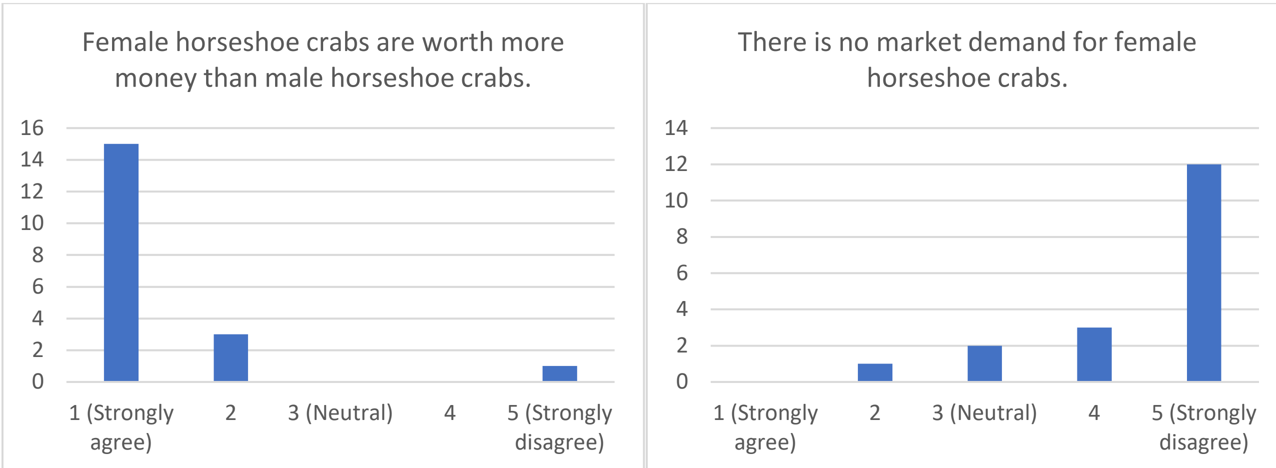

Figure 2. Perceived value (left) and demand for (right) of female horseshoe crabs.

Question 7. Preferences for female versus male harvest

Question 7 aimed to further understand the value of female harvest. Respondents were asked "Of the following two options, which do you prefer?" and only two possible choices were provided: 1) A larger overall quota of all male horseshoe crabs, or 2) A smaller overall quota including some female horseshoe crabs. The responses to this question were evenly split, with nine responses for each choice.

When the responses were broken down by state, two notable results are that all of the respondents from Virginia (n=4) prefer a smaller quota including some females, and the majority (70%) of respondents from New Jersey (n=10)—which currently has a moratorium on bait harvest—prefer a larger overall quota of all males. Table 2 provides responses by state.

Table 2. Question 7 responses by state.

State	A larger overall quota of all male horseshoe crabs	A smaller overall quota including some female horseshoe crabs
Delaware	2	1
Maryland		1
New Jersey	7	3
Virginia		4
Total	**9**	**9**

3.3 Perspectives on the Delaware Bay system

Question 8. Delaware Bay Perceptions

Question 8 was designed to elicit information on how stakeholders perceive different components of the Delaware Bay ecosystem, including the horseshoe crab population, bait fishery, and interactions with red knots. Participants were asked to respond to six statements with their level of agreement on a scale of 1 to 5, where 1 is "strongly agree" and 5 is "strongly disagree." The six statements are listed below:

A. The Delaware Bay population of horseshoe crabs is healthy.
B. The horseshoe crab bait fishery is negatively impacting the Delaware Bay population of horseshoe crabs.
C. The number of horseshoe crabs in the Delaware Bay population is increasing.
D. The horseshoe crab bait fishery is negatively impacting red knots in the Delaware Bay.
E. Fishermen should be allowed to harvest female horseshoe crabs from the Delaware Bay population if it is at a healthy level.
F. Fishermen should not be allowed to harvest male horseshoe crabs from the Delaware Bay population if it is at a healthy level.

There were 36 responses to this question. The responses to each statement tended to show bipolar trends, where the largest number of responses were divided between the two extremes, and fewer responses fell in the middle of the range. This seems to be primarily explained by diverging perspectives among different stakeholder groups (Table 3).

Table 3. Average responses to Question 8 by occupational group. Cells are color coded such that averages falling on the side of agreement are shaded in green, and averages falling on the side of disagreement are shaded in red, and averages in the neutral range are white.

Statement	Commercial fisheries (harvesters and dealers) (n=18)	Environmental conservation (n=7)	Unemployed or retired (n=3)	Biomedical industry (n=4)	Academia or research (n=4)
A	1.22	4.43	3.00	1.00	4.00
B	4.61	1.57	1.00	5.00	2.00
C	1.65	3.40	3.00	2.00	3.00
D	4.29	2.83	1.00	4.33	2.25
E	1.44	5.00	3.33	3.00	3.25
F	4.88	2.83	2.33	3.67	4.00

Question 9. Impacts on Horseshoe Crab Population

This question asked respondents to rank three issues by the level of impact they are thought to have on the Delaware Bay population of horseshoe crabs: climate change, horseshoe crab harvest, and human development of the shoreline.

There was a total of 35 responses to this question. The responses varied across occupational groups. When all responses from each occupational group were averaged, the ranking order of the three issues varied from group to group (Table 4, Figure 3). Higher average values equate to a higher level of perceived impact on the horseshoe crab population.

Table 4. Average rank value of horseshoe crab threats by occupational group. Higher value = higher impact.

Occupational Group	Average of Climate change	Average of Horseshoe crab harvest	Average of Human development of the shoreline
Academia or research (n=3)	2.00	2.25	1.75
Biomedical industry (n=4)	1.75	1.25	3.00
Commercial fisheries (harvesters and dealers) (n=18)	1.89	1.33	2.78
Environmental conservation (n=7)	1.50	2.50	2.00
Unemployed or retired (n=3)	1.67	2.00	2.33
Average of all responses (n=35)	1.80	1.69	2.51

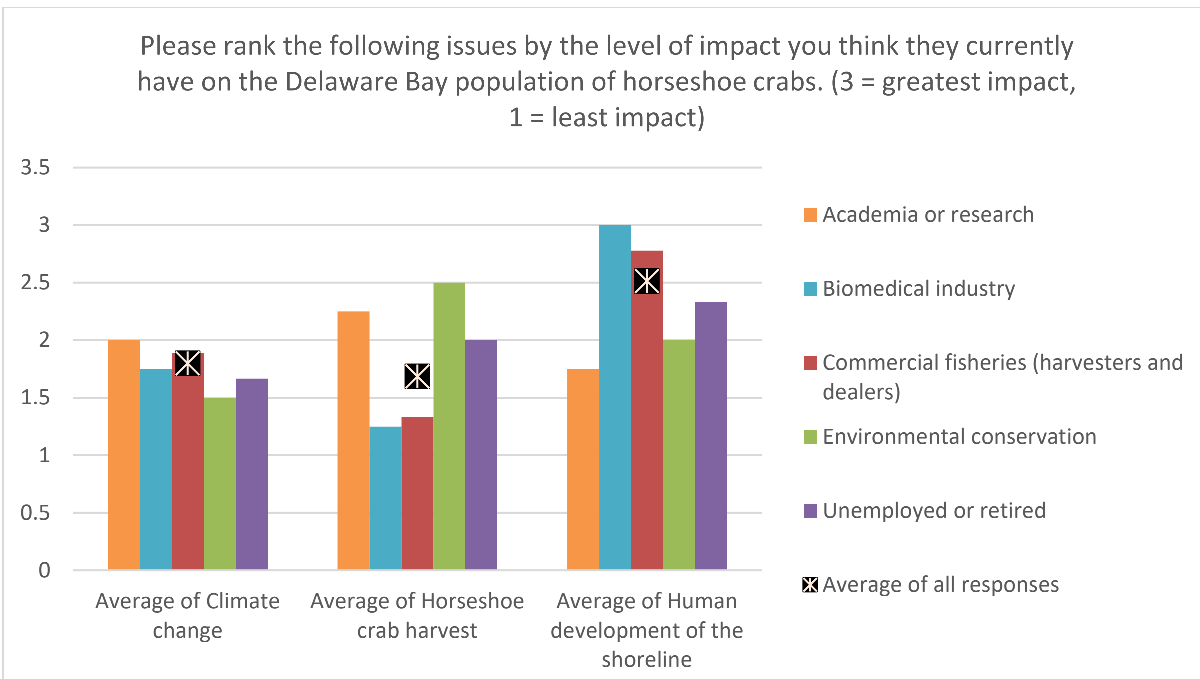

Figure 3. Perceived impacts of individual threats to horseshoe crab population. Higher average values equate to a higher level of perceived impact on the horseshoe crab population.

Question 10. Impacts on Red Knot Stopover Population

This question asked respondents to rank three issues by the level of impact they are thought to have on the red knots that stopover in the Delaware Bay during their migration: climate change, reduced food availability (horseshoe crab eggs) due to horseshoe crab harvest, and human development of the shoreline.

Similar to Question 9, there was substantial variation in the responses across different occupational groups (Table 5, Figure 4). Higher average values equate to a higher level of perceived impact on the red knot stopover population.

Table 5. Average rank value of red knot threats by occupational group. Higher value = higher impact.

Occupational Group	Average of Climate change	Average of Reduced food availability (horseshoe crab eggs) due to horseshoe crab harvest	Average of Human development of the shoreline
Academia or research (n=3)	2.00	2.33	1.67
Biomedical industry (n=4)	2.00	1.00	3.00
Commercial fisheries (harvesters and dealers) (n=18)	2.28	1.11	2.61
Environmental conservation (n=7)	1.43	2.57	2.00
Unemployed or retired (n=3)	2.00	2.00	2.00
Average across all responses (n=35)	2.03	1.57	2.40

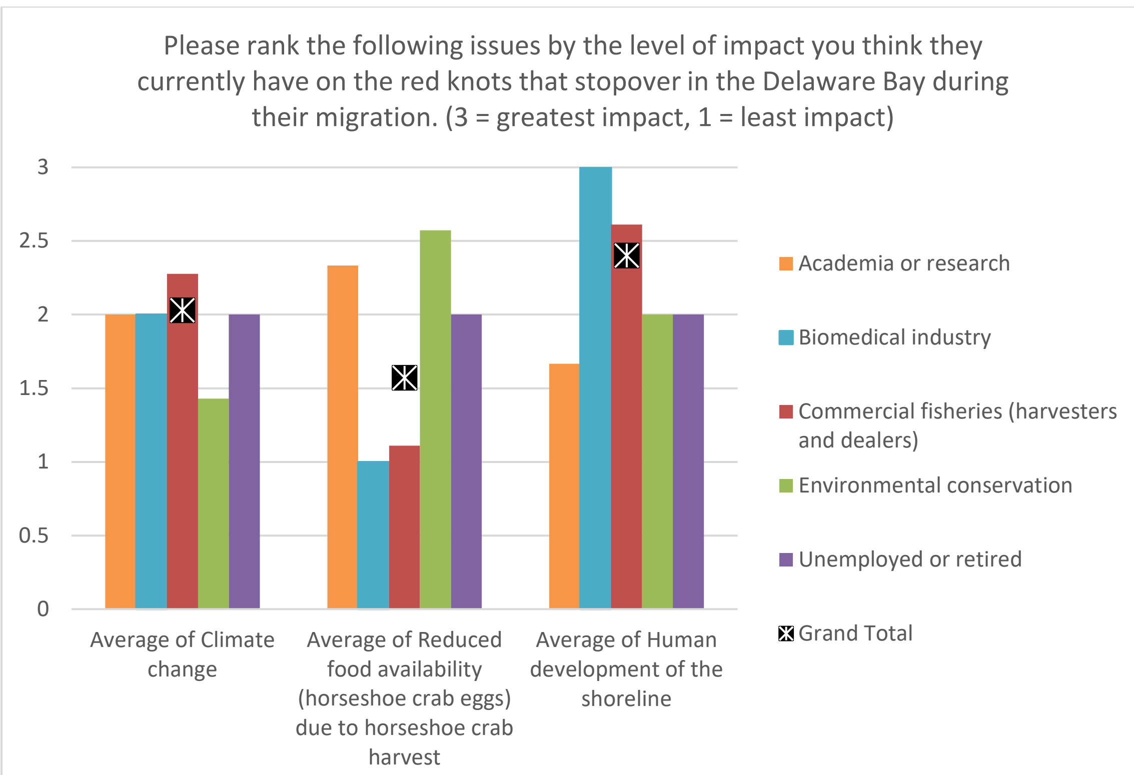

Figure 4. Perceived impacts of individual threats to red knot stopover population. Higher average values equate to a higher level of perceived impact on the red knot population.

Question 11. Importance of Management Objectives

Question 11 was designed to provide insight into the importance to stakeholders of various management objectives for the Delaware Bay horseshoe crab fishery. Participants were asked to indicate the level of importance of seven different management objectives. Possible responses included: Not Important at All, Of Little Importance, Of Average Importance, Very Important, and Absolutely Essential. The seven management objectives presented are listed below:

1. Maintaining a healthy population of horseshoe crabs
2. Maximizing forage (horseshoe crab eggs) for migrating shorebirds
3. Maximizing horseshoe crab bait harvest
4. Allowing horseshoe crabs to be used in the biomedical industry for human health
5. Protecting female horseshoe crabs
6. Using the best available science to inform management
7. Using a multi-species management approach that uses data on horseshoe crabs and shorebirds to recommend harvest levels

Thirty-four responses were received. For analysis, the responses were weighted as follows: Not Important at All = 1, Of Little Importance = 2, Of Average Importance = 3, Very Important = 4, and Absolutely Essential = 5. The average importance of each management objective was calculated across all responses and by occupational group (Figure 5, Table 6). Average values above 3.00 indicate that a management objective is perceived as above average importance, while average values below 3.00 indicate that an objective is perceived as below average importance.

Across all groups, Objective 1, Maintaining a healthy population of horseshoe crabs, was consistently considered to be above average importance (> 4.00) by all five groups. Maximizing forage (horseshoe crab eggs) for migrating shorebirds was considered above average importance for four of the five occupational groups. Maximizing horseshoe crab bait harvest was considered above average importance for two of the five groups ("commercial harvesters" and "unemployed or retired") and below average importance for the other three. Allowing horseshoe crabs to be used in the biomedical industry for human health was considered above average importance for four of five groups, with values generally falling closer to 3 (average importance) and showing greater variance than the responses for the other objectives (range: 2.57-5). For the last three objectives, all five groups considered them to be above average importance on average (> 3), but there was variation in the degree of importance across groups.

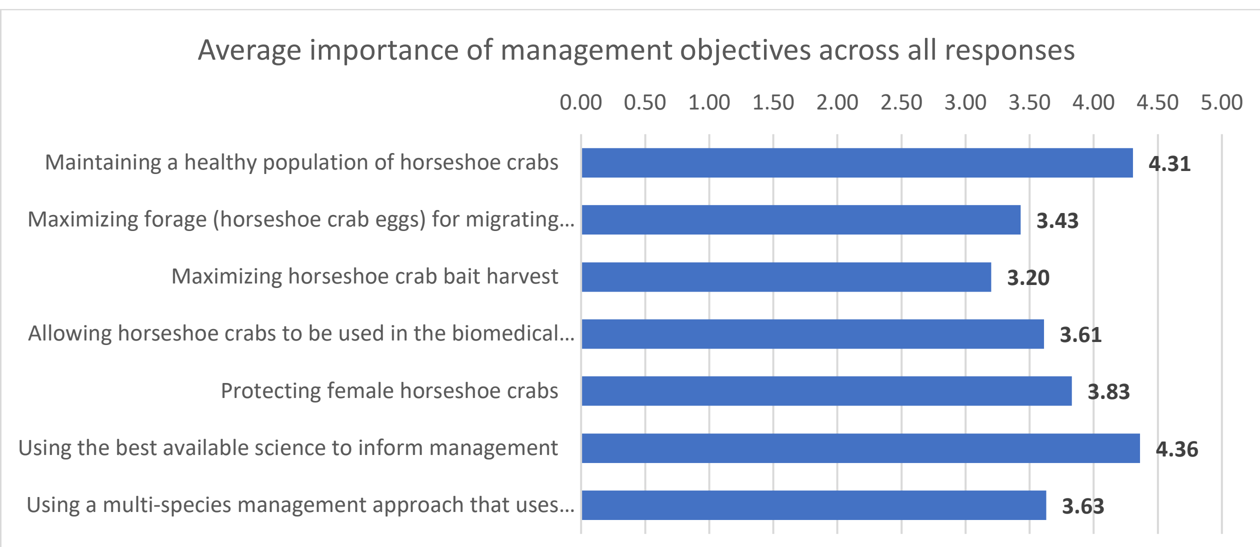

Figure 5. Average importance of management objectives across all responses.

Table 6. Average responses to Question 11 by occupational group. 1=Not important At All, 5=Absolutely Essential. Cells are color coded by column to indicate levels of importance assigned to each objective by each group, where the highest importance is shaded green and the lowest importance is shaded red.

Management Objectives	Academia or research (n=4)	Biomedical industry (n=3)	Commercial fisheries (harvesters and dealers) (n=18)	Environmental conservation (n=6)	Unemployed or retired (n=3)
Maintaining a healthy population of horseshoe crabs	5.00	4.75	4.00	4.43	4.33
Maximizing forage (horseshoe crab eggs) for migrating shorebirds	4.25	3.25	2.78	4.67	4.00
Maximizing horseshoe crab bait harvest	2.00	2.75	4.24	1.14	4.33
Allowing horseshoe crabs to be used in the biomedical industry for human health	3.25	5.00	3.78	2.57	3.67
Protecting female horseshoe crabs	4.50	3.33	3.28	5.00	4.00
Using the best available science…	4.75	3.33	3.17	4.00	4.33
Using a multi-species management approach…	4.75	3.33	3.17	4.00	4.33

Question 12. Ranking management goals

To provide additional insight into stakeholder priorities, Question 12 asked respondents to rank the first five management goals from the previous question by their level of importance. For analysis, responses were weighted with the most important item assigned a value of 5, and the least important assigned a value of 1. Consistent with the previous question, the results indicate that on average across all responses (n=36), maintaining a healthy population of horseshoe crabs is viewed as the most important management objective (Figure 6). Similar to previous issues, there is more variation among the responses when broken down by occupational group (Table 7).

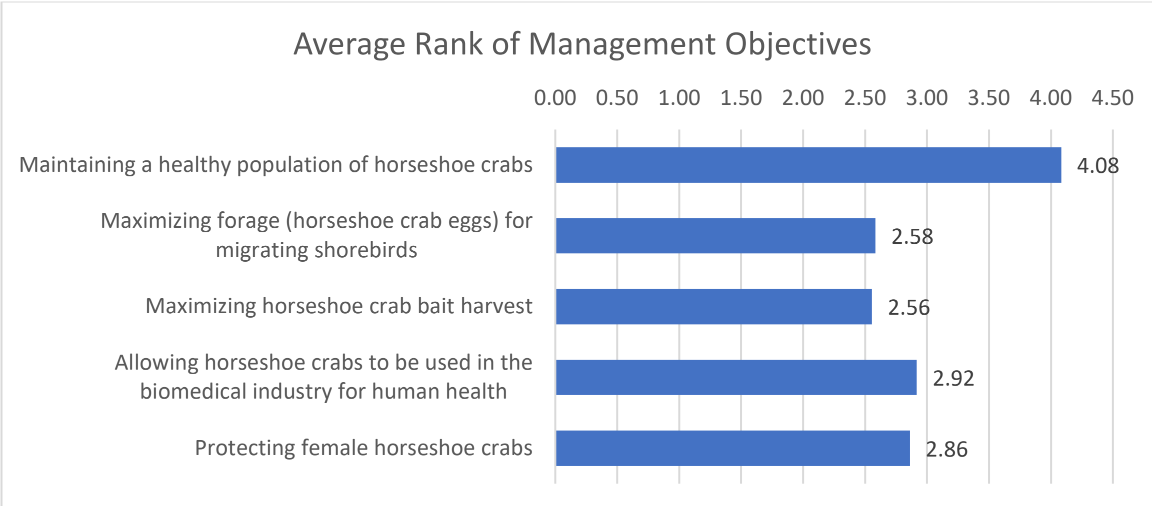

Figure 6. Average rank of management objectives based on importance across all responses. Higher value = higher rank.

Table 7. Average rank of management objectives based on importance, by occupational group. Cells are color coded by column to indicate average ranks assigned to each objective by each group, where the highest rank is shaded green and the lowest rank is shaded red.

Management Objectives	Academia or research (n=4)	Biomedical industry (n=3)	Commercial fisheries (harvesters and dealers) (n=18)	Environmental conservation (n=6)	Unemployed or retired (n=3)
Maintaining a healthy population of horseshoe crabs	4.75	4.25	4.17	4.00	2.67
Maximizing forage (horseshoe crab eggs) for migrating shorebirds	4.00	1.75	1.61	4.14	4.00
Maximizing horseshoe crab bait harvest	1.00	1.25	3.56	1.29	3.33
Allowing horseshoe crabs to be used in the biomedical industry for human health	2.00	4.25	3.39	2.00	1.67
Protecting female horseshoe crabs	3.25	3.50	2.28	3.57	3.33

3.4 Perspectives on the Adaptive Resource Management (ARM) Model and Female Harvest

Questions 13-14. Should the ARM model be modified?

Question 13 specifically asked survey participants if they think the ARM Model, as revised in 2021, should be modified. Of the 36 responses, 47% said yes, 20% said no, and 33% said “I don’t know” (Figure 7). Among most occupational groups, there was not a clear tendency toward any particular response.

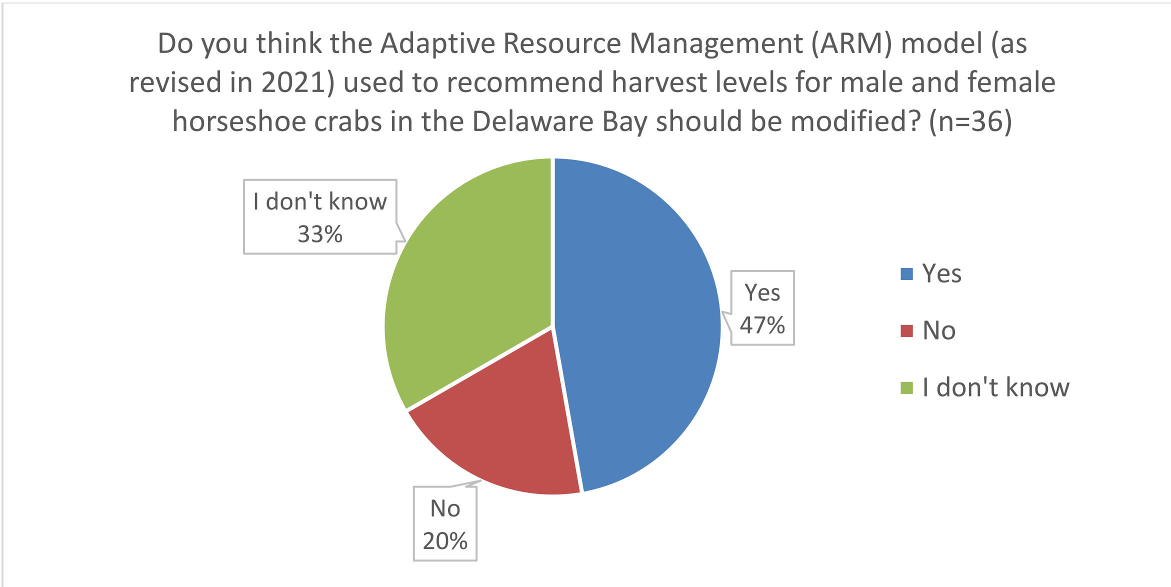

Figure 7. Opinion on whether the current ARM Model should be revised.

Respondents who answered "Yes" to Question 13 were presented with another question: "Why do you think ARM model used to recommend harvest levels for male and female horseshoe crabs in the Delaware Bay should be modified?" Sixteen open-ended responses were provided. Among the commercial fishery members who responded, a prevailing theme in the responses is that there are more horseshoe crabs than what is estimated in the ARM. A few responses stated that New Jersey should be given some opportunity for harvest. One commercial industry member advocated for Delaware Bay horseshoe crabs to be used only for biomedical purposes and not for bait because of the low mortality rate and the greater value of biomedical crabs. Seven responses, mostly from academic or environmental conservation respondents, referenced issues with the model and the built-in assumptions in the framework. For example, some stated that the model underestimates the relationship between horseshoe crabs and red knots, that the model population estimates do not accurately reflect the conditions of either species, and that it underestimates the impact of biomedical removals. Two comments stated that there should be a larger horseshoe crab population before increased harvest is allowed. All open-ended responses to this question are provided in Appendix B.

Questions 15-16. Should a limited amount of female harvest be allowed?

Question 15 specifically asked survey participants if they think a limited amount of female horseshoe crab bait harvest should be allowed at this point in time. Of 35 total responses, 49% said yes (n=17), 37% said no (n=13), and 14% said "I don't know" (n=5). The distribution of responses varied between occupational groups. For the "academia and research" group responses were split evenly between "No" and "I don't know." The majority (14 of 18) of commercial fisheries group answered "Yes," while 100% of the environmental conservation group answered "No." The "biomedical industry" group responses included two "Yes" and one "I don't know." The responses from the "unemployed or retired" group were split evenly among all three answers (Figure 8).

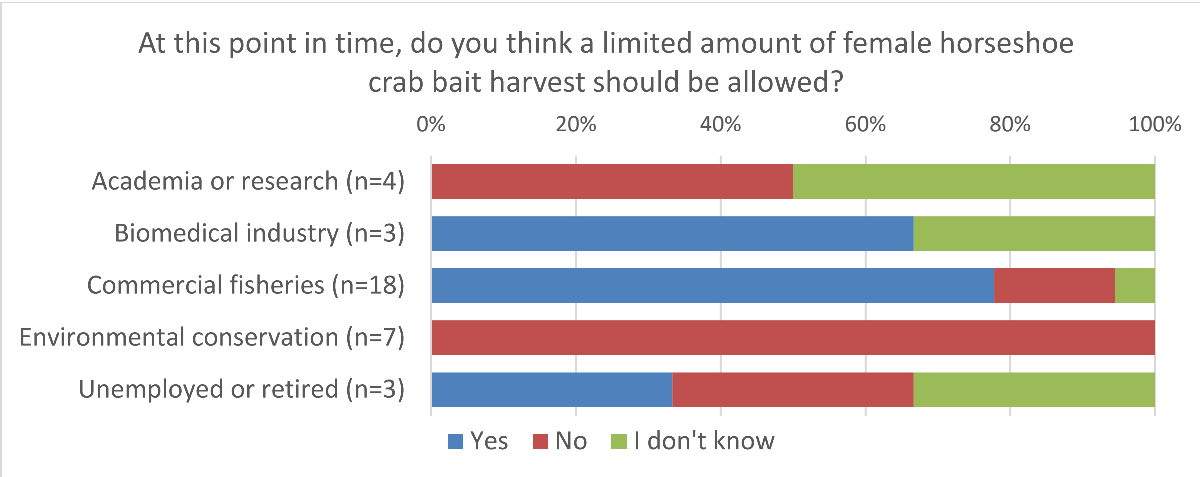

Figure 8. Opinion on allowing female bait harvest within occupational groups.

Participants that answered "No" to Question 15 were presented with another question: "Under what conditions should harvest of female horseshoe crabs be allowed?" Eleven open-ended responses were provided. Three responses indicated that female harvest of horseshoe crabs should not be allowed under any conditions, and another said that female harvest is not necessary. One response said that females should only be used for biomedical purposes. Three responses stated that female harvest should only be allowed once horseshoe crab and/or red knot populations have rebounded to near historic levels. One response argued that females should be harvested according to the original ARM framework until the current framework has been evaluated by multiple stakeholders. All open-ended responses to this question are provided in Appendix B.

Question 17. Use of female horseshoe crabs by the biomedical industry

This question aimed to understand stakeholder opinions about whether female horseshoe crabs should be collected for biomedical purposes. Thirty-five responses were given, and 46% said "Yes," 43% said "No" and 11% said "I don't know". Occupational groups responded differently to this question (Figure 9).

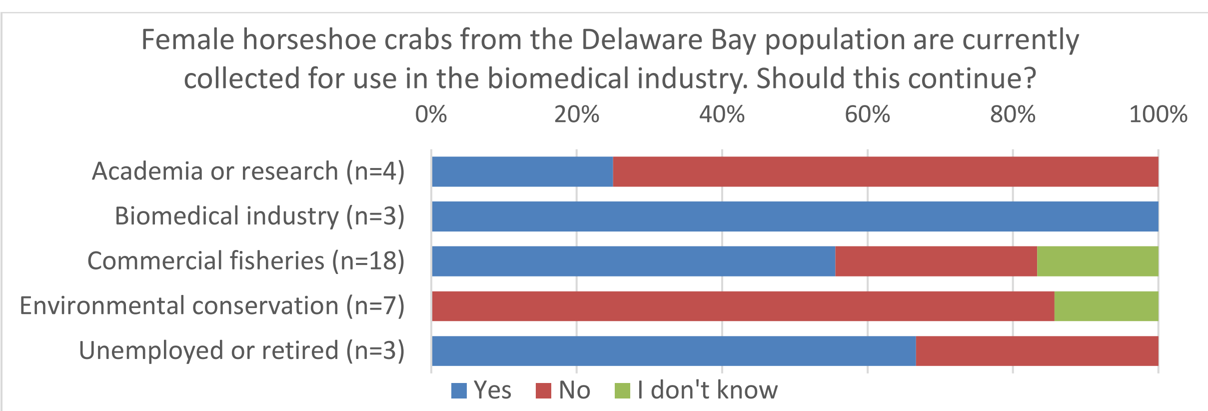

Figure 9. Opinion on biomedical use of female horseshoe crabs within occupational groups.

3.5 Question 18. What do you think is most important for managers to consider when making decisions about the management of the Delaware Bay horseshoe crab population?

The final survey question aimed to allow respondents to add additional information that may not have been considered in the other survey questions. Thirty-two open ended answers were submitted describing what the respondent thinks is the most important issue for managers to consider relative to this issue. A wide variety of topics and perspectives were addressed in these responses. The two most commonly mentioned issues were the health of the horseshoe crab population (n=9), and basing management decisions in robust science (n=5). Four responses focused on allowing sufficient bait harvest, and three responses emphasized the importance of impacts on fishermen and coastal communities. Two responses highlighted the importance of the greater ecosystem, including the role of horseshoe crabs and other species. Two responses specifically mentioned supporting shorebird recovery. Two responses highlighted allowing for biomedical use of horseshoe crabs, while two other responses advocated for switching to synthetic alternatives for bait and limulus amebocyte lysate (LAL). One response focused on the importance of maintaining adequate spawning beaches. One response emphasized the need to improve the data used for management. All open-ended responses to this question are provided in Appendix B.

4. DISCUSSION

The responses to this survey reflect one of the prominent challenges of managing the Delaware Bay horseshoe crab population, of which the Board has long been aware: a variety of stakeholders have an interest in the Delaware Bay population of horseshoe crab, but these stakeholder groups have diverging and sometimes contradictory management goals. The survey results provide some insight on the values and objectives of certain stakeholder groups.

The results clarify that within the commercial industry, including horseshoe crab harvesters and dealers, and fishermen who use horseshoe crab as bait, there is demand for female horseshoe crabs and they are considered more valuable than males. The majority of the commercial industry respondents have harvested females in the past, and indicate that harvesting females in the future is important to them. The majority of commercial industry respondents think a limited amount of female harvest should be allowed at present, but a few do not. Among the biomedical and academic stakeholders there is less certainty on allowing female harvest, and for environmental conservation respondents the unanimous opinion is that no female harvest should be allowed at this time. Among the respondents who do not think any female harvest should be allowed, there is a divide between individuals who think female harvest could be allowed once horseshoe crab and red knot populations have rebounded to near historic levels, and individuals who think it should never be allowed.

Regarding management goals, the results are mixed on which goals are perceived as most important. Researchers and environmental groups tended to value the protection of female horseshoe crabs and the ecological role of horseshoe crabs as a food source for shorebirds over the fishery. Commercial fishery participants attribute greater importance to bait harvest.

One area where almost all stakeholder groups agree is on the importance of maintaining a healthy horseshoe crab population. Across stakeholder groups this remains a top priority for management. However, there are differing opinions on the current state of the Delaware Bay population and the impacts of the bait fishery. While the commercial fishery participants tend to have a more positive perception, the environmental and academic participants tend to disagree with the idea that the Delaware Bay population is healthy, and think the bait fishery is having a negative impact on the horseshoe crab population.

A significant proportion of survey respondents think the ARM Model should be revised. Those respondents belong to various stakeholder groups and have a number of reasons for their opinions. Most commercial fishery respondents think the ARM should be revised because it is underestimating the numbers of horseshoe crabs, whereas other stakeholders argue it is overestimating the populations of horseshoe crabs and red knots. Nevertheless, the survey results are clear that stakeholders highly value the use of the best available science to inform management.

Appendix A. Survey Questionnaire

Delaware Bay Horseshoe Crab Management Survey

The Horseshoe Crab Management Board of the Atlantic States Marine Fisheries Commission (Commission) is seeking input from stakeholders regarding management of the Delaware Bay population of horseshoe crabs. As a stakeholder with an interest in horseshoe crab management, you have been selected to participate in this survey because of the valuable perspective you can provide on this issue. The purpose of the survey is to better understand the value of horseshoe crabs to stakeholders and guide the Board in evaluating the management objectives established in the fishery management plan.

All survey responses will be anonymous, and the results will be generalized such that individual responses will not be discernable. Your participation and engagement in the management process by completing this survey are greatly appreciated.

Delaware Bay Horseshoe Crab Management Survey

Participant Information

* 1. In what state or U.S. territory do you live?

* 2. What is your primary field of work?

- ◯ Commercial fisheries (harvesters and dealers)
- ◯ Fisheries management
- ◯ Environmental conservation
- ◯ Biomedical industry
- ◯ Academia or research
- ◯ Legislature
- ◯ Tourism industry
- ◯ State government
- ◯ Federal government
- ◯ Unemployed or retired
- ◯ Other (please specify)

Delaware Bay Horseshoe Crab Management Survey

Questions for Commercial Harvesters and Dealers

3. What are the horseshoe crabs that you harvest or sell used for?

- Bait
- Biomedical
- Both bait and biomedical
- I do not know
- I do not harvest horseshoe crabs
- Other (please specify)

4. Have you ever harvested or sold female horseshoe crabs for bait in the past?

- Yes
- No

5. How important is it to you to be able to harvest/sell female horseshoe crabs for bait in the future?

- Not Important at All
- Of Little Importance
- Of Average Importance
- Very Important
- Absolutely Essential
- This does not apply to me

6. On a scale of 1 to 5, where 1 is "strongly agree" and 5 is "strongly disagree," express your level of agreement with the following statements:

	1. Strongly agree	2	3. Neutral	4	5. Strongly disagree
Female horseshoe crabs are worth more money than male horseshoe crabs.	○	○	○	○	○
There is no market demand for female horseshoe crabs.	○	○	○	○	○

7. Of the following two options, which do you prefer?

- ○ A larger overall quota of all male horseshoe crabs
- ○ A smaller overall quota including some female horseshoe crabs

ATLANTIC STATES MARINE FISHERIES COMMISSION

Delaware Bay Horseshoe Crab Management Survey

The questions in this survey ask about the Delaware Bay horseshoe crab population, and the management of the fishery in the Delaware Bay region. The Delaware Bay population includes horseshoe crabs within the state waters of New Jersey, Delaware, Maryland, and Virginia and adjacent federal waters.

Horseshoe crabs from the Delaware Bay region (New Jersey-Virginia) have been of particular concern due to their relationship with red knots, a shorebird species currently listed as Threatened by the US Fish and Wildlife Service. The red knot is one of the many shorebird species that feed on horseshoe crab eggs in the Delaware Bay region during their annual migration from South America to the Arctic.

For the purposes of this survey, a "healthy" horseshoe crab population is considered to be one with enough horseshoe crabs to supply enough food for the shorebirds and sustain fishery harvest.

8. On a scale of 1 to 5, where 1 is "strongly agree" and 5 is "strongly disagree," express your level of agreement with the following statements:

	1. Strongly agree	2	3. Neutral	4	5. Strongly disagree
The Delaware Bay population of horseshoe crabs is healthy.	○	○	○	○	○
The horseshoe crab bait fishery is negatively impacting the Delaware Bay population of horseshoe crabs.	○	○	○	○	○
The number of horseshoe crabs in the Delaware Bay population is increasing.	○	○	○	○	○
The horseshoe crab bait fishery is negatively impacting red knots in the Delaware Bay.	○	○	○	○	○
Fishermen should be allowed to harvest female horseshoe crabs from the Delaware Bay population if it is at a healthy level.	○	○	○	○	○
Fishermen should not be allowed to harvest male horseshoe crabs from the Delaware Bay population if it is at a healthy level.	○	○	○	○	○

9. Please rank the following issues by the level of impact you think they currently have on the Delaware Bay population of horseshoe crabs. (1 = greatest impact, 3 = least impact)

- ☐ Climate change
- ☐ Horseshoe crab harvest
- ☐ Human development of the shoreline

10. Please rank the following issues by the level of impact you think they currently have on the red knots that stopover in the Delaware Bay during their migration. (1 = greatest impact, 3 = least impact)

- ☐ Climate change
- ☐ Reduced food availability (horseshoe crab eggs) due to horseshoe crab harvest
- ☐ Human development of the shoreline

Delaware Bay Horseshoe Crab Management Survey

11. How important to you is each of the following management objectives for the Delaware Bay population of horseshoe crabs?

	Not Important at All	Of Little Importance	Of Average Importance	Very Important	Absolutely Essential
Maintaining a healthy population of horseshoe crabs					
Maximizing forage (horseshoe crab eggs) for migrating shorebirds					
Maximizing horseshoe crab bait harvest					
Allowing horseshoe crabs to be used in the biomedical industry for human health					
Protecting female horseshoe crabs					
Using the best available science to inform management					
Using a multi-species management approach that uses data on horseshoe crabs and shorebirds to recommend harvest levels					

12. Rank these management goals for the Delaware Bay region by their level of importance to you. (1 = most important, 5 = least important)

- Maintaining a healthy population of horseshoe crabs
- Maximizing forage (horseshoe crab eggs) for migrating shorebirds
- Maximizing horseshoe crab bait harvest
- Allowing horseshoe crabs to be used in the biomedical industry for human health
- Protecting female horseshoe crabs

Delaware Bay Horseshoe Crab Management Survey

In 2012, the Commission adopted the use of the Adaptive Resource Management (ARM) Framework for setting harvest levels for horseshoe crabs of Delaware Bay-origin given the important ecological role horseshoe crab eggs play in the food web for migrating shorebirds in that region. The ARM Framework considers the abundance levels of horseshoe crabs and red knots, as well as values previously expressed by stakeholders, in determining the optimal harvest level for horseshoe crabs from the Delaware Bay population. The ARM Framework was revised and peer reviewed in 2021.

Abundance surveys are used for both red knots and horseshoe crabs to estimate population sizes. The ARM Revision uses fishery-dependent data for horseshoe crabs from the commercial bait fishery, dead discard estimates from other fisheries, and mortality estimates from the biomedical industry. Based on these population estimates, and stakeholder values, the Framework recommends the appropriate number of male and female horseshoe crabs that can be harvested for the commercial bait fishery without limiting the population growth of red knots.

13. Do you think the Adaptive Resource Management (ARM) model (as revised in 2021) used to recommend harvest levels for male and female horseshoe crabs in the Delaware Bay should be modified?

- ◯ Yes
- ◯ No
- ◯ I don't know

Delaware Bay Horseshoe Crab Management Survey

14. Why do you think ARM model used to recommend harvest levels for male and female horseshoe crabs in the Delaware Bay should be modified? Answer below.

Delaware Bay Horseshoe Crab Management Survey

15. The current management framework allows for the possibility of limited commercial harvest of female horseshoe crabs from the Delaware Bay population based on the number of horseshoe crabs and red knots. At this point in time, do you think a limited amount of female horseshoe crab bait harvest should be allowed?

- ◯ Yes
- ◯ No
- ◯ I don't know

Delaware Bay Horseshoe Crab Management Survey

16. Under what conditions should harvest of female horseshoe crabs be allowed?

Delaware Bay Horseshoe Crab Management Survey

17. Female horseshoe crabs from the Delaware Bay population are currently collected for use in the biomedical industry. Should this continue?

- Yes
- No
- I don't know

Delaware Bay Horseshoe Crab Management Survey

18. What do you think is most important for managers to consider when making decisions about the management of the Delaware Bay horseshoe crab population?

Delaware Bay Horseshoe Crab Management Survey

Optional Demographic Information

19. What is your age?

- 17 or younger
- 18-20
- 21-29
- 30-39
- 40-49
- 50-59
- 60 or older
- Choose not to answer

20. What is your gender?

- Female
- Male
- Other
- Choose not to answer

21. Which race/ethnicity best describes you? (Select all that apply)

- American Indian or Alaskan Native
- Asian / Pacific Islander
- Black or African American
- Hispanic
- White / Caucasian
- Choose not to answer
- Multiple ethnicity / Other (please specify)

Delaware Bay Horseshoe Crab Management Survey

Thank you for completing this survey!

The Commission's Horseshoe Crab Management Board greatly appreciates your perspective on this topic. The Management Board will review the results of the survey at its next meeting.

Appendix B. Open-Ended Survey Responses

Question 14. Why do you think ARM model used to recommend harvest levels for male and female horseshoe crabs in the Delaware Bay should be modified?
The horseshoe crab levels should be a lot stronger than they have been because the harvesting have been restrictive.
The ARM model vastly underestimates the importance of horseshoe crabs to red knots and thus recommends dangerously high harvest levels. It also generates estimates and projections of horseshoe crab and red knot abundance that do not accurately reflect the conditions of either species. Considering the precarious state of the ecosystem, ASMFC should take a risk-averse approach.
More crabs now then 2007.
I believe it underestimates the levels of impacts to both horseshoe crabs and shore birds
I think NJ should be allowed to harvest
I feel that female horseshoe crabs should be exclusively utilized for bio-medical purposes. The value per crab and the very low mortality rate by live return to sea, far outweighs the value of females for bait and far outweighs 100% bait mortality. Female survival is essential to sustaining a healthy stock biomass.
Because it sucks
We need more harvest and mortality data from the pharmaceutical industry. They should not be exempt from supplying data. In addition, the model should be giving more weight to the horseshoe crab / shorebird recourses in the Delaware Bay. The bait harvest industry while a worthwhile endeavor should not trump the resources. Female horseshoe crabs should not be harvested until the population recovers to near historic levels.
I feel that there are many more crabs than they think
The numbers of crabs in the Delaware Bay are not yet at a sustainable level. I believe we need a few more years of significant increase not occurring using the current ARM model
Puts too much emphasis on allowing HSC harvest before the populations number have fully rebounded. Also underestimates negative effect of crab bleeding.
You are not taking in consideration the use of one female horseshoe crab for bait will save millions of eggs. We are using the horseshoe crabs to catch everything that is eating the eggs in the water. For instance one horseshoe crab could catch 10 pounds of eels how many eggs do you think 10 pounds of eels can eat in a year?
Crabs are more plentiful and NJ moratorium in place 16 years lifted and NJ and Delaware should be alternate. 1 state every other year to be more equitable
It should be modified to include harvest impacts in a diversity of species, not just red knots.
Many assumptions of the model are problematic and unsupported, likely affecting the inferences being made by model developers with respect to the status of the horseshoe crab populations and their relationship to Red Knot population viability.
Because it doesn't allow for female harvest of local population of female's that are not from the Delaware Bay population

Question 16. Under what conditions should harvest of female horseshoe crabs be allowed?
Given the importance of female horseshoe crabs to the ecosystem and the harm that their removal has caused, it is difficult to imagine a scenario when harvesting them would be justified. At a minimum, both horseshoe crabs and red knots would need to have recovered to their pre-overharvest abundance levels, with enough of a buffer to ensure that a female harvest would not precipitate another decline. Those conditions seem very remote today.
Under no conditions should female horseshoe crabs be harvested
It isn't necessary
Bio-Medical use only
none
After the population recovers to near historic levels.
When fishermen needed them just like it was.
When HSC populations number and egg densities on the spawning beaches are up to earlier documented levels.
ABSOLUTELY NONE
As proposed in the original ARM framework. However, interpretation of the existing data and the outputs of the current ARM framework must be scrutinized and evaluated by multiple stakeholders. To date, this has not been done.
On all occasions

Question 18. What do you think is most important for managers to consider when making decisions about the management of the Delaware Bay horseshoe crab population?
Healthy population so you can have enough for the biomedical research
Managers should prioritize the critical and unique role of horseshoe crabs in the ecosystem, including the many species and processes that depend on them.
The health of the horseshoe crab population, utilizing the best available horseshoe crab population data and ensuring that horseshoe crabs can continue to be collected for the Limulus Amebocyte Lysate (LAL) test that is critical to human health
Make a decision on future harvest or buy the few licenses that are left. People make a living off the water!
Increasing the population of horseshoe crabs and supporting shore bird migration and populations.
I'm in MD there management is working fine
Not sure
In New Jersey the harvest method should be addressed. Many horseshoe permit holders have the ability to harvest crabs in other fisheries that do not require a hand harvest on the beach during the spawn of the horseshoe crab. If a permit holder can harvest horseshoe crabs in another legal fishery it will eliminate the interaction of harvesters and horseshoe crabs spawning on the shoreline as our current regulation requires that method to collect them. As an example such as a winter dredge fishery or spring Gillnet, the horseshoe crab that could be harvested in that manner would not be pulled from the sandy shorelines during the time when the crab spawns. The beach collection is not favorable due to the fact that that crab is there to

spawn. If it's harvest in another fishery other than hand/beach harvest it's not collecting a spawning crab which may or may not make it to the shoreline due to other environmental reasons or threats.
Whether horseshoe crabs have the ability to change sex depending on the lesser of one or the other sex
The use of existing alternative to HSC blood is now possible HSC should be phased out Bait alternatives also exist
Keeping the resource strong and robust. Create the greatest use benefit to human population in mortality estimates and calculations. The Red Knot need for the eggs is essential, although should not be arbitrary in reasoning to limit Horseshoe Crab usage. How will having a Wind Energy Farm located on top of the Schuster Sanctuary, effect the long-term viability of the resource?
Ecological interrelationships between horseshoe crabs and other species including shorebirds
That Delaware's season is after the bulk of the crabs have already laid their eggs.
Use scientifically-robust data and models, including analyses and interpretation by scientists not affiliated with affected states.
Maintain a balance of both the female and male population to their percentage so they can reproduce sufficiently. We do not want to overharvest to prevent their reproduction. Our main goal is to not only preserve the red knots but also the horseshoe crabs also.
Current population and collection data is extremely important, especially data from the pharma industry. Without this data the current model does not work as well as it could.
Having real science done and not made up science like all the science in the past for the birds..!!
The stock of the crabs
When making the decisions managers should take the actual science for what it's worth and not change the method once it doesn't meet their agenda.
I think they need to push for additional use of synthetic baits for the fishing industry and synthetic blood substitutes for the medical industry. They need to look at overall impacts, not just horseshoe crab population size.
Data. Full stop.
Make a reasonable amount of horseshoe crabs available for bait.
That HSC population numbers haven't fully rebounded and is not producing an overabundance of eggs needed to sustain shorebird foraging needs.
Recovery of the Red Knot
Using horseshoe crabs for bait and catching what is eating their eggs we help the population. Less predators more prey Simple
NJ license permit holders should be the ones to harvest these biomedical crabs currently NJ has established monopoly should be ivestigated anti trust violations
Horseshoe crab population
The current population of horseshoe crabs is just a fraction of its historic numbers. Any management decisions should be to increase their population numbers not just maintain current levels.

Use ecological endpoints for recovery of horseshoe crab populations.   Consider the importance of horseshoe crabs as a keystone species in near shore inter tidal communities, not only for migratory shorebirds, but fishes and other marine organisms.
The fisherman
Financial and cultural impact on small coastal communities.
It is very important to keep the spawning beaches from becoming over developed and not having anywhere for the Horseshoe Crabs to spawn

Appendix C. Additional Figures

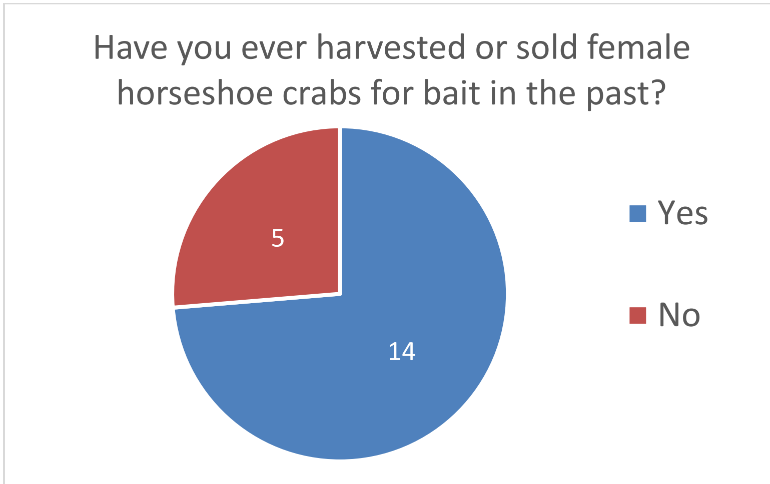

Figure A1. Past female horseshoe crab harvest.

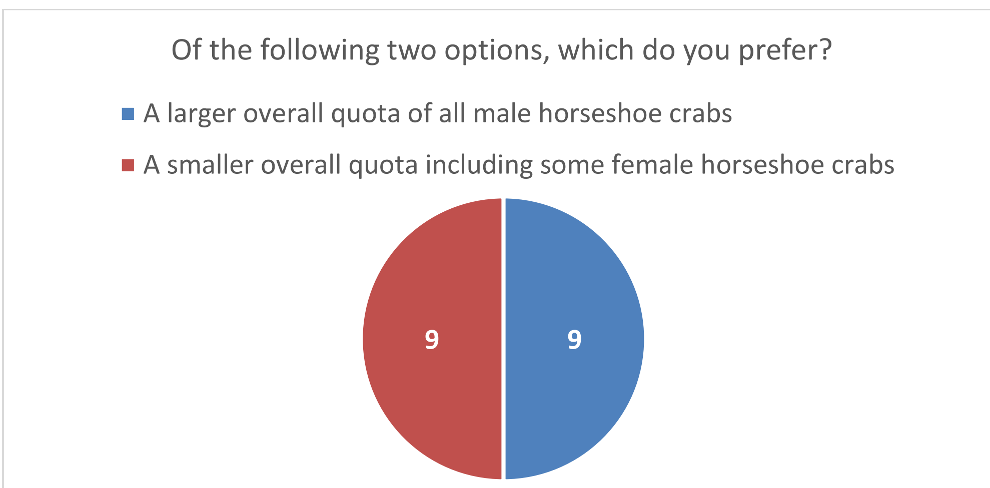

Figure A2. Preferences for harvest quota makeup.

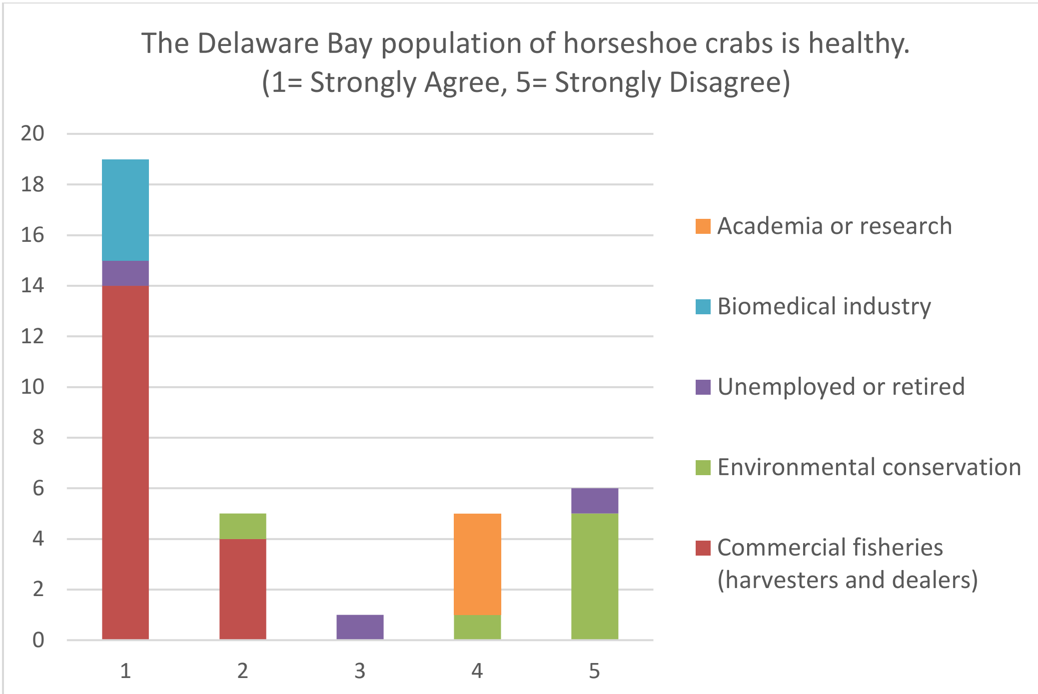

Figure A3. Perception of Delaware Bay horseshoe crab population health.

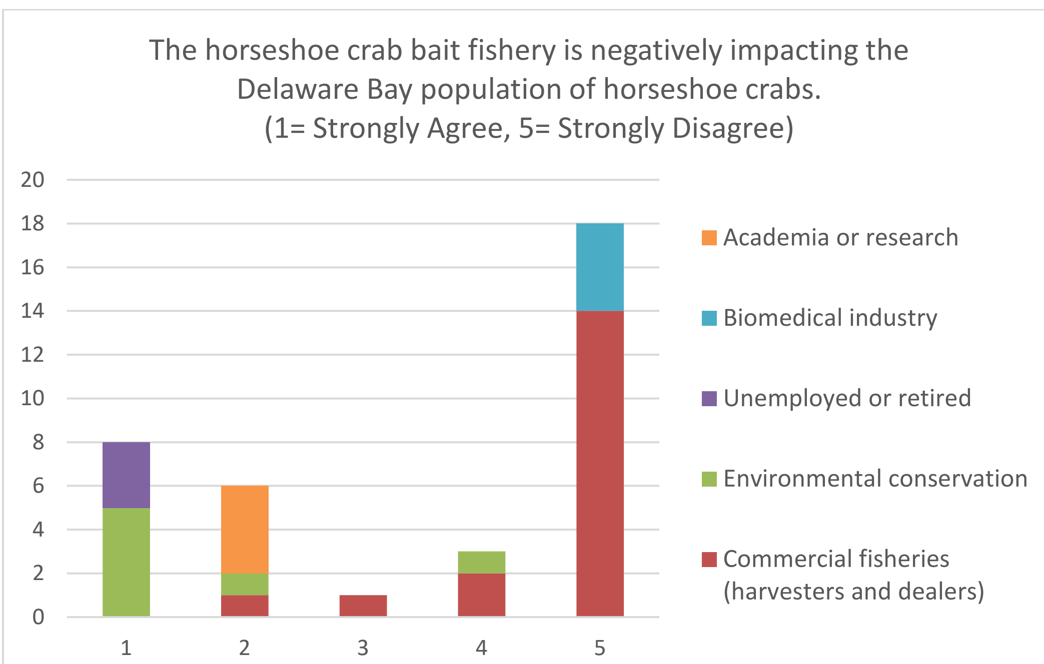

Figure A4. Perception of bait fishery impacts on horseshoe crab population.

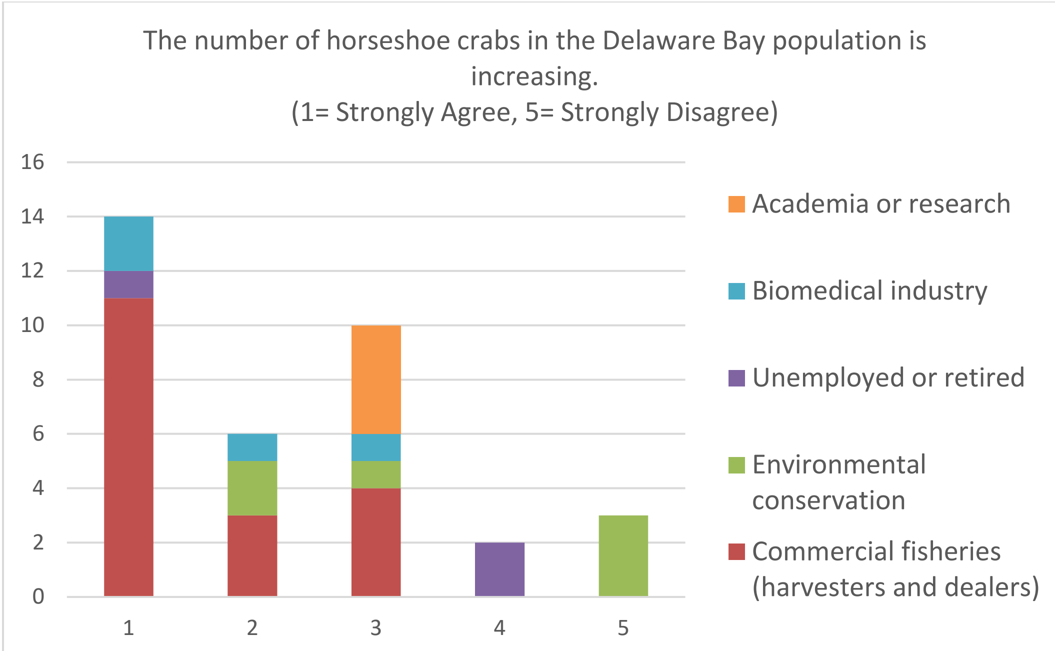

Figure A5. Perception of Delaware Bay horseshoe crab population growth.

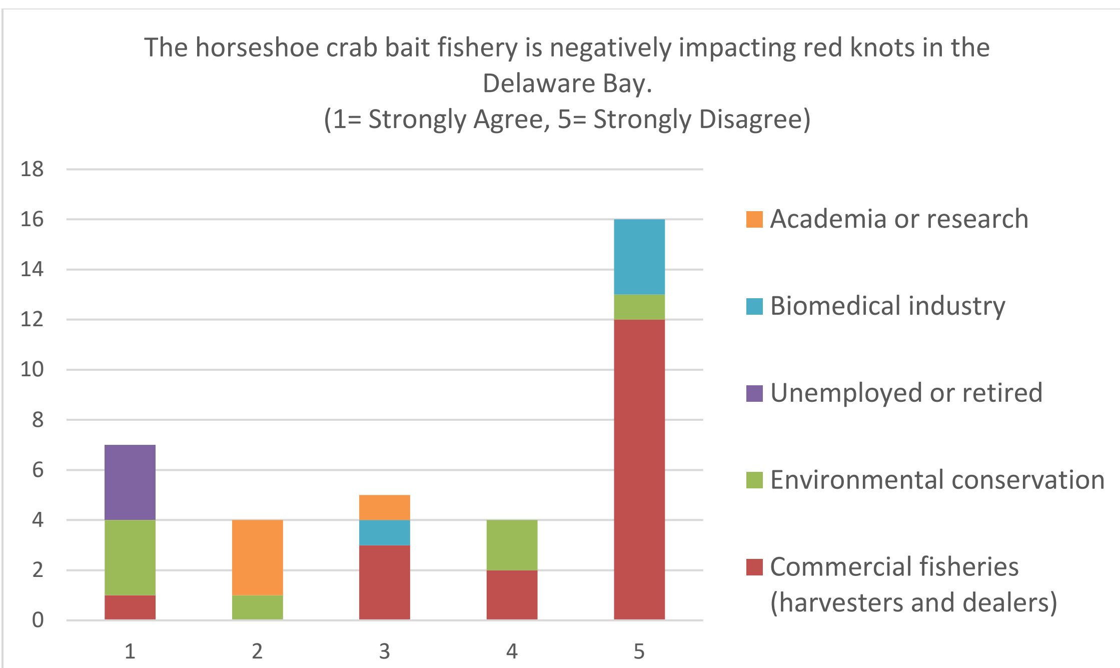

Figure A6. Perception of bait fishery impacts on red knots.

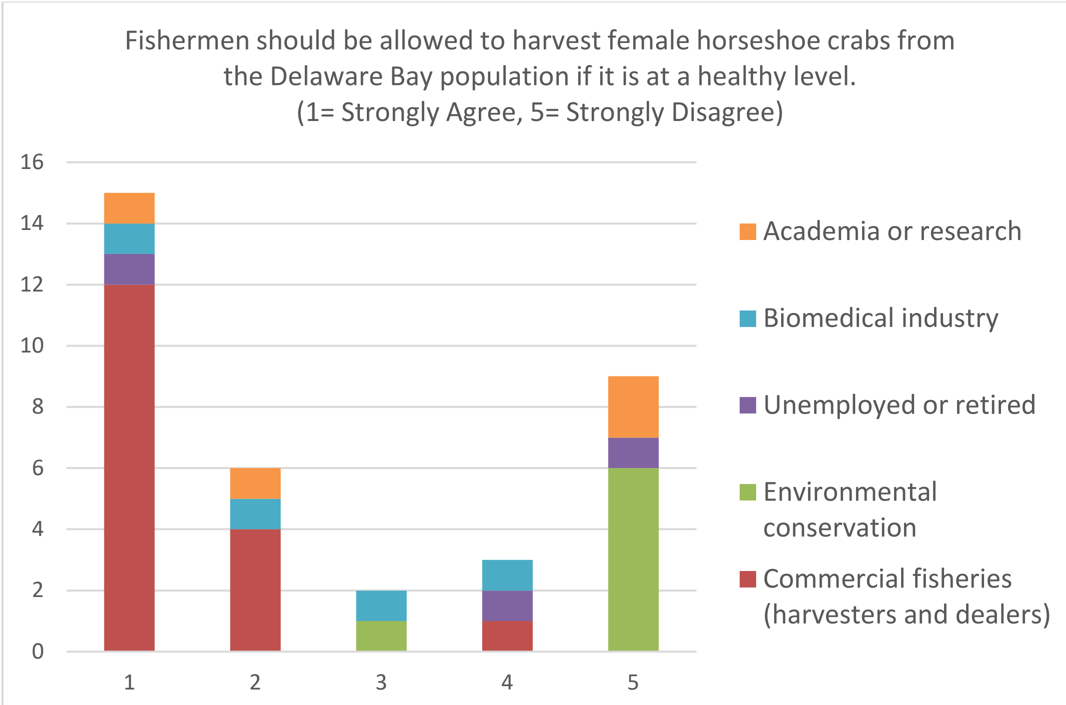

Figure A7. Opinion on female harvest allowance.

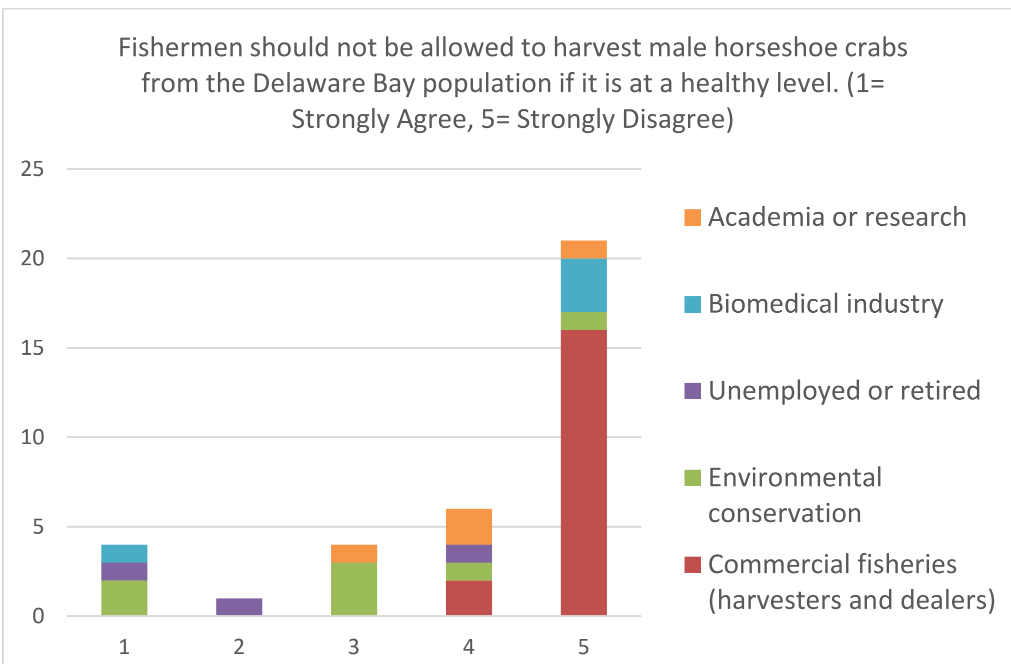

Figure A8. Opinion on male harvest allowance.

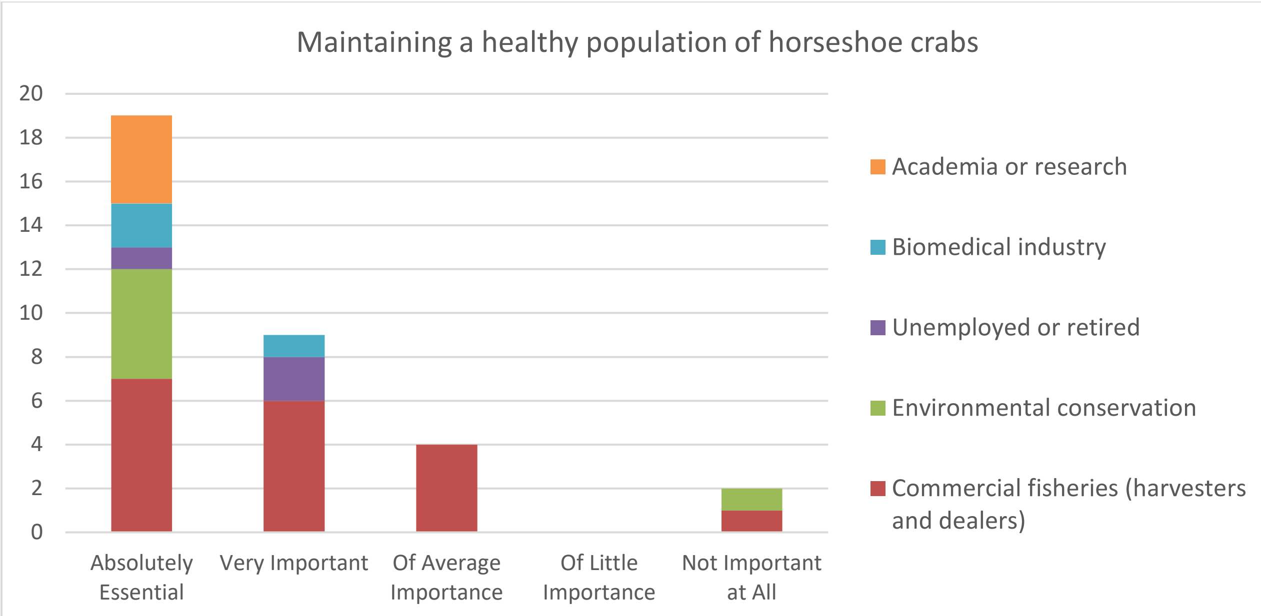

Figure A9. Importance of maintaining a healthy population of horseshoe crabs.

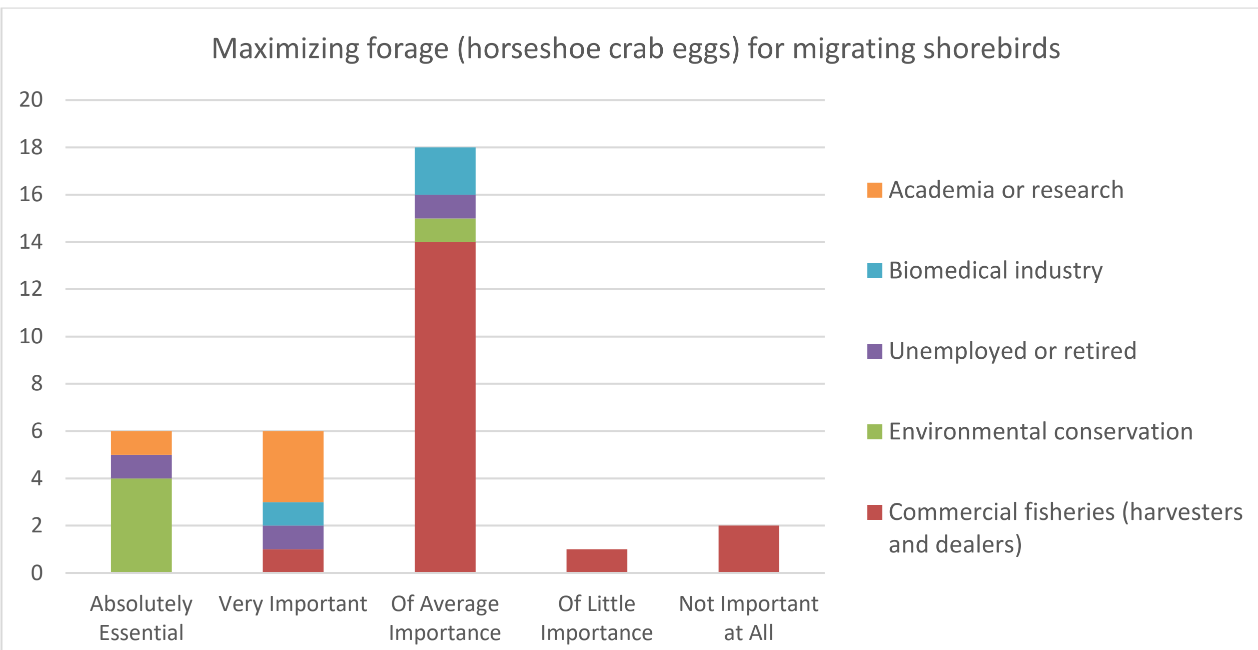

Figure A10. Importance of maximizing forage (horseshoe crab eggs) for migrating shorebirds.

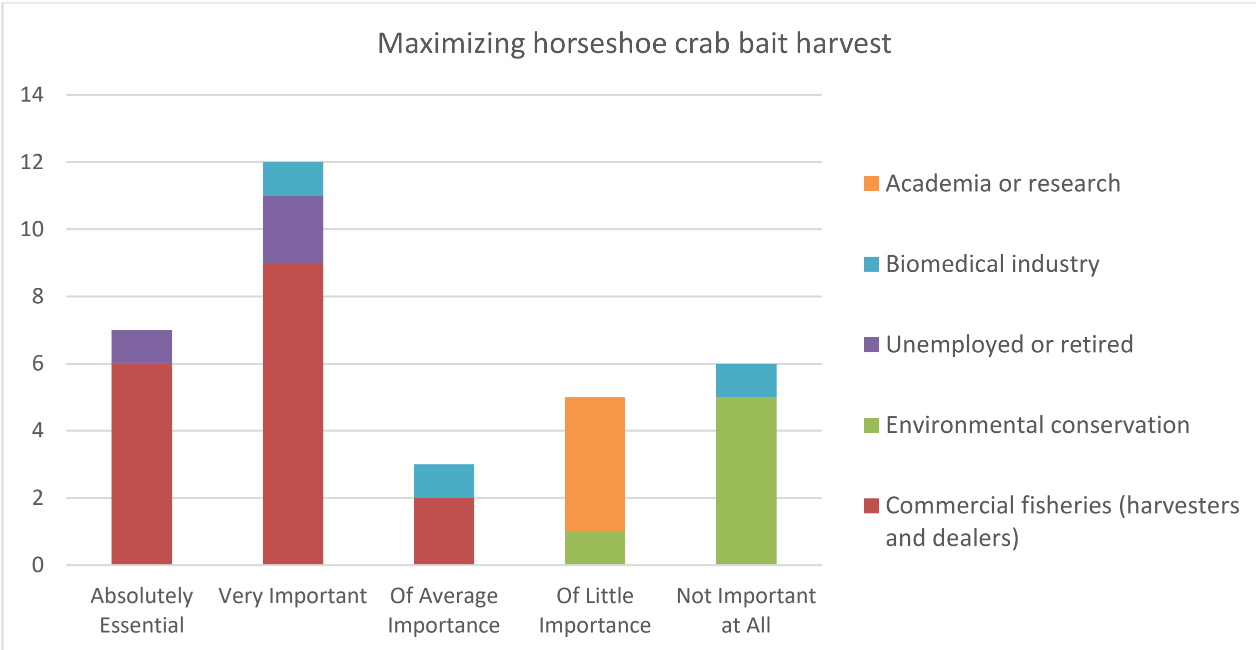

Figure A11. Importance of maximizing horseshoe crab bait harvest.

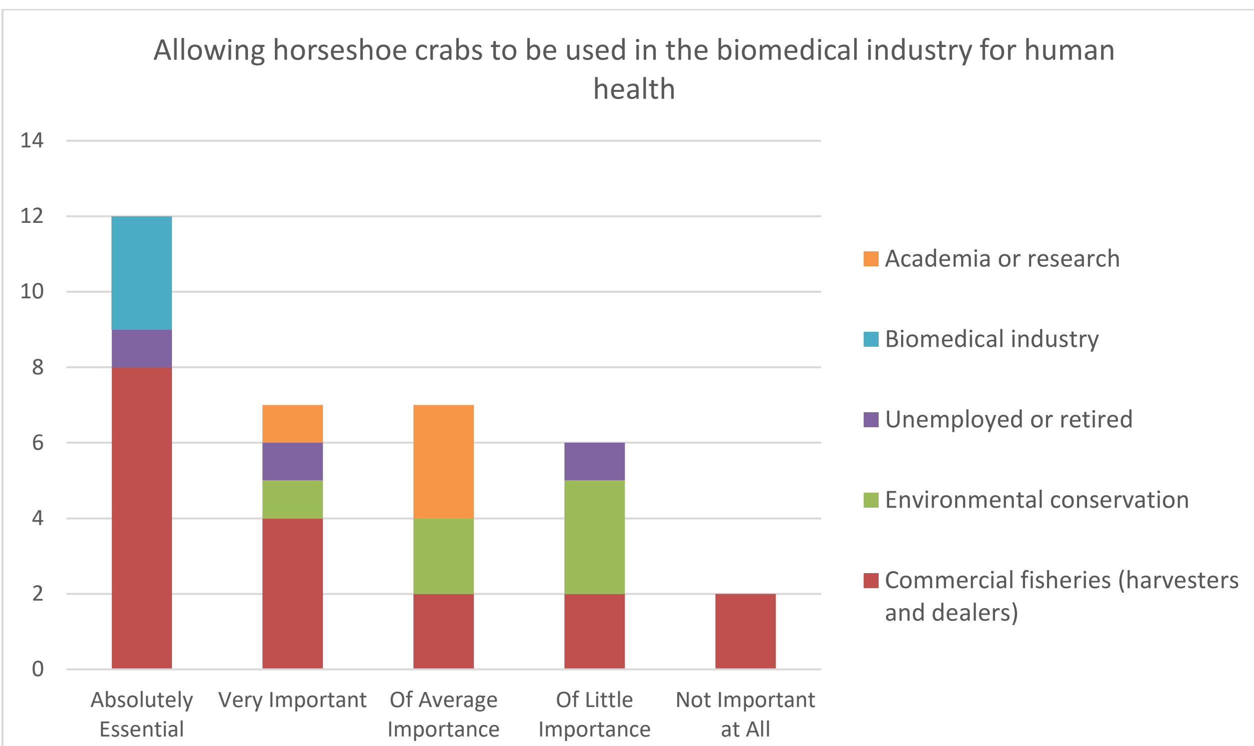

Figure A12. Importance of allowing horseshoe crabs to be used in the biomedical industry.

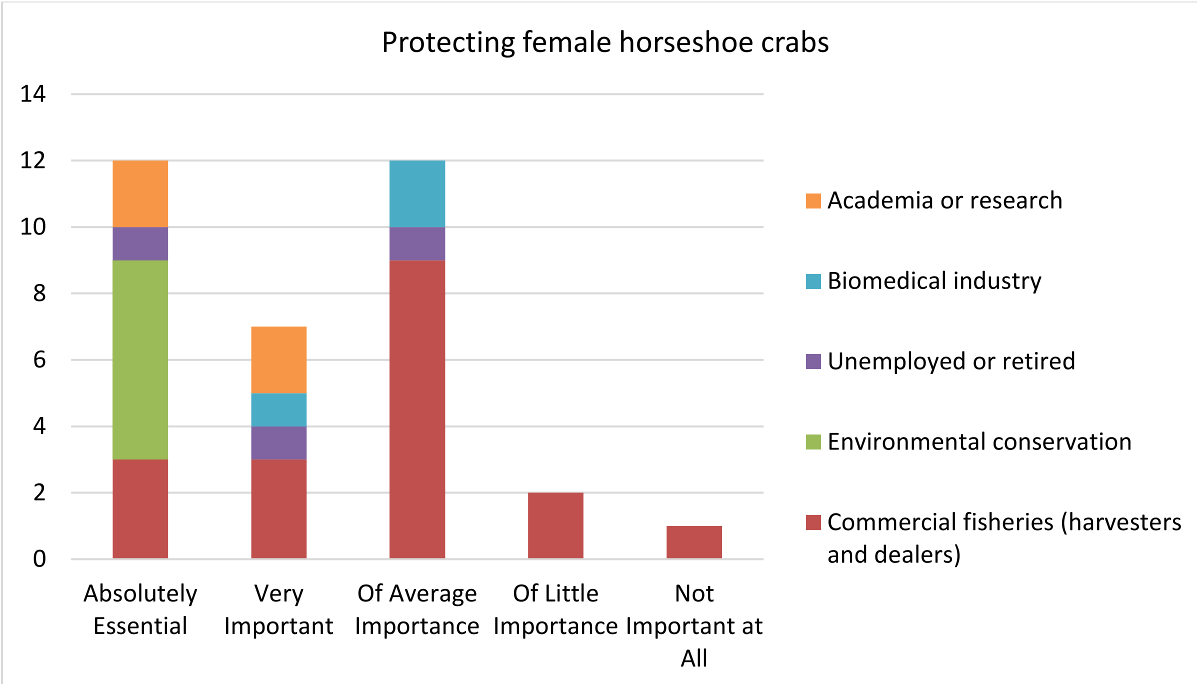

Figure A13. Importance of protecting female horseshoe crabs.

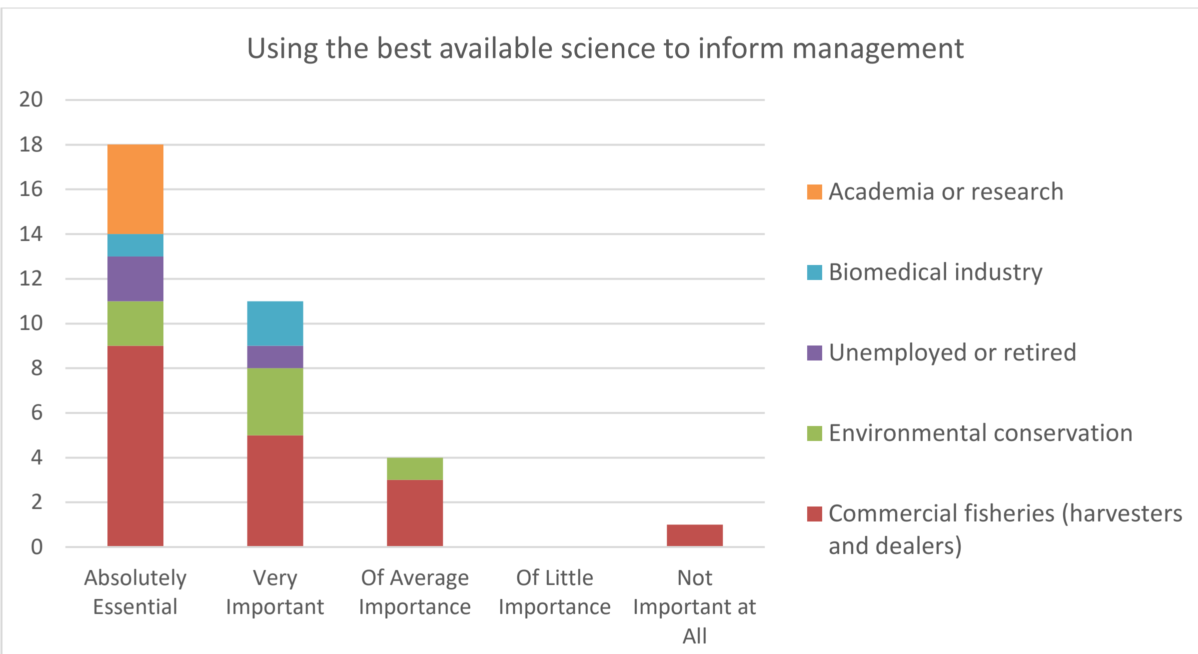

Figure A14. Importance of using the best available science to inform management.

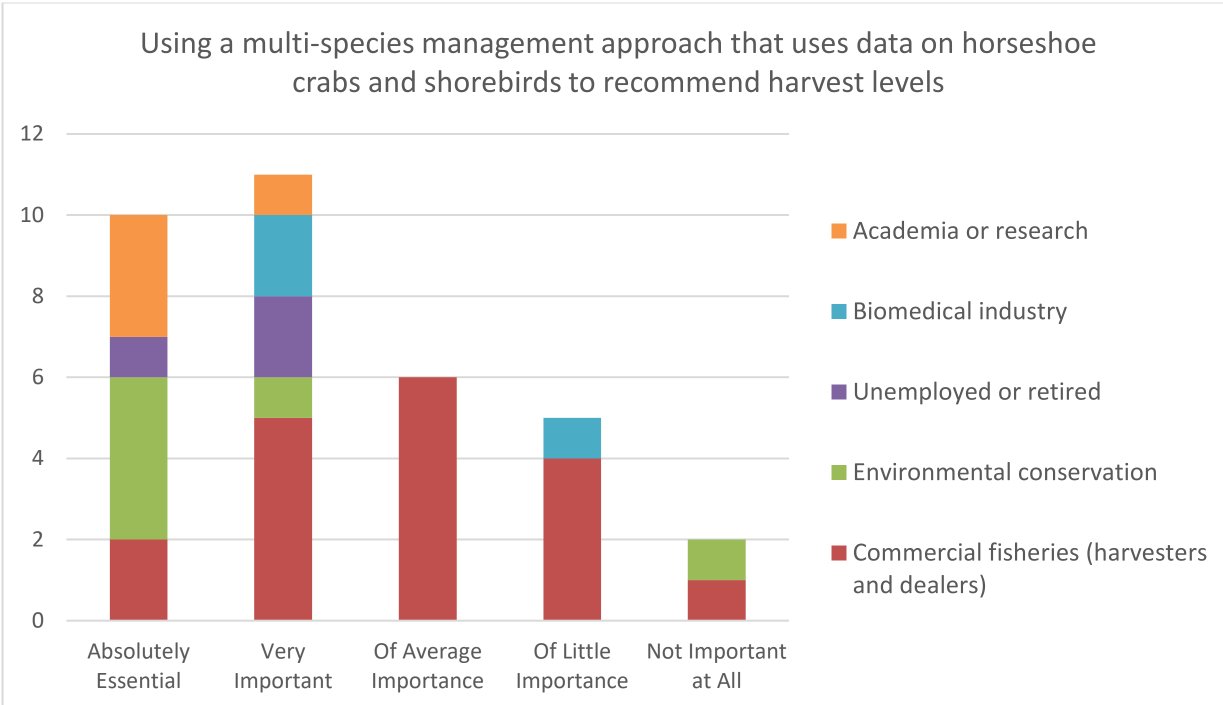

Figure A15. Importance of using a multi-species management approach.

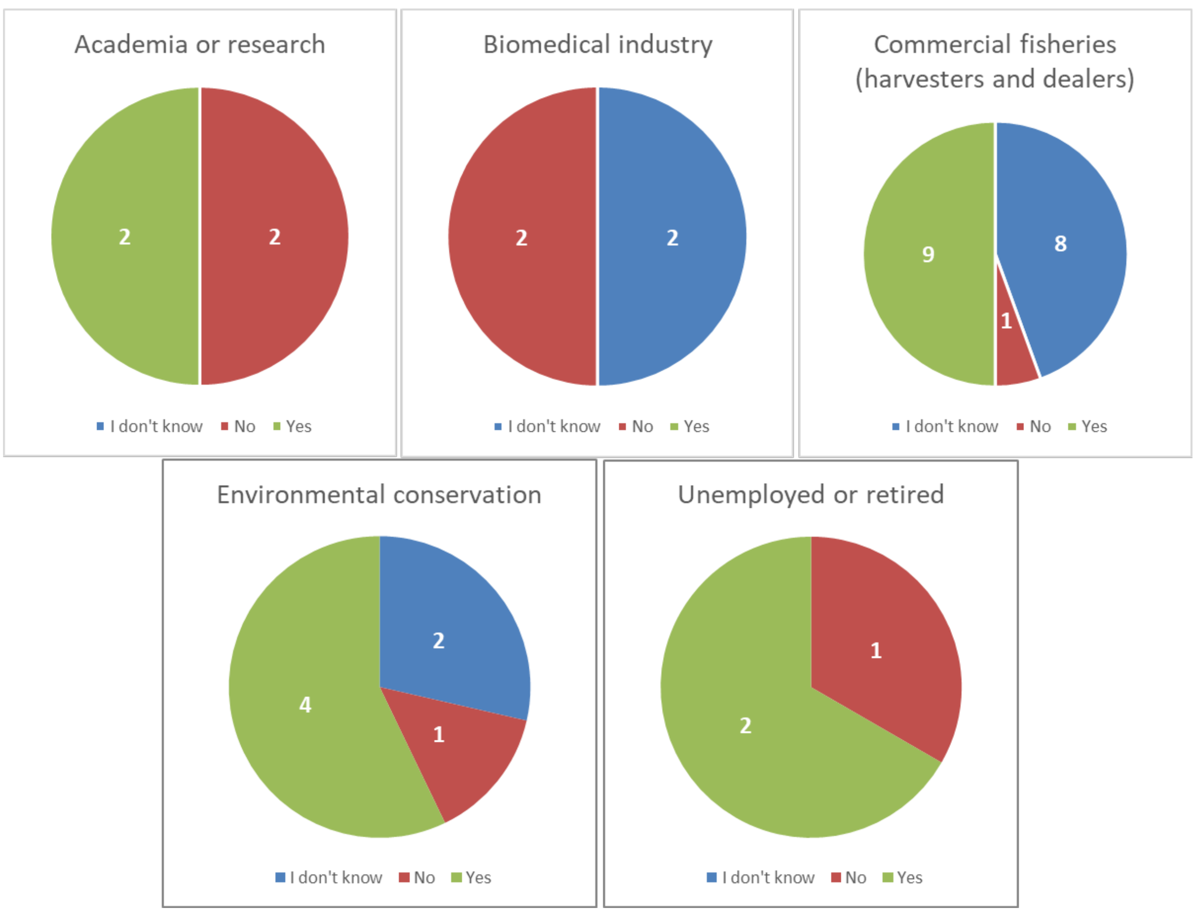

Figure A16. Opinion on whether the current ARM Model should be revised by occupational group.

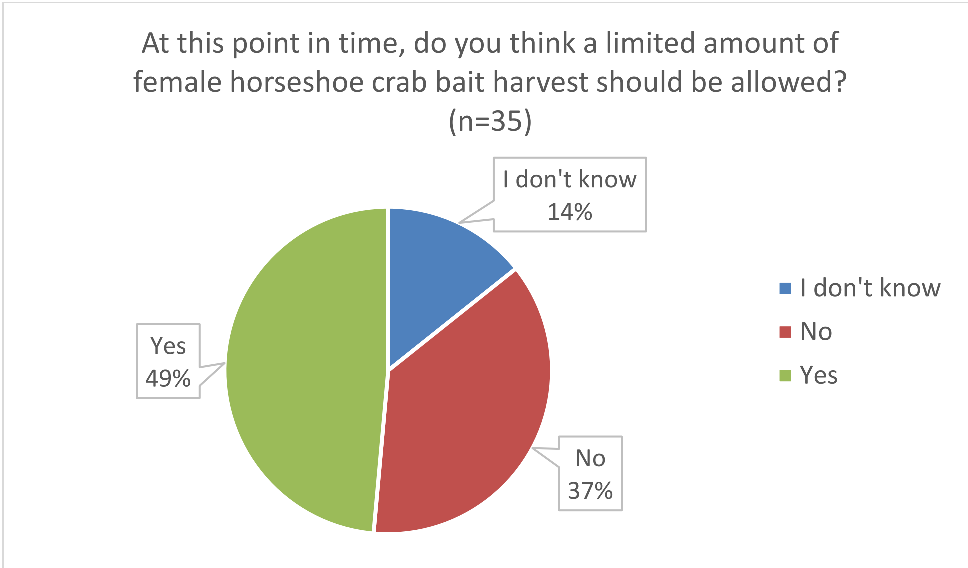

Figure A17. Opinion on allowing female bait harvest.

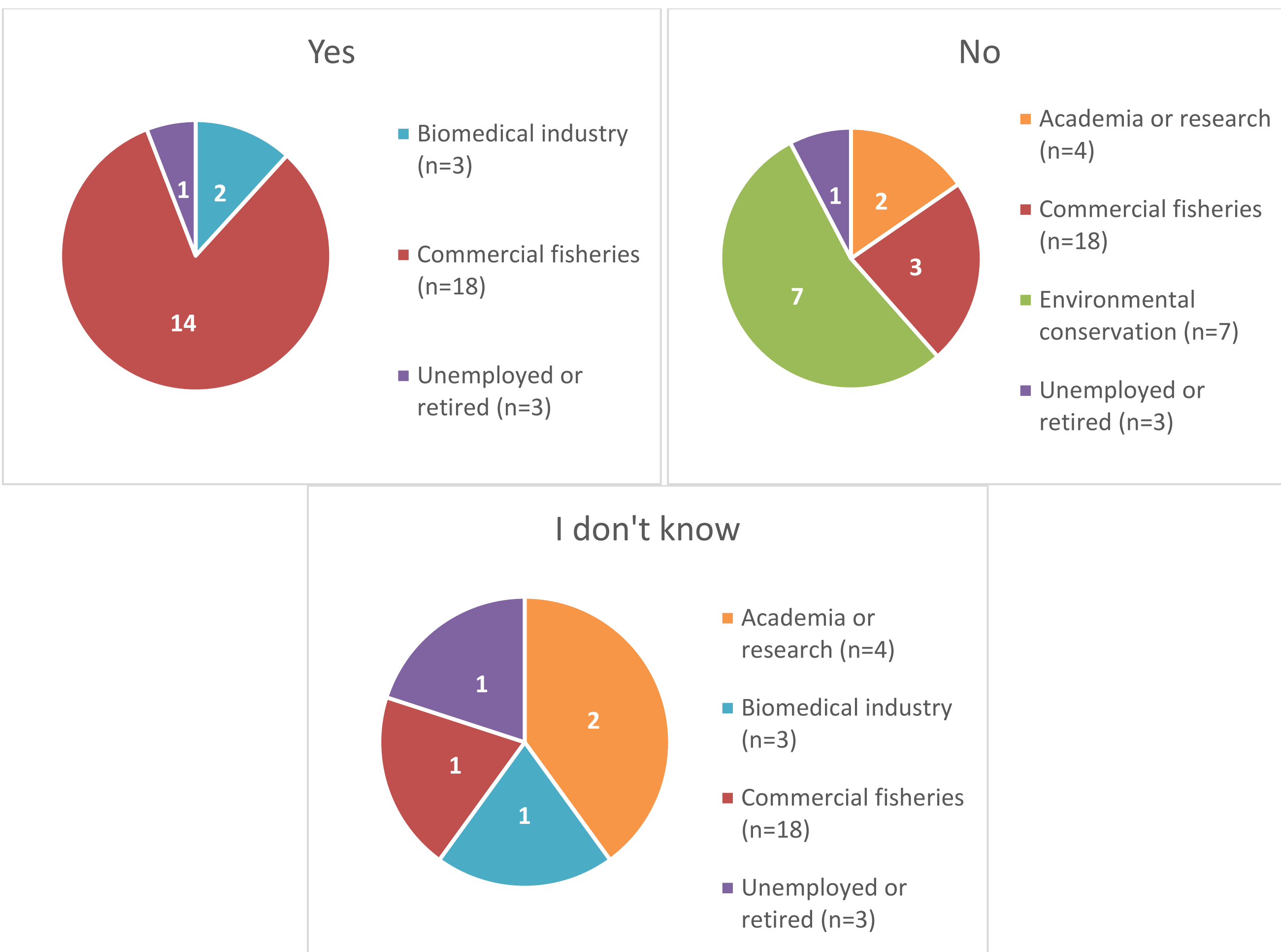

Figure A18. Makeup of respondents to Question 15 by answer provided.

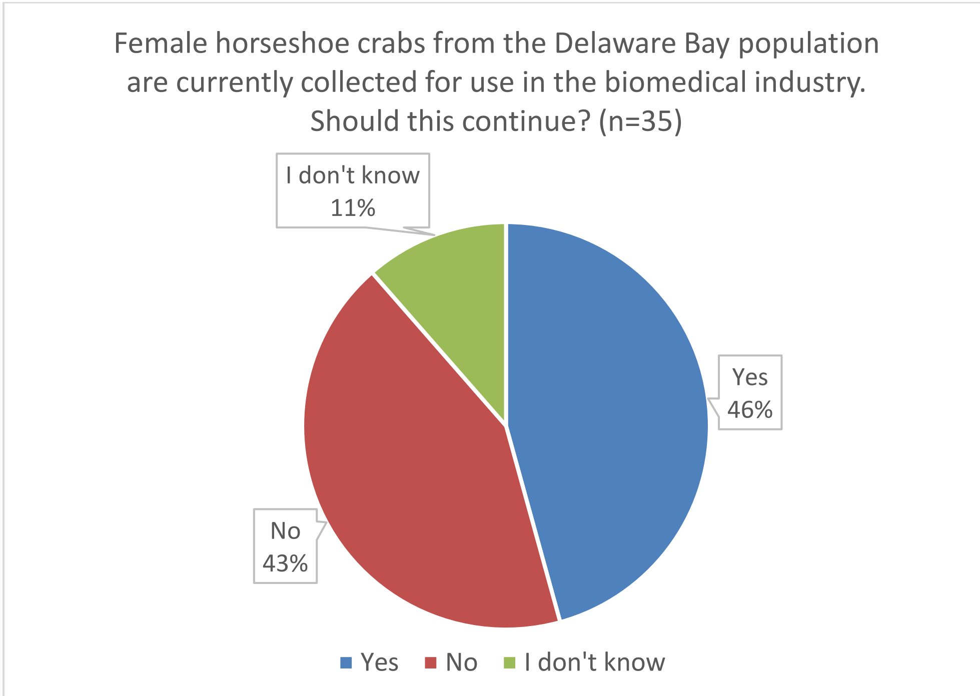

Figure A19. Opinion on use of female horseshoe crabs in the biomedical industry.

Atlantic States Marine Fisheries Commission

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MEMORANDUM

TO: Horseshoe Crab Management Board

FROM: Delaware Bay Ecosystem Technical Committee and Adaptive Resource Management Subcommittee

DATE: October 2, 2023

SUBJECT: Delaware Bay Horseshoe Crab Harvest Recommendation for 2024

This memo describes the 2024 harvest recommendation for Delaware Bay region horseshoe crabs using the methods from the Adaptive Resource Management, or ARM Framework (ASMFC 2022a). Since 2013, horseshoe crabs in the Delaware Bay Region (New Jersey, Delaware, Maryland, and Virginia) have been managed under the ARM Framework to set harvest levels with consideration of the needs of migratory shorebirds. The ARM was developed jointly by the Commission, U.S. Fish and Wildlife Service, and U.S. Geological Survey in recognition of the importance of horseshoe crab eggs to migratory shorebirds stopping over in the Delaware Bay region. In particular, horseshoe crab eggs are an important food source for the *rufa* red knot, which is listed as threatened under the Endangered Species Act.

Under Addendum VIII (ASMFC 2022b), the 2022 ARM Revision is used to annually produce bait harvest recommendations for male and female horseshoe crabs of Delaware Bay-origin based on the abundance of horseshoe crabs and red knots. The maximum number of male and female horseshoe crabs the ARM Revision can recommend is 500,000 males and 210,000 females. The ARM Revision was used for the first time to set harvest for the 2023 fishing year and the recommended harvest levels were 475,000 male and 125,000 female horseshoe crabs. Acknowledging public concern about the status of the red knot population in the Delaware Bay, the Board elected to implement harvest limits of zero female and 475,000 male horseshoe crabs for the 2023 season. To make up for the lost harvest of female crabs, the Board agreed to increase Maryland and Virginia's male harvest quotas with an offset ratio of 2:1 males to females.

1. Objective Statement

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

2. Population estimates

Red knot abundance estimates used to make harvest recommendations under the ARM Revision are based on mark-resight total stopover population estimates (Figure 1; Lyons 2023). The 2022 red knot population estimate was 39,800.

In the ARM Revision, all quantifiable sources of mortality (i.e., bait harvest, coastwide biomedical mortality, and commercial dead discards; Figure 2 - Figure 3) were used in the catch multiple survey analysis (CMSA) to estimate male and female horseshoe crab population estimates. 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. The harvest recommendation is based on the results using confidential biomedical data from the region. The Virginia Tech Trawl Survey estimates are used in the CMSA along with the New Jersey Ocean Trawl and the Delaware Fish and Wildlife Adult Trawl Surveys (ASMFC 2022a; Wong et al. 2023; Figure 4 -Figure 5).

In 2021, the number of newly mature female horseshoe crabs estimated in the Virginia Tech Trawl survey was zero (Table 1). 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.

To gap-fill the newly mature female horseshoe crab time series so there are no zeros, the ARM Subcommittee and DBETC decided to use an average ratio of newly mature to mature females from previous years. For 2002-2018, newly mature female horseshoe crabs comprised 19.9% of the total mature crabs (newly mature plus mature) in the Virginia Tech Trawl data. Additionally, the Delaware Adult Trawl Survey is used in the CMSA as an index of abundance and has been collecting staged data since 2017 (Figure 6). While the Delaware Adult Trawl has fewer years of stage data, the two stages have tracked each other also with an average of 19.9% of the female horseshoe crabs being newly mature for 2017-2022 (Figure 7). Using the average of 19.9%, the years of 2019-2022 in the Virginia Tech Trawl were adjusted where the observed newly mature and mature female horseshoe crabs were added together and then 19.9% 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 hard to reconcile the high number of mature female and low newly mature female horseshoe crabs in recent years given the single year time step. 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 8 - Figure 9). The Virginia Tech Trawl population estimates were 44.9 million male and 15.5 million female mature horseshoe crabs for comparison (Table 1).

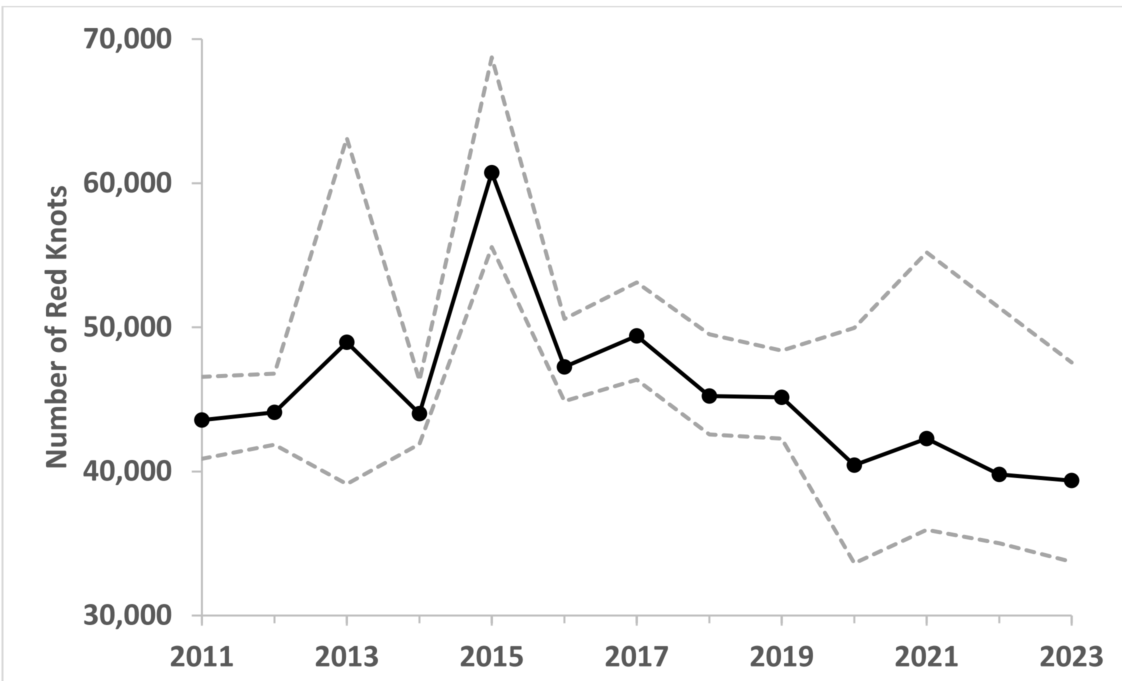

Figure 1. Mark-resight abundance estimates for the red knot stopover population with 95% confidence intervals, 2011-2023.

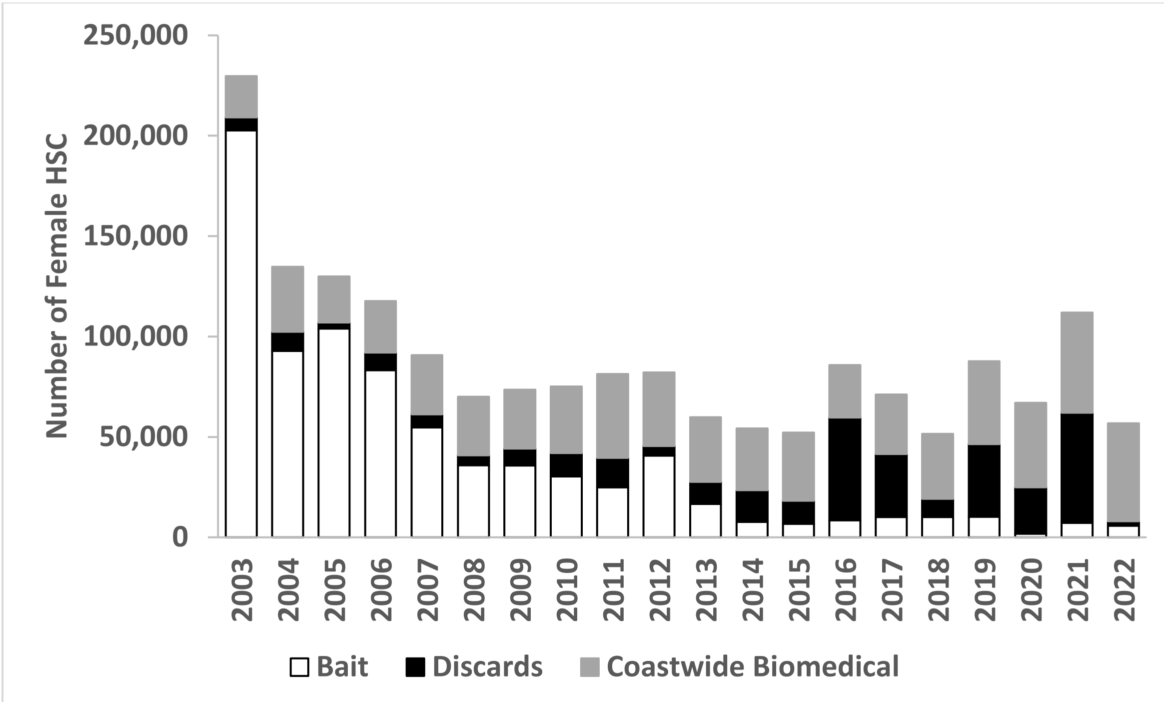

Figure 2. Total female horseshoe crab harvest by source in the Delaware Bay, 2003-2022.

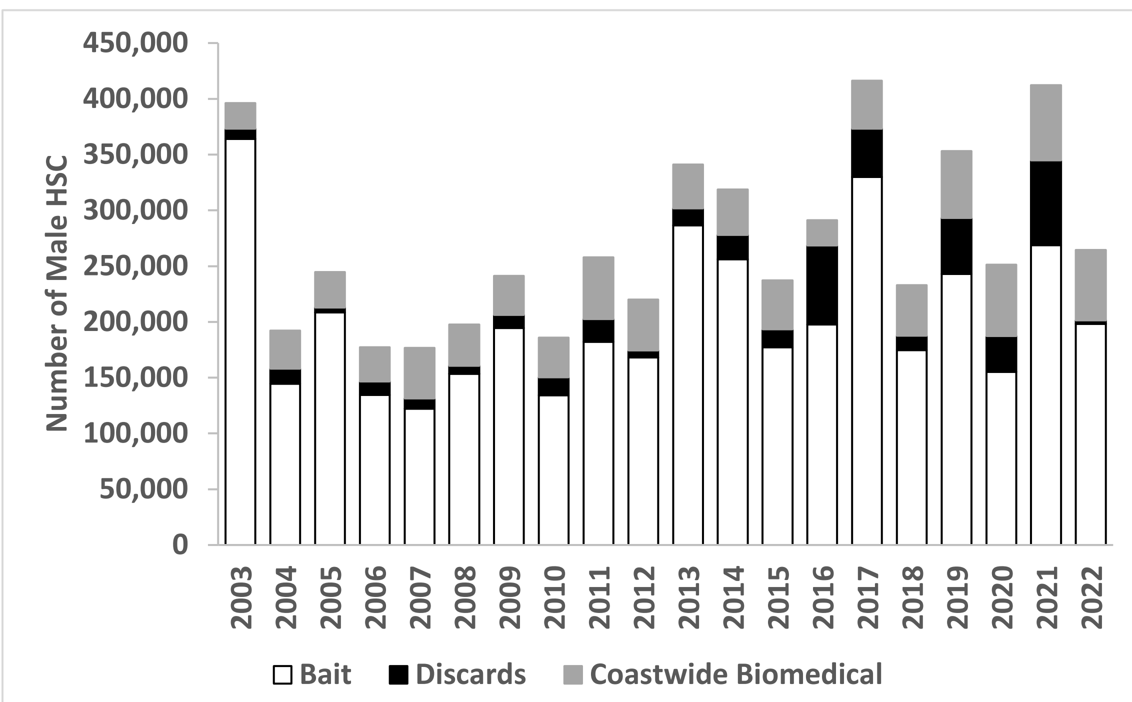

Figure 3. Total male horseshoe crab harvest by source in the Delaware Bay, 2003-2022.

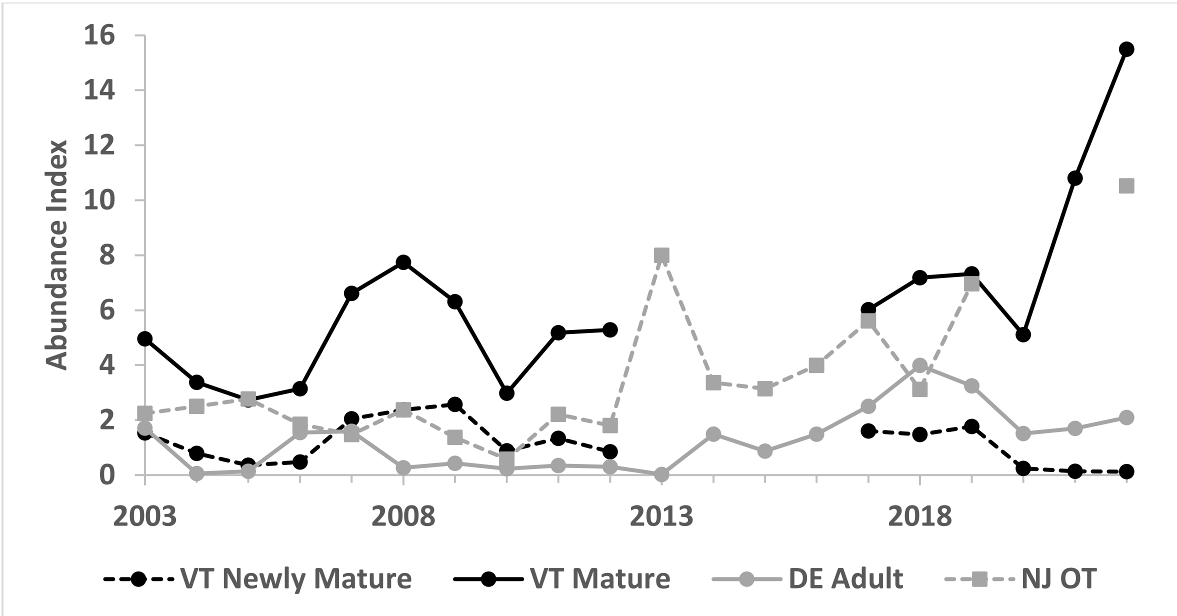

Figure 4. Female horseshoe crab abundance indices used in the CMSA. The Virginia Tech (VT) indices are in millions of newly mature and mature crabs while the Delaware Adult (DE Adult) and New Jersey Ocean Trawl (NJ OT) are in catch-per-tow.

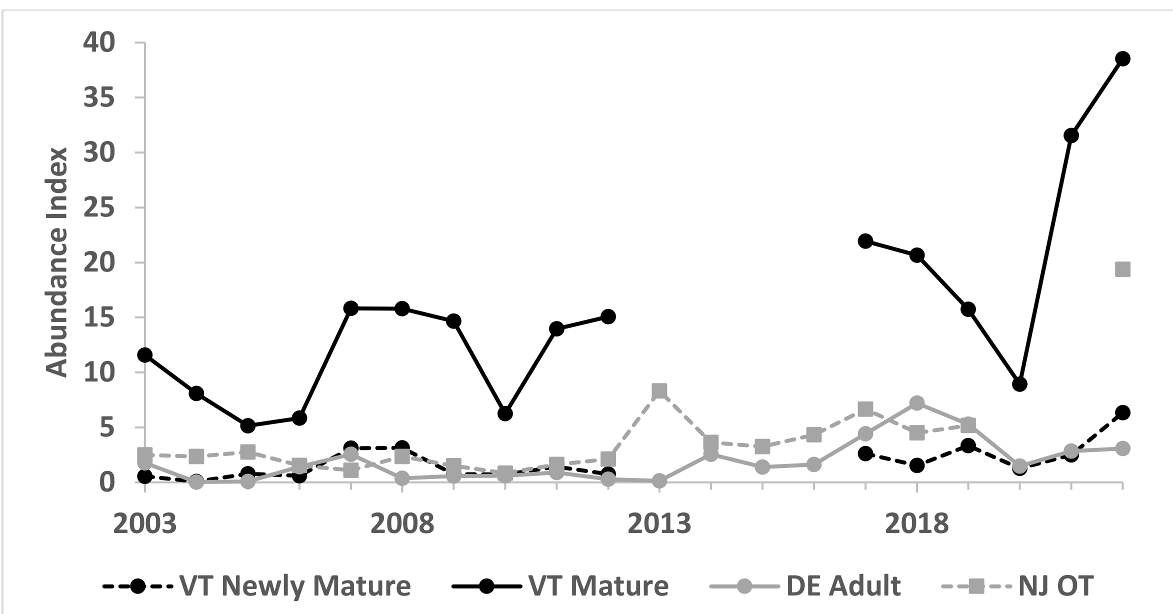

Figure 5. Male horseshoe crab abundance indices used in the CMSA. The Virginia Tech (VT) indices are in millions of newly mature and mature crabs while the Delaware Adult (DE Adult) and New Jersey Ocean Trawl (NJ OT) are in catch-per-tow.

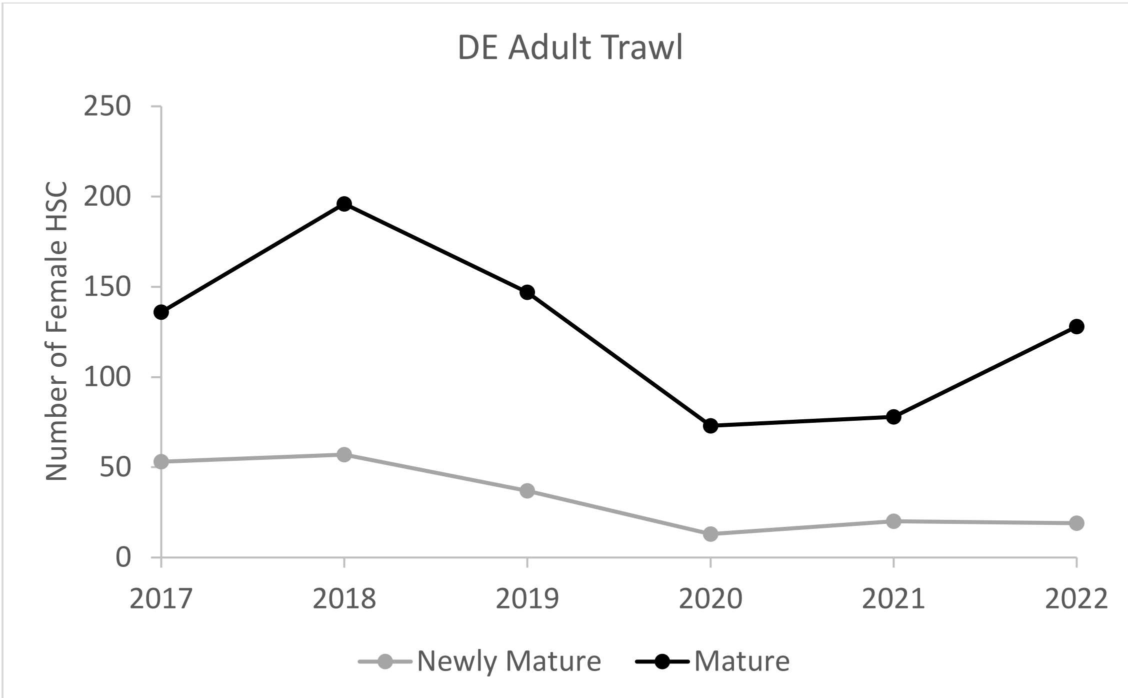

Figure 6. Mature and newly mature female horseshoe crabs caught in the Delaware Adult (30 foot) Trawl, 2017-2022.

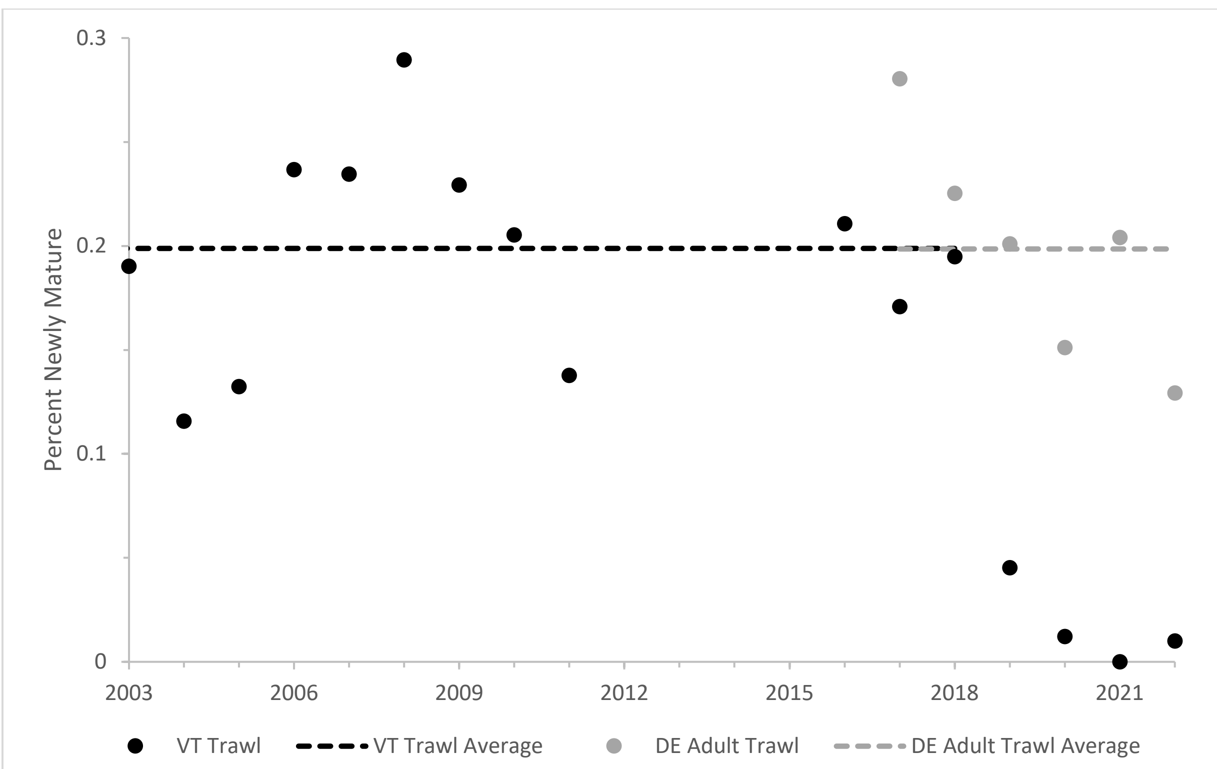

Figure 7. Percent of newly mature female horseshoe crabs in the Virginia Tech and Delaware Adult Trawls. The low years of newly mature female horseshoe crabs (2019-2022) were not included in the average for the Virginia Tech Trawl.

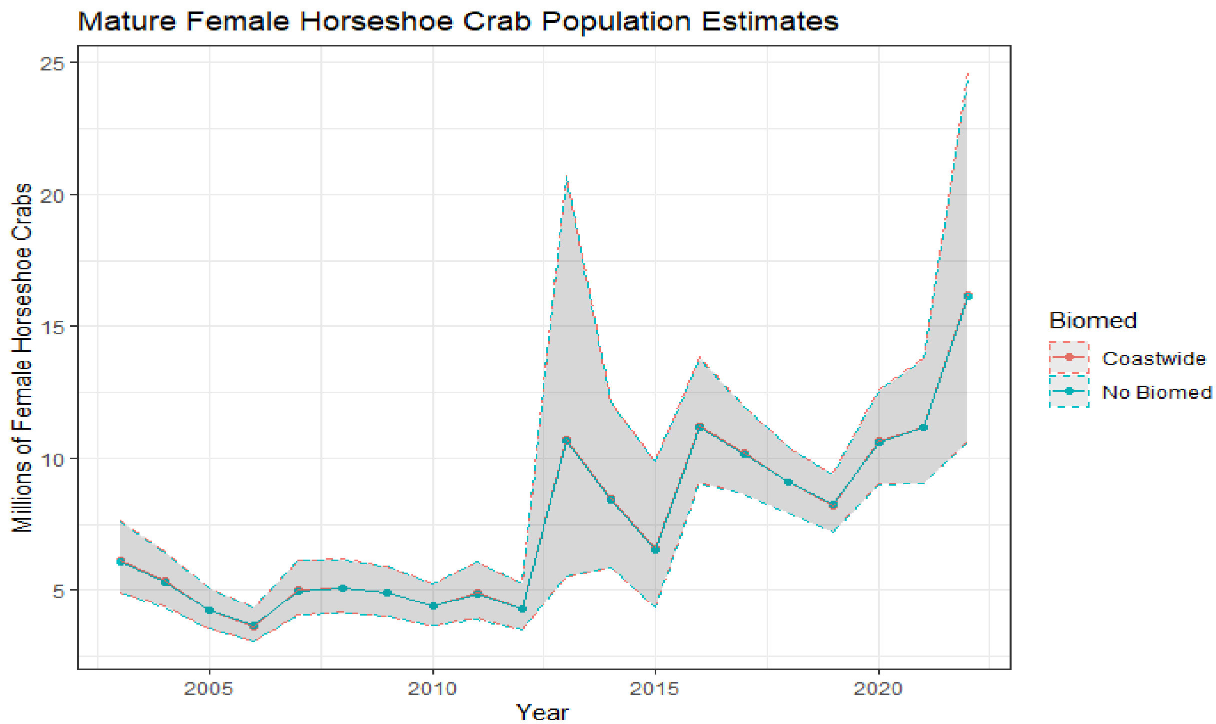

Figure 8. Population estimates from the CMSA for mature female horseshoe crabs with 95% confidence intervals. Delaware Bay biomedical data is confidential so population estimates using coastwide and zero biomedical data provide upper and lower bounds, although there is very little difference between the two and the time series overlap on the figures.

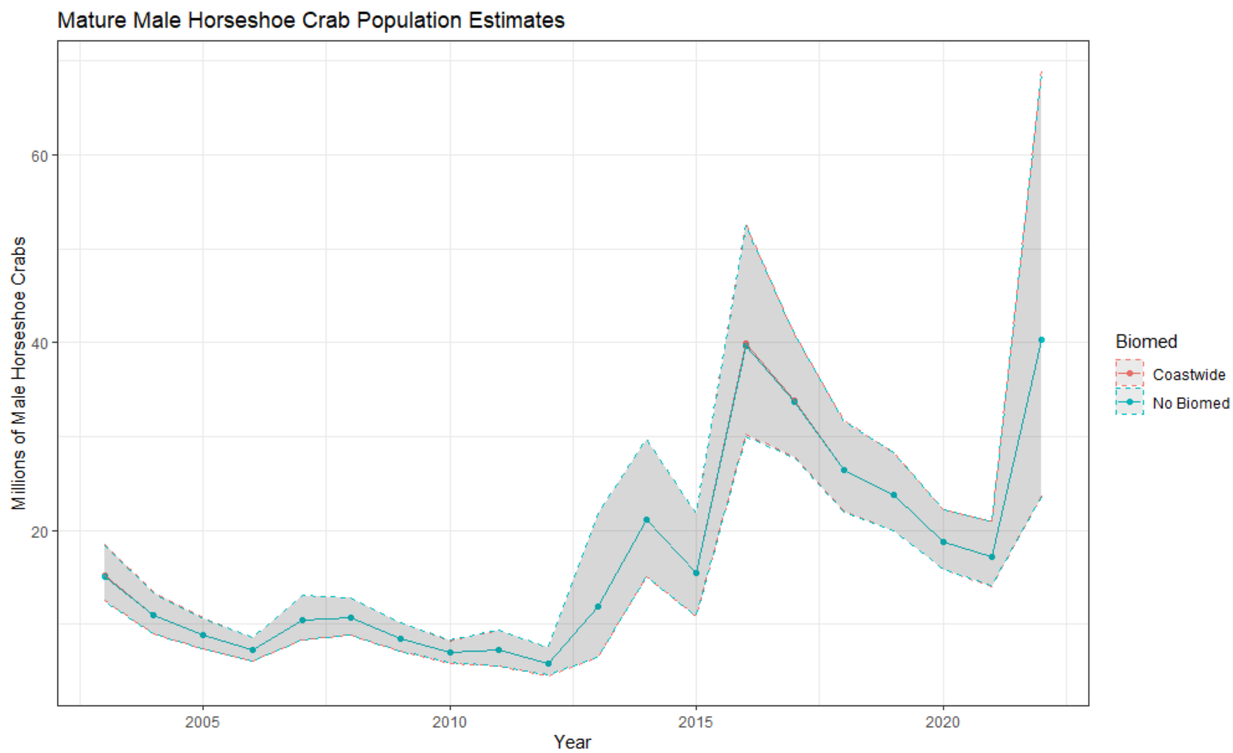

Figure 9. Population estimates from the CMSA for male horseshoe crabs with 95% confidence intervals. Delaware Bay biomedical data is confidential so population estimates using coastwide and zero biomedical data provide upper and lower bounds, although there is very little difference between the two and the time series overlap on the figures.

Table 1. 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

3. Harvest Recommendation

Harvest recommendations for the 2024 fishing year made using the ARM Revision are based on CMSA estimates of horseshoe crab abundance and the red knot mark-resight abundance estimates. ARM harvest recommendations are based on a continuous scale rather than the discrete harvest packages in the previous ARM Framework. Therefore, a harvest number up to the maximum allowable harvest could be recommended, not just the fixed harvest packages. Harvest of females is decoupled from the harvest of males so that each is determined separately. The maximum possible harvests for both females and males are maintained from the previous ARM Framework at 210,000 and 500,000, respectively.

The annual recommendation of allowable Delaware Bay horseshoe crab harvest is based on current state of the system (abundances of both species in the previous calendar year) and the optimal harvest policy functions from the ARM Revision. Annual estimates of horseshoe crab and red knot abundances are used as input to the harvest policy functions, which then output the optimal horseshoe crab harvest to be implemented. As per Addendum VIII, the optimal recommended harvest is rounded down to the nearest 25,000 crabs to uphold data confidentiality.

The harvest recommendation based on the ARM Framework for 2024 is 175,000 female and 500,000 male horseshoe crabs.

4. Quota Allocation

Allocation of allowable harvest was conducted in accordance with the methodology in Addendum VIII (Table 2).

Table 2. Delaware Bay-origin and total horseshoe crab quota for 2024 by state. Virginia total quota only refers to the amount that can be harvested east of the COLREGS line.

State	Delaware Bay-Origin Quota		Total Quota	
	Male	Female	Male	Female
Delaware	173,014	60,555	173,014	60,555
New Jersey	173,014	60,555	173,014	60,555
Maryland	132,865	46,503	126,410	44,243
Virginia	21,107	7,387	40,667	20,331
TOTAL	500,000	175,000	513,106	185,684

5. References

ASMFC. 2022a. Revision to the Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Inclusive of Red Knot Conservation and Peer Review Report. Arlington, VA. 302 pp.

ASMFC. 2022b. Addendum VIII to the Fishery Management Plan for Horseshoe Crab. Washington D.C. 12pp.

Lyons, J.E. 2023. Red Knot Stopover Population Estimate for 2023. Memorandum to the Delaware Bay ARM Working Group. U.S. Geological Survey Patuxent Wildlife Research Center, Laurel, Maryland. 13 pp.

Wong, C. Y. Jiao, and E. Hallerman. 2023. Results of the 2022 Horseshoe Crab Trawl Survey: Report to the Atlantic States Marine Fisheries Commission Horseshoe Crab and Delaware Bay Ecology Technical Committees. 28 pp.

Results of the 2022 Horseshoe Crab Trawl Survey:

Report to the Atlantic States Marine Fisheries Commission Horseshoe Crab and Delaware Bay Ecology Technical Committees

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Abstract

With the continued growth of the mid-Atlantic horseshoe crab (*Limulus polyphemus*) fishery, annual analyses of the population dynamics of key demographic groups are needed for defensible, science-based management. We conducted a trawl survey within the lower Delaware Bay and along the coast of the Delaware Bay area (DBA – Virginia to New Jersey), quantified mean catch per 15-minute tow, and compared relative abundance of demographic groups with those of prior years. Due to time constraints, no trawls were performed in the lower Delaware Bay this year. Mean catch-per-tow of all demographic groups were similar to last year's analysis, with the exception of the increase in newly mature females, which were not caught in the previous survey. Mean stratified catch-per-tow for all demographic groups continues to be highly variable, although mature females appear to show a positive trend over the study period. Newly mature males also appear to exhibit an increasing trend in recent years. Prosomal widths of all demographic groups, except immature individuals, show decreasing trends over the time-series in the DBA. Our findings will be used to parameterize the Adaptive Resource Management model used to set annual harvest levels for horseshoe crabs.

Introduction

To effectively manage the mid-Atlantic horseshoe crab (*Limulus polyphemus*) fishery, accurate information on relative abundance levels and trends is needed. The Adaptive Resource Management model (McGowan et al. 2011) adopted by the ASMFC requires annual, fishery-independent indices of newly mature recruit and adult abundances. Since its inception, the ARM Framework has used the VT trawl survey's swept area-based population estimates of horseshoe crab numbers and a theoretical population model developed primarily from literature-derived values. With more data collected in the region in recent years and other sources of mortality that can now be quantified, Anstead et al. (in press) developed a catch multiple survey analysis (CMSA) for Delaware Bay horseshoe crabs to provide robust population estimates for harvest management. The CMSA provides the best and most comprehensive population estimates of horseshoe crabs in the region and will improve modeling efforts within the ARM Framework going forward. The purpose of this project was to conduct a horseshoe crab trawl survey along the Mid-Atlantic coast in order to: (1) determine horseshoe crab relative abundance, (2) describe horseshoe crab population demographics, and (3) track inter-annual changes in horseshoe crab relative abundance and demographics. Here, we report our cumulative results through the fall 2022 trawl survey.

We have provided the Adaptive Resource Management (ARM) Subcommittee relative abundance estimates of horseshoe crabs in the DBA and LDB surveys to inform the ARM model runs. Herein, we present the population estimates through the 2022 survey. Gear catchability has not been evaluated for these estimates, so they should be considered conservative.

Methods

The Virginia Polytechnic Institute and State University horseshoe crab trawl survey is traditionally conducted in two areas (Figure 1). The coastal Delaware Bay area (DBA) survey extended in the Atlantic Ocean from shore out to 22.2 km (12 nautical miles), and from 39º 20' N (Atlantic City, NJ) to 37º 40' N (slightly north of Wachapreague, VA). This area was previously sampled from 2002 to 2011, and again from 2016 to 2022. The lower Delaware Bay (LDB) survey area, which extends from the Bay mouth to a line between Egg Island Point, New Jersey and Kitts Hummock, Delaware, was not sampled this year due to budget and time constraints. The LDB was previously sampled from 2010 to 2012 and 2016 to 2021. The surveys were conducted between 2 August to 12 October 2022.

The DBA survey area was stratified by distance from shore (0-3 nm, 3-12 nm) and bottom topography (trough, non-trough) as in previous years. The LDB survey area was stratified by bottom topography only, as in previous years. Sampling was conducted aboard a 16.8-m chartered commercial fishing vessel operated out of Ocean City, MD. We used a two-seam flounder trawl with an 18.3-m headrope and 24.4-m footrope, rigged with a Texas Sweep of 13-mm link chain and a tickler chain. The net body consisted of 15.2-cm (6-in) stretched mesh, and the bag consisted of 14.3-cm (5 5/8-in) stretched mesh. Tows were usually 15-minutes bottom time, but were occasionally shorter to avoid fishing gear (e.g., gill nets, crab and whelk pots) or vessel traffic. Start and end positions of each tow were recorded when the winches were stopped and when retrieval began, respectively. Bottom water temperature was recorded for each tow. We sampled 41 stations in the DBA survey. Two of these trawls were shorter in duration than average, one being a six-minute tow within our inshore/non-trough stratum and the other being a one-minute trawl in the offshore/trough stratum. Data from this latter one-minute trawl was not included in our data analysis as there were net malfunctions that resulted in the loss of the net. We included the six-minute inshore/non-trough trawl in our analysis as it did not involve net malfunction and hence provides useful data. Additionally, due to the high variance in CPUE and density of HSCs in each stratum (Figure 2), a larger sample size will help better explain variability.

Horseshoe crabs were culled from the catch, and either all individuals or a subsample were examined for prosomal width (PW, millimeters) and identified for sex and maturity. Maturity classifications were: immature, newly mature (those that are capable of spawning but have not yet spawned), and mature (those that have previously spawned). Newly mature and mature males are morphologically distinct and are believed to be classifiable without error. However, some error is associated with distinguishing newly mature from immature females. All examined females that were not obviously mature (i.e., bearing rub marks) or immature (too small or soft-shelled) were probed with an awl to determine presence or absence of eggs. Females with eggs but without rub marks were considered newly mature. Females with both eggs and rub marks were considered mature. Initial sorting classifications were: presumed adult males (newly mature and mature), presumed adult females, and all

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immature. Up to 25 adult males, 25 adult females, and 50 immatures were retained for examination. The remainder were counted separately by classification and released. Characteristics of the examined subsamples were then extrapolated to the counted portions of the catch

In each stratum, the mean catch per 15-minute tow and associated variance were calculated using two methods, i.e., either assuming a normal-distribution model or a delta-lognormal distribution model (Pennington, 1983). Stratum mean and variance estimates were combined using formulas for a stratified random sampling design (Cochran, 1977). The approximate 95% confidence intervals were calculated using the effective degrees of freedom (Cochran, 1977). Annual means were considered significantly different if 95% confidence limits did not overlap. Stratified means calculated using the delta-lognormal distribution model are not additive - i.e., means calculated for each demographic group do not sum to the mean calculated using all crabs. Means calculated using the normal-distribution model are additive, within rounding errors.

Annual size-frequency distributions, in intervals of 10-mm prosomal width, were calculated for each sex/maturity category by pooling size-frequency distributions of all stations (adjusted for tow duration if necessary) in a stratum in a year to determine the relative proportions for each size interval. Those proportions then were multiplied by the stratum mean catch-per-tow that year to produce a stratum size-frequency distribution. Stratum size-frequency distributions then were multiplied by the stratum weights and added in the same manner as calculating the stratified mean catch per tow. Areas under the distribution curves represent the stratified mean catch per tow at each size interval.

Within the DBA, excluding the one shorter trawl, the average tow distance for a 15-min tow was 1.50 kilometers at a speed of 4.80 KPH. No net-spread measurement device was used during sampling. Instead, net-spread was calculated using the net-spread regression relationship, *net spread* (*S,* in meters)/tow speed (*C,* in KPH), developed from previous trawl *surveys* ($S = 13.84 - 0.858 \times C$). From our combined 40 tows, the average net-spread was 8.68 meters.

For each tow, catch density (catch/km^2) was calculated from the product of tow distance (in km) and estimated net-spread (converted from meters to km) assuming that all fishing was done only by the net, and that there was no herding effect from the ground gear (sweeps):

$$\text{catch/km}^2 = \text{catch}/[\text{tow distance (km)} \times \text{net-spread (km)}].$$

Within each stratum, the mean catch per square-kilometer and associated variance were calculated assuming a normal-distribution model and a lognormal delta-distribution model. Stratum mean densities and variance estimates were combined to produce a stratified mean density ($\bar{X}_{st}$) using formulas for a stratified random sampling design as with the catch-per-tow estimates described above. Population totals were estimated by multiplying stratified mean density ($\bar{X}_{st}$) by survey area (DBA = 5127.1 km^2; LDB = 528.4 km^2):

$$\text{Population total} = \bar{X}_{st} \times (5127.1 \text{ or } 528.4 \text{ km}^2)$$

Results

<u>Delaware Bay Area</u>

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For all demographic groups other than newly mature males, mean stratified catch-per-tow values have remained relatively consistent between 2016 and 2018. Since then, there has been a substantial increase in variation over the past four years among newly mature and mature individuals (Tables 1 and 2; Figure 3). While the mean stratified catches-per-tow for newly mature males and mature individuals decreased compared to last year, means for newly mature females and immature individuals all exhibited an increase. No estimates were significantly different from last year, besides newly mature females, as none were caught last year.

There is a significant correlation between stratified mean catches of mature males and mature females ($r = 0.94$; $p < 0.001$; $T = 10.81$; $n = 17$) when considering all data since 2002. This is also true for immature males and females ($r = 0.98$; $p < 0.001$; $T = 19.36$; $n = 17$), but not for newly mature individuals. Previously, there was a significant positive correlation between newly mature individuals between 2002 – 2018. However, this correlation was lost with the addition of data from 2019 and 2022, likely due to the low number of newly mature females trawled in recent years compared to newly mature males. For example, newly mature females were caught in only 15% of all trawls performed in 2022 for a total of 8 measured individuals. Newly mature males were caught in 40% of the forty trawls performed this year for a total of 82 measured individuals.

Lower Delaware Bay

No samples were collected within the Delaware Bay in 2022 as with rising operating costs, time became limiting. Since 2016, there has been a relative decrease in the mean relative abundances of almost all demographic groups in the LDB except newly mature females, which have remained consistently low. The mean stratified catch-per-tow in 2021 increased significantly from 2020 for immature females, immature males, and mature females (Tables 3 and 4; Figure 4). No newly mature females have been trawled in the LDB since 2018, and in 2021, no newly mature males were caught. 2021 presented the lowest mean value for newly mature males in the time series. Mean catches of mature males were significantly correlated with mean catches of mature females ($r = 0.91$; $p < 0.001$; $T = 5.9831$; $n = 9$). This was also present among immature males and immature females ($r = 0.97$; $p < 0.001$; $T = 11.513$; $n = 9$).

Size distributions

Similar to results in last year's report, size-frequency distributions remained highly variable (Figure 5). There were no distinct modal groups simultaneously in both sexes other than in 2009 for immature individuals. However, this modal group did not continue into the following years and was not found within previous year of sampling in the lower Delaware Bay (Figure 6).

We had previously reported that mean prosomal widths of mature and newly mature and mature male and female crabs in the DBA survey displayed slight, but detectable, decreases over time (Table 5, Figure 7) (Hata and Hallerman 2017, 2019, Hallerman and Jiao 2020). This trend appears to have continued this year within the Delaware Bay area. The negative correlation between years and mean prosomal width of newly mature and mature individuals strengthened compared to last year and remained statistically significant. The LDB portion of the table has been retained for comparison but has not changed from our previous analysis as no new data were added. A similar trend is present within the LDB amongst newly mature females and mature individuals.

Sex ratios

Overall, mature males were generally twice as common as mature females throughout the sampling period. Sex ratios (M:F) from mean catch-per-tow within the DBA ranged from 1.72 in 2019 to 3.64 in 2016, with an average of 2.38 over the time series. Male to female sex ratios in newly mature individuals have been highly variable, ranging from 0.11 in 2003 to 47.7 in 2022, with a new overall average of 5.70 over the time-series. This may reflect sampling effects, temporal variability in recruitment to the newly mature class relative to survey period, or differences in year-class abundance because females are believed to mature a year later than males.

Compared to the coast, the lower Delaware Bay continues to have a much higher male-to-female sex ratio in mature individuals. These values for mature individuals have ranged from 2.60 in 2018 to 20.5 in 2020, with an average of 5.98. This relationship between the coast and bay has been historically similar for newly mature individuals, with a low of 0.45 in 2010 and high of 6.10 in 2012. Excluding 2019 and 2020 — where newly mature males were caught but no newly mature females — led to an average of 3.09. The higher sex ratios within Delaware Bay may reflect a tendency for male horseshoe crabs to remain near the spawning beaches.

Population estimates

Annual population estimates of immature crabs in the DBA survey mirror trends observed in the catch-per-tow estimates and have been variable over time, with a large peak in 2009 (Tables 6 and 7). Compared to the previous year, estimated mean population total decreased for mature individuals and newly mature males, while newly mature females and immature individuals have increased. Assuming the normal distribution, the significance found in catch-per-tow estimates is mirrored in population total estimates. These mean population total estimates are similar to those seen since 2016 for immature individuals. Newly mature-males and mature individuals appear to have a recent increasing trend, while newly mature females appear to show a recent decreasing trend. There is a significant correlation between population estimates for mature males and females ($r = 0.92$; $p < 0.001$; $T = 9.18$; $n = 17$) and immature males and females ($r = 0.99$; $p < 0.001$; $T = 32.571$; $n = 17$), as observed in mean catches per tow above. There is no significant correlation amongst newly mature individuals in the DBA.

Lacking new data, population estimates for immature crabs in lower Delaware Bay in 2022 are not available. The estimates in 2021 were consistent with coastal estimates since the LDB survey began in 2010 (Tables 8 and 9). Despite the LDB representing only 9.3% of the entire sampling area, 19.4% of immature males and 15.3% of immature females were collected in this area over the time-series. In 2021, only 5.2% of immature males and 3% immature females were collected within the lower Delaware Bay. Proportions of newly mature crabs within the LDB compared to the DBA in 2021 are most similar to what one would expect based on the sample area that the LDB represents within the total available sampling area. Newly mature females from the LDB on average represent only 4.8% of the total population during the time series, along with newly mature males representing only 7.3%. No immature males or females were caught inside the LDB in 2021. On average, only 16% of mature males and 11% of mature females occurred within the lower Delaware Bay. In 2021, less than 1% of mature males, and mature females, were caught in the LDB. This low representation of mature individuals within the lower Delaware Bay is likely due to grown, mature individuals moving offshore towards the continental shelf, away from nursery grounds.

Effects of sampling period

Sampling in the Delaware Bay Area occurred primarily during September and early October, with the last trawls occurring October 12th. This time frame is similar to those in sampling years prior to 2019, as trawls between 2019 – 2021 were performed earlier in August and September. Although the water temperature was lower than last year, it was similar to the higher average water temperature seen in the past six years compared to sampling prior to 2016 (Table 10; Figure 8). This more consistent temperature within the Delaware Bay Area is in contrast to the lower Delaware Bay, where average water temperature is more directly inversely proportional to the ordinal date.

When comparing water temperature and the time of our sampling period, there appears to be a correlation within the DBA of mean catches-per-tow of immature males and females with both water temperature ($p = 0.026$, $p = 0.028$) and ordinal date ($p = 0.016$, $p = 0.019$) (Table 11). This is also seen in mature males ($p_{temp} = 0.014$, $p_{date} = 0.001$) and females ($p_{temp} = 0.020$, $p_{date} = 0.002$). For newly mature males, there appears to be a correlation only among newly mature females and ordinal date ($p = 0.036$).

Key Findings

1. Mean catches-per-tow among all demographic groups was similar to last year, with the exception of newly mature females, which were caught this year unlike the previous year.
2. Mean catch-per-tow of immature male and female horseshoe crabs in the coastal Delaware Bay area have remained variable since 2002 and have no apparent trend.
3. Mean catch-per-tow of newly mature male horseshoe crabs in the coastal Delaware Bay area remained highly variable, with newly mature males showing a weak positive trend since 2016, while newly mature females have remained relatively low since 2019.
4. Mean catch-per-tow of mature male and female horseshoe crabs in the coastal Delaware Bay area continue to be highly variable, with their highest points in 2021, with mature-females appearing to show a positive trend since 2016.
5. Mean catch-per-tow of all demographic groups except newly mature males in the DBA may be correlated with ordinal date. Mean catch-per-tow of immature and mature individuals may be correlated with temperature.
6. Annual mean prosomal width appears to still be decreasing in mature and newly mature males and females in the DBA.

Literature Cited

Anstead, K.A., J.A. Sweka, L. Barry, D.R. Smith, E.M. Hallerman, R.A. Wong, M. Schmidtke, and N. Ameral. 2023. Application of a catch multiple survey analysis for horseshoe crab in the Delaware Bay. Coastal and Marine Fisheries, in press.

Cochran, W. G. 1977. Sampling Techniques, 3rd ed. John Wiley and Sons, Inc., New York. 428 p.

Hata, D. and E. Hallerman. 2017. Results of the 2016 Horseshoe Crab Trawl Survey: Report to the Atlantic States Marine Fisheries Commission Horseshoe Crab and Delaware Bay Ecology Technical Committees.

Hata, D. and E. Hallerman. 2019. Results of the 2018 Horseshoe Crab Trawl Survey: Report to the Atlantic States Marine Fisheries Commission Horseshoe Crab and Delaware Bay Ecology Technical Committees.

Hallerman, E. and Y. Jiao. 2021. Results of the 2020 Horseshoe Crab Trawl Survey: Report to the Atlantic States Marine Fisheries Commission Horseshoe Crab and Delaware Bay Ecology Technical Committees.

McGowan, C.P., D. R. Smith, J. A. Sweka, J. Martin, J. D. Nichols, R. Wong, J. E. Lyons, L. J. Niles, K. Kalasz, J. Brust, and M. Klopfer. 2011. Multispecies modeling for adaptive management of horseshoe crabs and red knots in the Delaware Bay. Natural Resource Modeling 24:117-156.

Pennington, M. 1983. Efficient estimators of abundance, for fish and plankton surveys. Biometrics 39:281-286.

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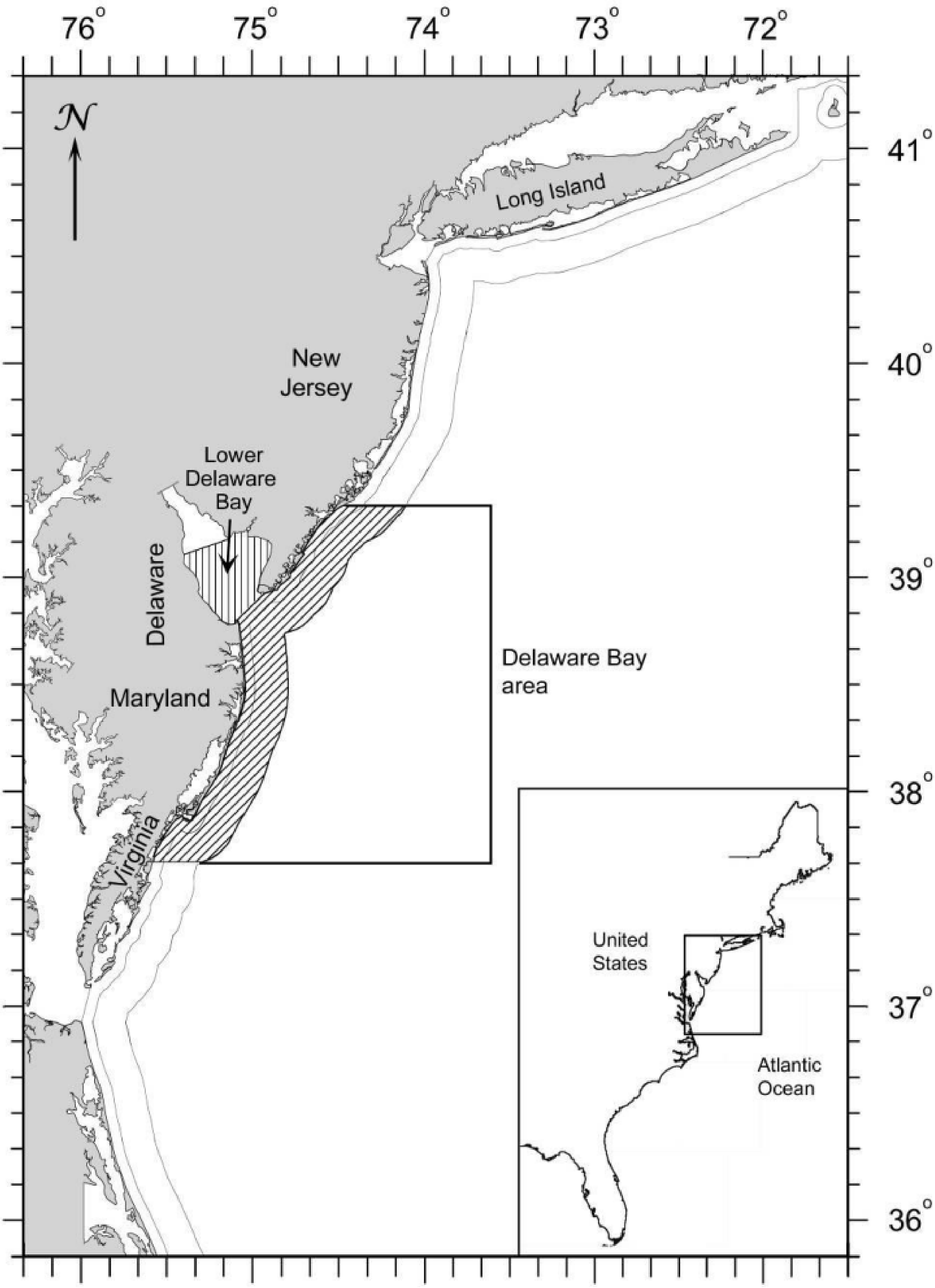

Figure 1. Fall 2022 horseshoe crab trawl survey sampling area. The coastal Delaware Bay area (DBA) and Lower Delaware Bay (LDB) survey areas are indicated. Mean catches between years were compared using stations within the shaded portions of the survey areas.

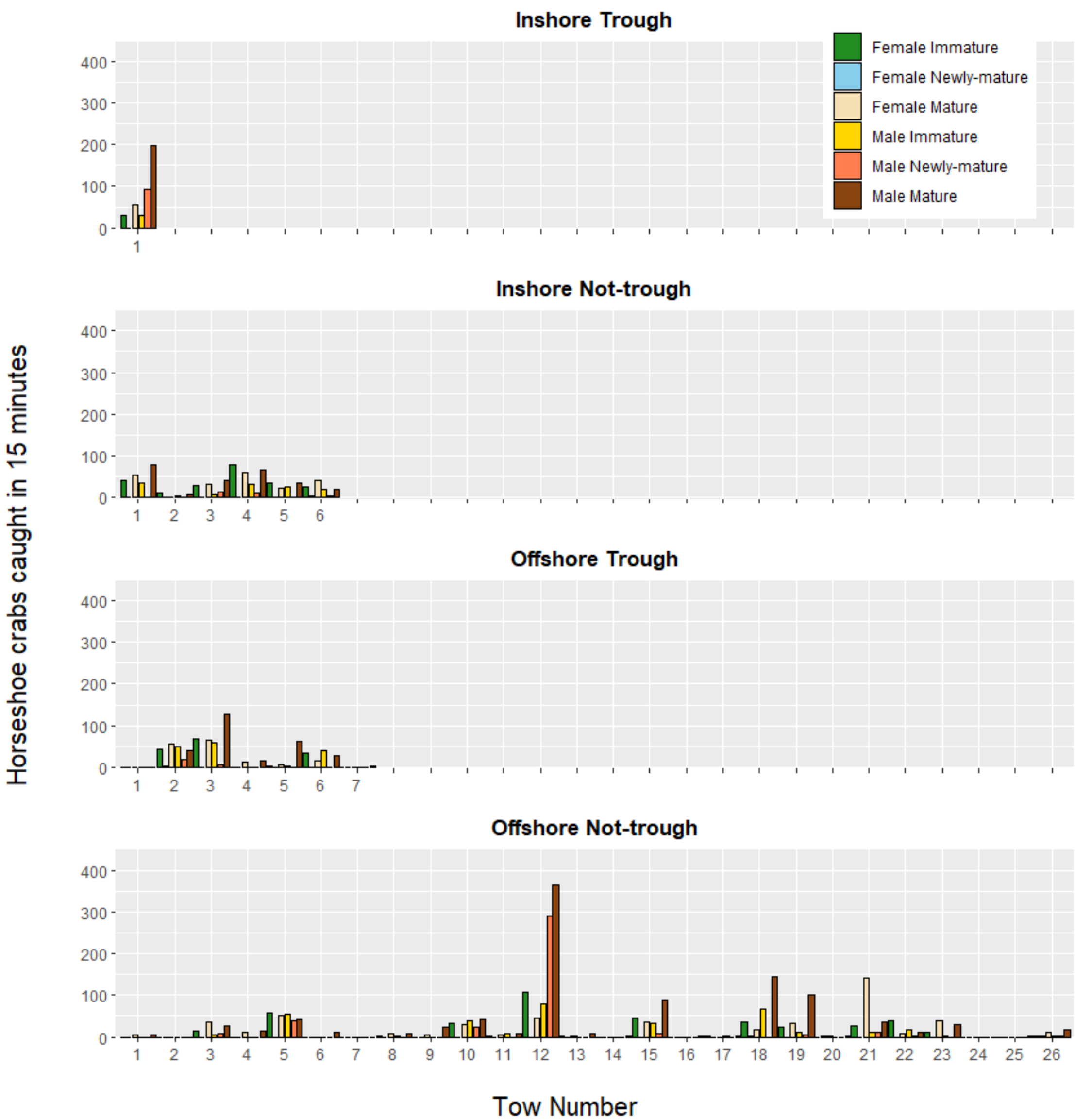

Figure 2. Plots showing high variability of relative abundances of horseshoe crabs of different demographic groups caught within the same strata in fifteen-minute tows in 2022.

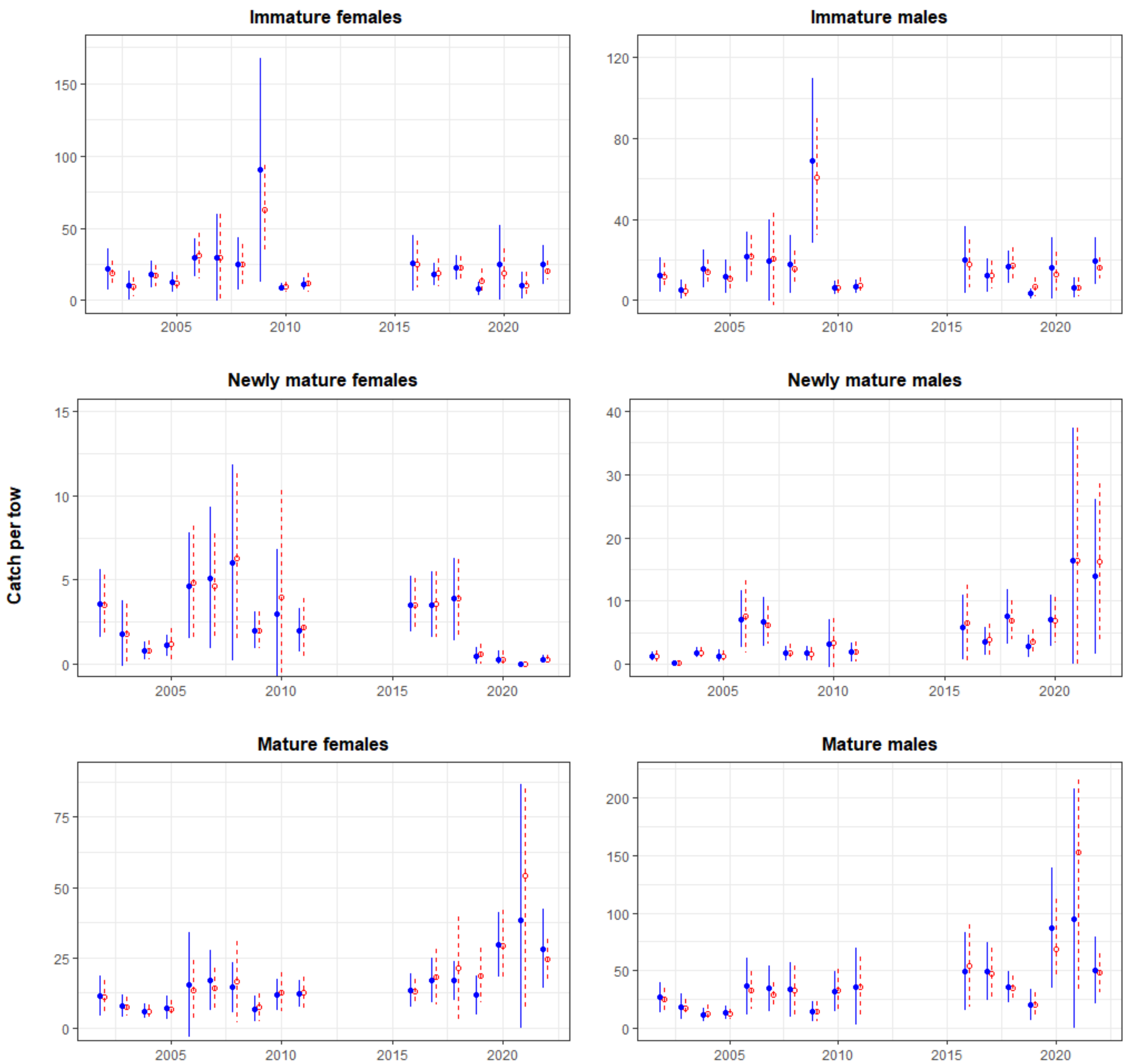

Figure 3. Plots of stratified mean catches per 15-minute tow of horseshoe crabs in the coastal **Delaware Bay area** survey by demographic group. Vertical lines indicate 95% confidence intervals. Solid blue symbols and lines indicate the **delta distribution** model. Open red symbols and dashed lines indicate the **normal distribution** model. Data are from Tables 1 and 2. Note the differences in the *y*-axis scales.

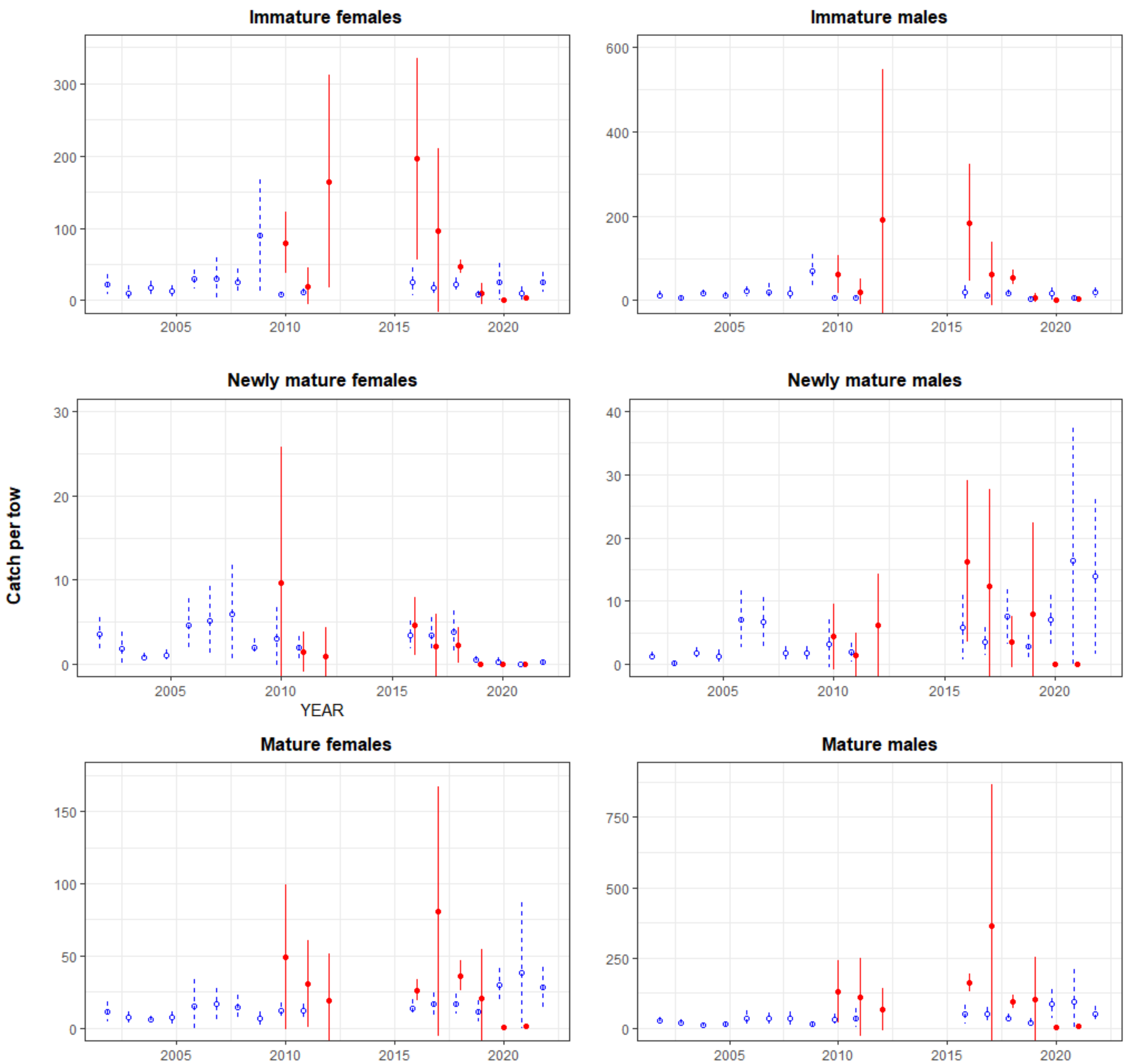

Figure 4. Plots of stratified mean catches per 15-minute tow of horseshoe crabs in the **lower Delaware Bay** survey by demographic group, with coastal **Delaware Bay area** survey means for comparison. Vertical lines indicate 95% confidence limits. Only the **delta distribution** model means are presented for clarity. Solid symbols and lines indicate **the lower Delaware Bay survey**. Open symbols and dashed lines indicate the coastal **Delaware Bay area** survey. Note differences in y-axis scales.

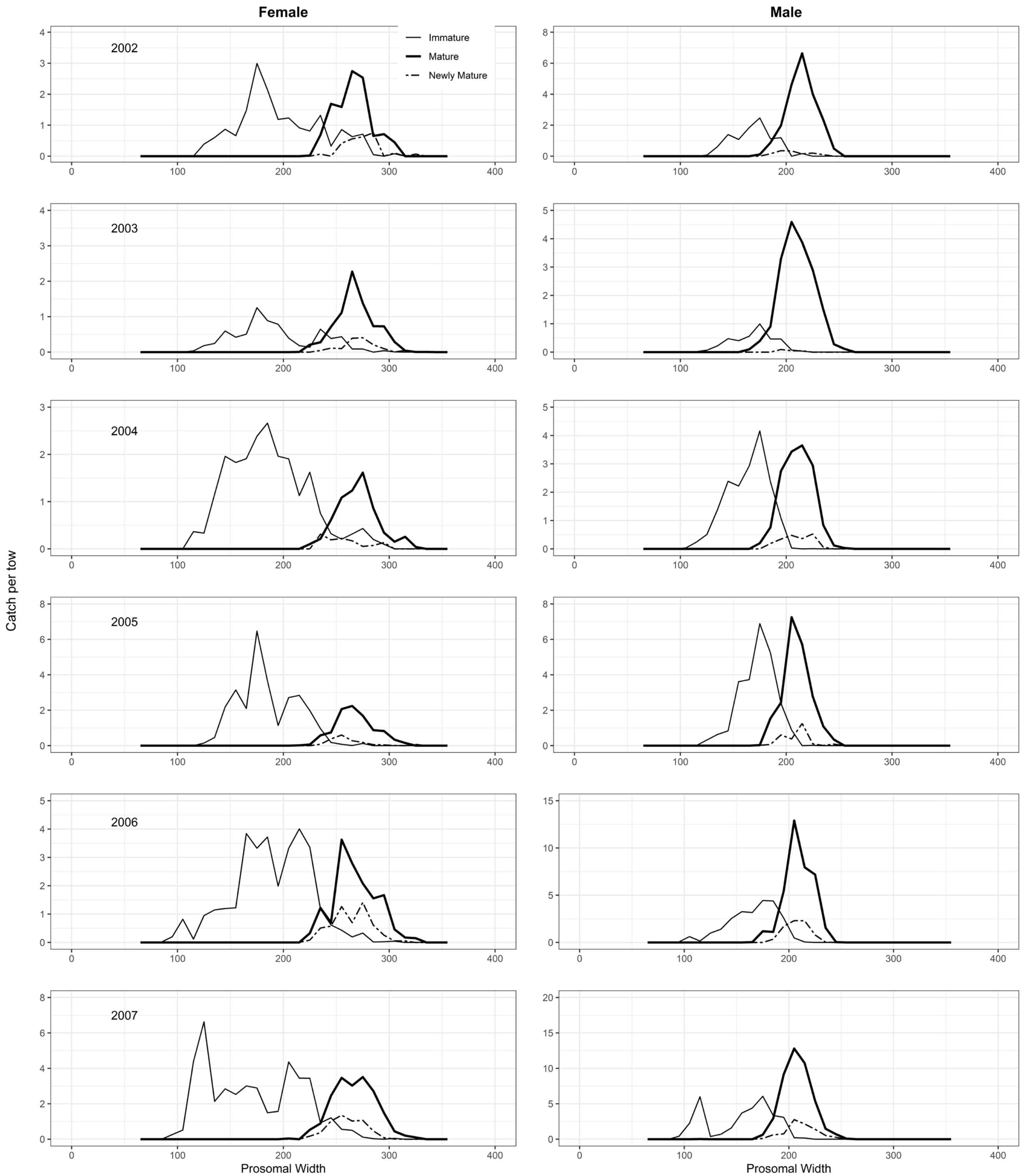

Figure 5. Size-frequency distributions of horseshoe crabs by demographic group and year in the coastal **Delaware Bay area** trawl survey. Relative frequencies are scaled to represent stratified mean catches in Table 1.

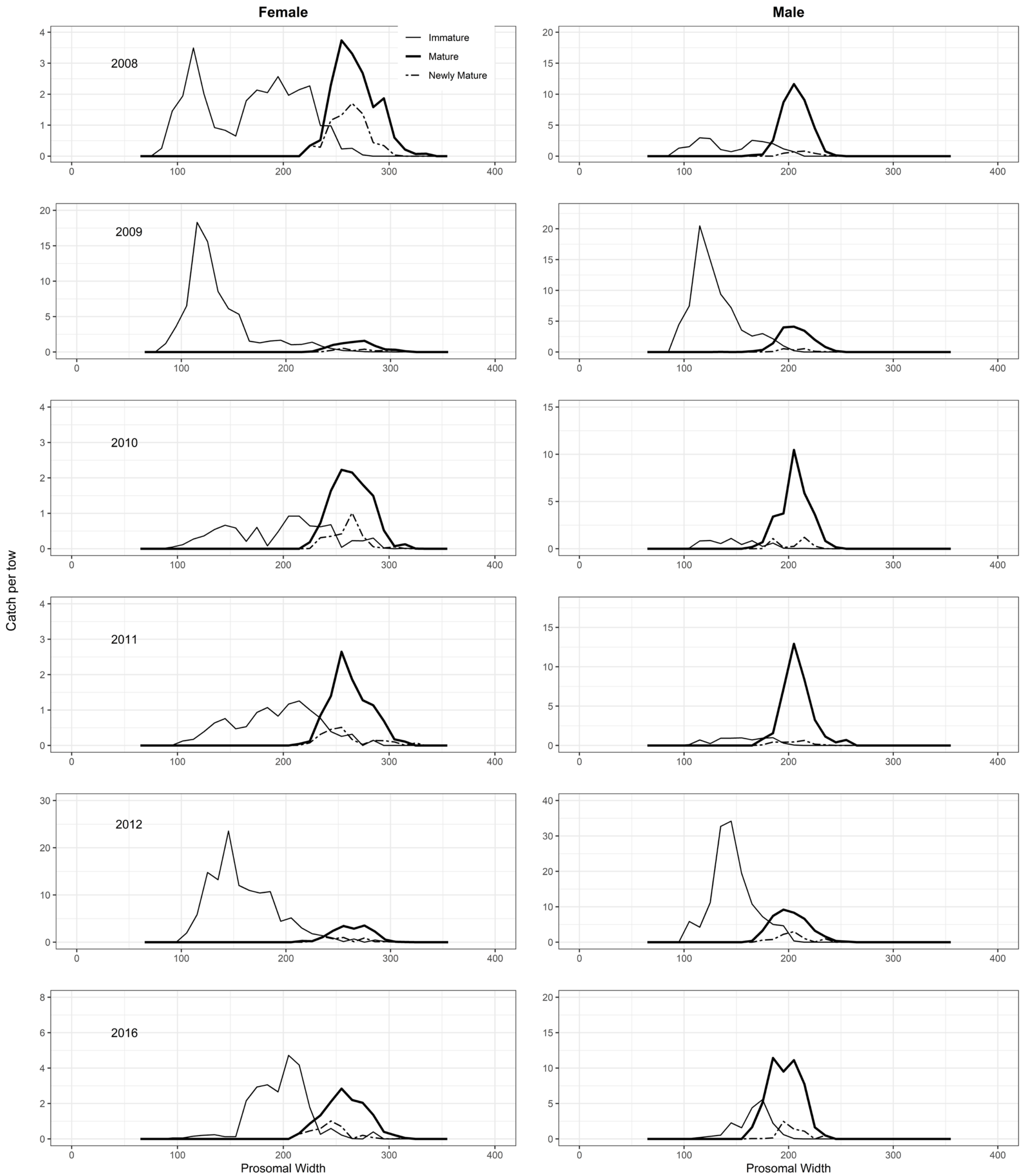

Figure 5. continued.

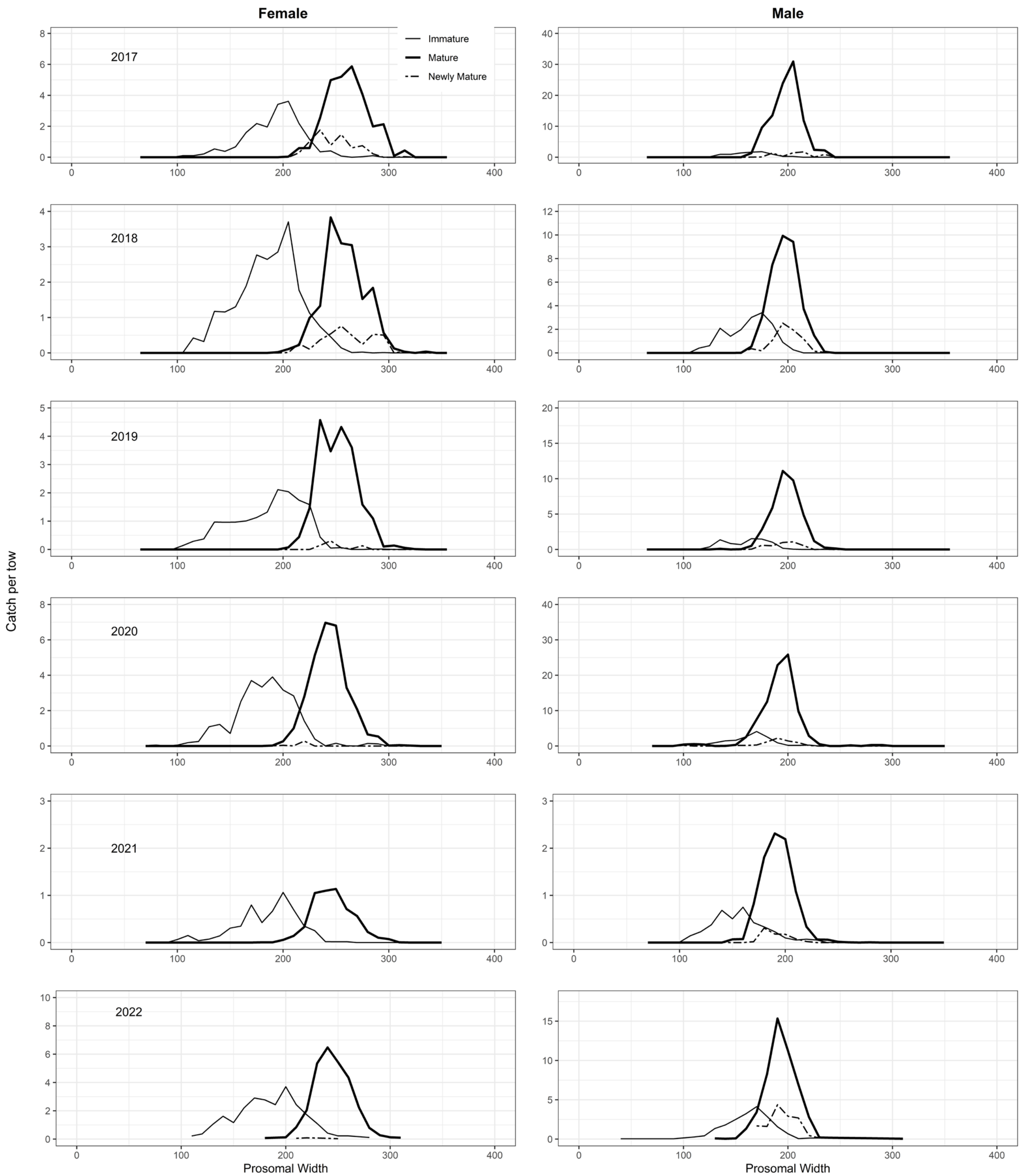

Figure 5. continued.

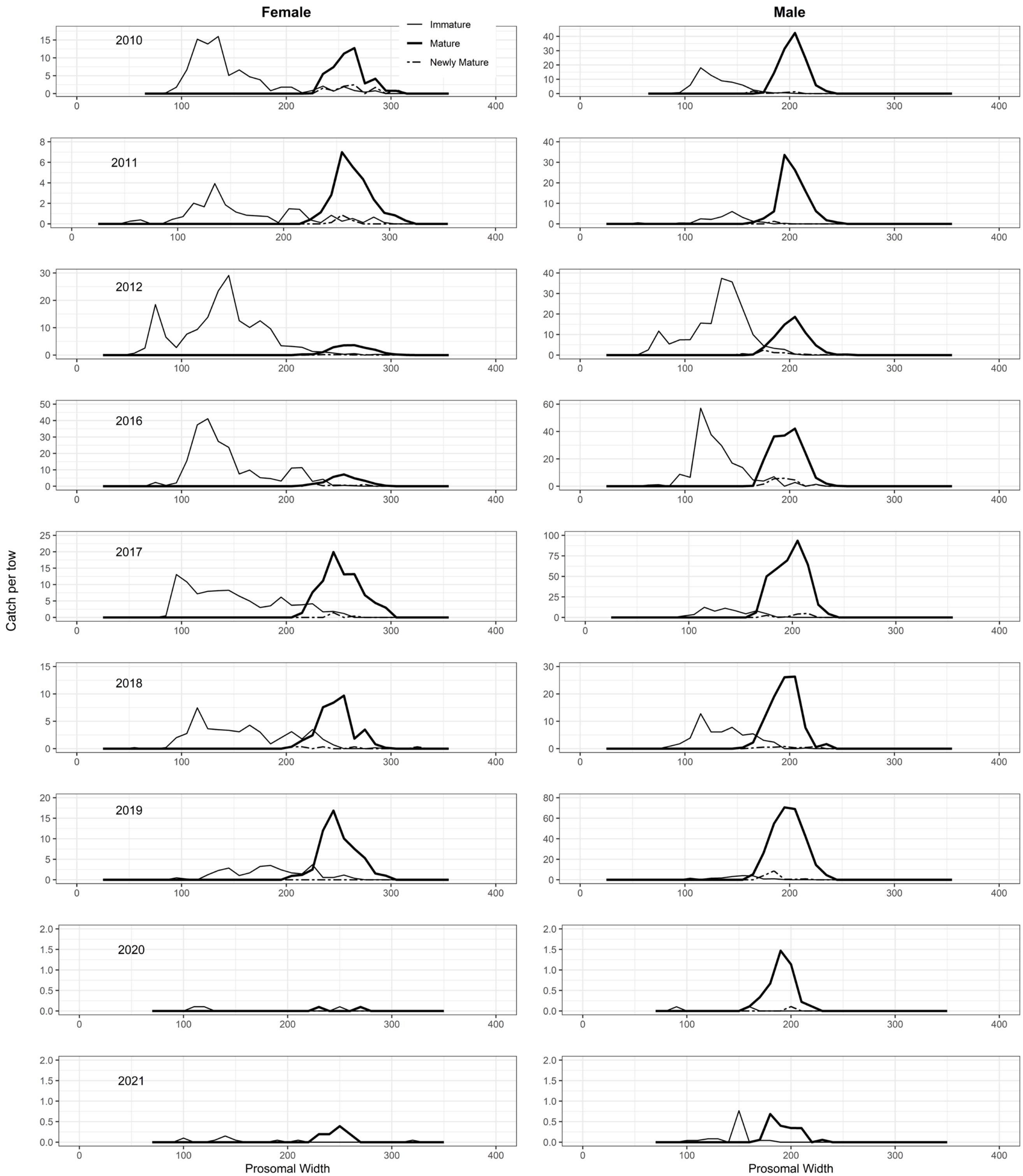

Figure 6. Relative size-frequency distributions of horseshoe crabs by demographic group and year in the **lower Delaware Bay** trawl survey. Relative frequencies are scaled to represent stratified mean catches in Table 3.

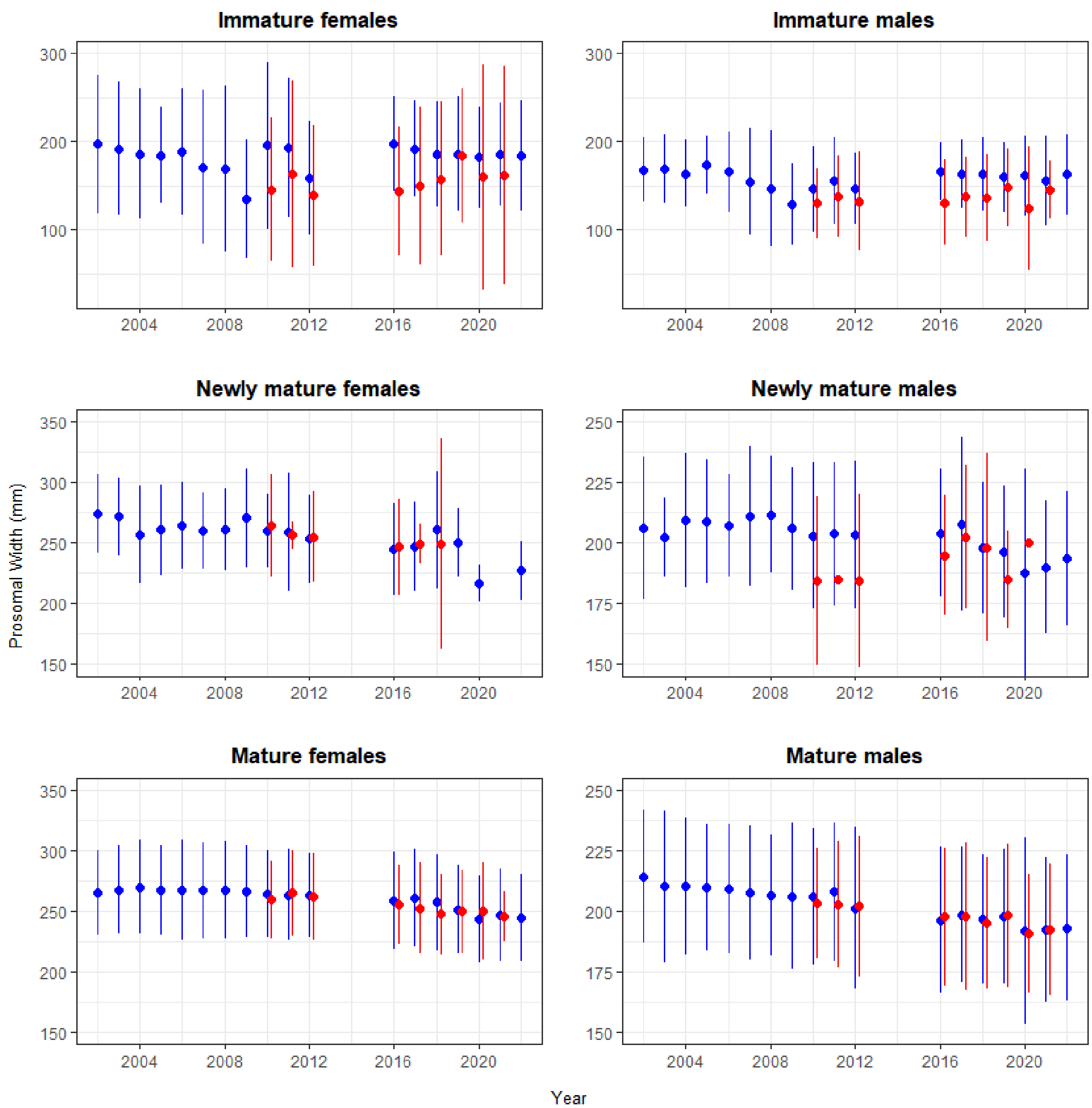

Figure 7. Mean prosomal widths (mm) (± 2 standard deviations) of mature and newly mature female and male horseshoe crabs in the Delaware Bay area (blue symbols and lines) and lower Delaware Bay (red symbols and lines) surveys.

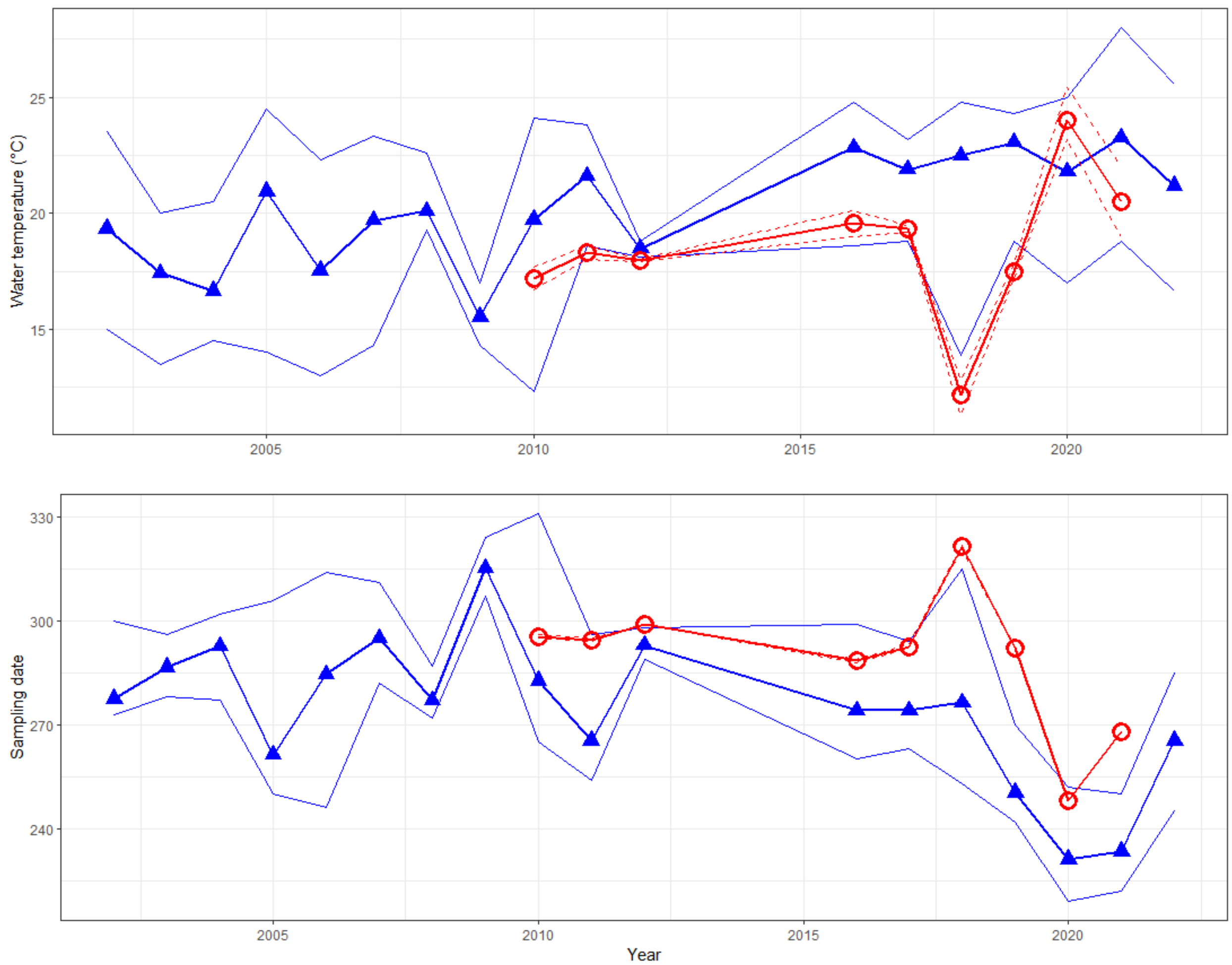

Figure 8. Plots of bottom water temperatures and ordinal sampling dates (days since 1 January) in the coastal Delaware Bay area and lower Delaware Bay trawl surveys. Solid symbols and blue lines indicate coastal Delaware Bay area. Open symbols and red lines indicate lower Delaware Bay. Points indicate mean values. Thinner lines indicate maximum and minimum values. Approximate calendar dates are indicated by gray horizontal lines for reference (ordinal dates are shifted by one day for leap years).

Table 1. Stratified mean catch-per-tow of horseshoe crabs in the coastal **Delaware Bay area** survey, 2002-2022, with the mean, standard deviation (sd), and coefficient of variation (CV), calculated using the **delta distribution** model by demographic group. Also included are the estimated upper and lower 95% confidence limits (UCL, LCL).

YEAR	MEAN	UCL	LCL	CV	SD	YEAR	MEAN	UCL	LCL	CV	SD
Immature Females						**Immature Males**					
2002	21.9	36.1	7.6	0.31	6.8	2002	12.6	21.4	3.9	0.33	4.2
2003	10.5	20.4	0.7	0.43	4.6	2003	5.4	9.9	0.9	0.39	2.1
2004	17.9	27.2	8.6	0.25	4.5	2004	15.7	25	6.4	0.29	4.5
2005	12.7	19.9	5.5	0.28	3.5	2005	11.9	20	3.8	0.33	3.9
2006	29.5	42.8	16.3	0.21	6.3	2006	21.6	33.9	9.2	0.25	5.4
2007	29.6	59.4	-0.2	0.41	12.2	2007	19.5	39.6	-0.6	0.42	8.2
2008	25.3	43.7	6.9	0.33	8.3	2008	18	32.4	3.6	0.35	6.3
2009	90.2	167.4	12.9	0.39	35.5	2009	69	109.7	28.3	0.29	19.8
2010	9	11.9	6.1	0.16	1.4	2010	6.1	9.5	2.8	0.27	1.6
2011	11.4	15.9	6.9	0.19	2.2	2011	6.9	10.1	3.7	0.23	1.6
2016	25.8	45.1	6.5	0.36	9.2	2016	20	36.6	3.5	0.39	7.9
2017	17.9	25.4	10.4	0.19	3.4	2017	12.3	20.5	4.2	0.27	3.3
2018	22.5	31.2	13.9	0.18	4.1	2018	16.5	24.4	8.7	0.22	3.7
2019	8	12.7	3.2	0.3	2.4	2019	3.5	6	1	0.35	1.2
2020	25.3	51.9	0.1	0.6	15.2	2020	16	31.3	0.8	0.56	9.1
2021	10.4	19.8	1.1	0.52	5.5	2021	6.4	11.5	1.3	0.46	3
2022	**24.6**	**38.5**	**10.8**	**0.33**	**8.1**	**2022**	**19.3**	**30.8**	**7.7**	**0.36**	**6.9**
Mature Females						**Mature Males**					
2002	11.4	18.5	4.2	0.3	3.4	2002	26.6	39.7	13.4	0.24	6.3
2003	7.7	11.7	3.7	0.25	1.9	2003	18.4	29.6	7.3	0.28	5.2
2004	5.9	8.6	3.3	0.21	1.3	2004	11.4	17.1	5.7	0.24	2.8
2005	7.2	11.4	3	0.27	2	2005	13.2	19.1	7.3	0.21	2.8
2006	15.3	33.8	-3.2	0.44	6.7	2006	36.2	60.9	11.4	0.28	10.1
2007	16.9	27.5	6.2	0.3	5.1	2007	34.3	54.4	14.3	0.28	9.7
2008	14.4	23.3	5.4	0.29	4.2	2008	33.5	57.2	9.8	0.33	11.2
2009	6.7	11.2	2.3	0.32	2.1	2009	14.1	22.8	5.3	0.3	4.2
2010	11.8	17.3	6.3	0.22	2.6	2010	31.5	49.2	13.8	0.27	8.6
2011	12.3	17.1	7.6	0.18	2.2	2011	36	69.8	2.2	0.41	14.7
2016	13.5	19.5	7.6	0.21	2.9	2016	49.2	83.1	15.2	0.29	14.3
2017	16.9	24.8	9	0.23	3.9	2017	48.9	74	23.9	0.25	12.2
2018	16.8	23.7	9.9	0.2	3.3	2018	35.7	48.9	22.5	0.17	6.2
2019	11.6	18.7	4.5	0.3	3.5	2019	20	33.3	6.8	0.33	6.6
2020	29.6	41.2	18.1	0.23	6.9	2020	87	139.4	34.5	0.36	31.1
2021	38.2	86.5	0	0.72	27.4	2021	95	207.8	0	0.67	64.1
2022	**28.2**	**42.3**	**14.1**	**0.29**	**8.3**	**2022**	**50**	**79.1**	**20.9**	**0.34**	**17.2**
Newly Mature Females						**Newly Mature Males**					
2002	3.6	5.6	1.6	0.26	0.9	2002	1.3	2	0.5	0.28	0.4
2003	1.8	3.8	-0.1	0.49	0.9	2003	0.2	0.5	-0.1	0.84	0.2
2004	0.8	1.3	0.3	0.3	0.2	2004	1.8	2.6	1	0.21	0.4
2005	1.1	1.7	0.5	0.28	0.3	2005	1.3	2.3	0.4	0.33	0.4
2006	4.6	7.8	1.5	0.3	1.4	2006	7.1	11.6	2.6	0.36	2.7
2007	5.1	9.3	0.9	0.39	2	2007	6.7	10.6	2.8	0.28	1.9
2008	6	11.8	0.2	0.44	2.7	2008	1.8	2.9	0.6	0.32	0.6
2009	2	3.1	0.9	0.26	0.5	2009	1.7	2.8	0.5	0.34	0.6
2010	3	6.8	-0.7	0.59	1.8	2010	3.2	7	-0.5	0.55	1.8
2011	2	3.3	0.7	0.31	0.6	2011	1.9	3.4	0.4	0.37	0.7
2016	3.5	5.2	1.9	0.23	0.8	2016	5.9	11	0.7	0.42	2.5
2017	3.5	5.5	1.6	0.27	0.9	2017	3.6	5.8	1.5	0.29	1
2018	3.9	6.3	1.4	0.3	1.2	2018	7.5	11.9	3.1	0.27	2.1
2019	0.5	1	0	0.46	0.2	2019	2.8	4.6	1	0.32	0.9
2020	0.3	0.8	0	0.85	0.3	2020	7	11	2.9	0.35	2.4
2021	0	NA	NA	NA	0	2021	16.4	37.3	0	0.69	11.3
2022	**0.29**	**0.52**	**0.05**	**0.46**	**0.13**	**2022**	**13.8**	**26**	**1.7**	**0.52**	**7.2**

Table 2. Stratified mean catch-per-tow of horseshoe crabs in the coastal **Delaware Bay area** survey, 2002-2022, with the mean, standard deviation (sd), and coefficient of variation (CV), calculated using the **normal distribution** model by demographic group. Also included are the estimated upper and lower 95% confidence limits (UCL, LCL).

YEAR	MEAN	UCL	LCL	CV	SD	YEAR	MEAN	UCL	LCL	CV	SD
Immature Females						**Immature Males**					
2002	19.1	27.6	10.5	0.22	4.1	2002	11.7	18.3	5	0.27	3.2
2003	9.5	15.9	3	0.32	3.1	2003	4.9	8.1	1.8	0.3	1.5
2004	17	24.5	9.5	0.21	3.6	2004	14	20.3	7.6	0.22	3.1
2005	11.5	17	6.1	0.23	2.6	2005	10.6	16.7	4.4	0.28	2.9
2006	31.1	46.9	15.3	0.24	7.5	2006	21.5	32	11.1	0.23	5
2007	29.8	59.6	0	0.41	12.2	2007	20.5	43.2	-2.3	0.45	9.3
2008	24.6	38.9	10.3	0.27	6.6	2008	15.9	24.2	7.6	0.24	3.8
2009	63.1	93.8	32.4	0.24	14.9	2009	61	89.8	32.1	0.23	14
2010	9.4	13	5.7	0.19	1.8	2010	6.4	10.1	2.6	0.29	1.8
2011	12.2	18.5	6	0.25	3	2011	7.3	11.2	3.3	0.26	1.9
2016	25.1	41.1	9	0.31	7.7	2016	18.1	29.9	6.3	0.31	5.7
2017	19.1	28.7	9.6	0.24	4.6	2017	12.4	19.3	5.5	0.26	3.3
2018	22.5	30.6	14.5	0.17	3.8	2018	17.2	25.9	8.6	0.24	4.1
2019	13.7	21.9	5.5	0.3	4.1	2019	6.6	11.1	2	0.34	2.2
2020	18.8	35.4	8.7	0.32	6	2020	12.7	24	4.7	0.37	4.75
2021	10.14	19.20	1.54	0.50	5.05	2021	6.39	10.99	1.83	0.42	2.66
2022	**20.7**	**27.2**	**14.2**	**0.18**	**3.83**	**2022**	**16.0**	**21.4**	**10.7**	**0.20**	**3.2**
Mature Females						**Mature Males**					
2002	11	17	4.9	0.26	2.8	2002	24.6	34.4	14.8	0.19	4.7
2003	7.5	10.9	4.1	0.22	1.6	2003	17	24.7	9.4	0.21	3.6
2004	6	8.3	3.7	0.19	1.1	2004	12.6	20.2	5.1	0.29	3.6
2005	6.8	10	3.5	0.22	1.5	2005	12.3	16.7	7.8	0.17	2.1
2006	13.5	24.2	2.7	0.31	4.2	2006	32.8	49.5	16.1	0.22	7.4
2007	14.2	21.3	7.1	0.24	3.4	2007	28.4	39.9	16.8	0.2	5.6
2008	16.5	31	2	0.41	6.8	2008	32.7	53.7	11.7	0.31	10
2009	7.3	12.3	2.2	0.33	2.4	2009	14.2	22.9	5.5	0.29	4.1
2010	12.7	19.7	5.7	0.26	3.3	2010	32.5	50.9	14.1	0.27	8.8
2011	12.6	18.1	7.2	0.2	2.6	2011	35.4	61.4	9.5	0.32	11.5
2016	12.8	17.4	8.2	0.17	2.2	2016	53.9	90	17.8	0.3	16.2
2017	18.2	28	8.4	0.26	4.8	2017	47.2	69.3	25.1	0.23	10.8
2018	21.1	39.6	2.5	0.41	8.7	2018	34.9	44.9	24.9	0.14	4.8
2019	18.7	28.4	9	0.26	4.8	2019	19.7	31	8.4	0.28	5.6
2020	29.4	41.8	17.3	0.25	7.2	2020	68.8	111.7	44.1	0.21	14.7
2021	54.03	85.27	6.79	0.50	26.82	2021	152.63	215.49	30.01	0.46	69.66
2022	**24.3**	**31.5**	**17.1**	**0.18**	**4.3**	**2022**	**47.8**	**64.7**	**31**	**0.21**	**9.90**
Newly Mature Females						**Newly Mature Males**					
2002	3.5	5.3	1.7	0.24	0.9	2002	1.3	2.2	0.4	0.31	0.4
2003	1.8	3.6	0.1	0.45	0.8	2003	0.2	0.5	-0.2	0.84	0.2
2004	0.8	1.4	0.3	0.33	0.3	2004	1.8	2.6	1	0.21	0.4
2005	1.2	2.1	0.3	0.35	0.4	2005	1.3	2.1	0.5	0.29	0.4
2006	4.8	8.2	1.4	0.33	1.6	2006	7.5	13.2	1.8	0.36	2.7
2007	4.6	7.7	1.5	0.32	1.5	2007	6.1	9.1	3.2	0.23	1.4
2008	6.3	11.3	1.3	0.37	2.3	2008	1.8	3.1	0.5	0.34	0.6
2009	2	3.1	0.9	0.26	0.5	2009	1.6	2.6	0.6	0.3	0.5
2010	4	10.3	-2.3	0.74	3	2010	3.3	7.2	-0.6	0.56	1.9
2011	2.2	3.9	0.5	0.38	0.8	2011	1.9	3.5	0.4	0.38	0.7
2016	3.5	5.1	1.9	0.22	0.8	2016	6.6	12.6	0.6	0.43	2.9
2017	3.6	5.5	1.6	0.27	1	2017	3.8	6.4	1.3	0.32	1.2
2018	3.9	6.2	1.6	0.28	1.1	2018	6.9	10	3.9	0.21	1.5
2019	0.6	1.2	0	0.48	0.3	2019	3.5	5.5	1.5	0.29	1
2020	0.3	0.8	0	0.84	0.28	2020	6.9	10.6	3.3	0.31	2.1
2021	0.00	NA	NA	NA	0.00	2021	16.33	37.39	0.00	0.69	11.31
2022	**0.29**	**0.53**	**0.04**	**0.46**	**0.13**	**2022**	**16.2**	**28.6**	**3.8**	**0.45**	**7.2**

Table 3. Stratified mean catch–per-tow of horseshoe crabs in the **lower Delaware Bay** survey area in 2010-2022, with the mean, standard deviation (sd), and coefficient of variation (CV), calculated using the **delta distribution** model, by demographic group. Also included are the estimated upper and lower 95% confidence limits (UCL, LCL).

YEAR	MEAN	UCL	LCL	CV	SD	YEAR	MEAN	UCL	LCL	CV	SD
Immature Females						**Immature Males**					
2010	79.7	122.2	37.3	0.21	16.5	2010	61.2	105.5	16.9	0.3	18.1
2011	19.7	45.2	-5.9	0.47	9.2	2011	20.2	50.7	-10.4	0.55	11
2012	164.3	311.8	16.9	0.32	53.1	2012	192.6	548.4	-163.3	0.43	82.7
2016	196	335.5	56.6	0.29	57	2016	184.2	322.9	45.5	0.32	58.7
2017	96.7	210	-16.7	0.46	44.1	2017	62.9	137.6	-11.7	0.46	29
2018	47.2	56.2	38.1	0.08	3.8	2018	55.1	71.8	38.4	0.12	6.8
2019	9.5	24.3	-5.3	0.6	5.7	2019	5.7	15.8	-4.5	0.7	4
2020	0.3	0.8	0	0.97	0.3	2020	0.2	0.6	0	0.97	0.2
2021	3.1	NA	NA	0.99	3.1	2021	3.3	NA	NA	0.78	2.6
2022	**NA**	**NA**	**NA**	**NA**	**NA**	**2022**	**NA**	**NA**	**NA**	**NA**	**NA**
Mature Females						**Mature Males**					
2010	48.8	98.9	-1.2	0.4	19.5	2010	130.3	242.6	18.1	0.34	43.7
2011	30.3	60.4	0.2	0.36	10.8	2011	110.2	249	-28.6	0.45	50
2012	19.1	51.6	-13.4	0.4	7.6	2012	66.8	141.1	-7.4	0.35	23.3
2016	26.3	33.9	18.7	0.12	3.2	2016	161.7	192.5	131	0.08	13.3
2017	80.6	167.1	-5.8	0.39	31.1	2017	362.7	868.5	-143.2	0.5	182.2
2018	36.2	46.6	25.8	0.12	4.3	2018	94.3	117.9	70.7	0.11	10
2019	20.8	54.7	-13	0.63	13.2	2019	100.4	254	-53.2	0.59	59.7
2020	0.2	0.5	0	0.97	0.2	2020	4.1	8.8	0	0.67	2.7
2021	1.6	NA	NA	0.99	1.5	2021	8.7	NA	NA	0.72	6.3
2022	**NA**	**NA**	**NA**	**NA**	**NA**	**2022**	**NA**	**NA**	**NA**	**NA**	**NA**
Newly Mature Females						**Newly Mature Males**					
2010	9.7	25.8	-6.3	0.64	6.2	2010	4.4	9.5	-0.8	0.46	2
2011	1.4	3.8	-0.9	0.58	0.8	2011	1.4	4.9	-2.2	0.94	1.3
2012	1	4.4	-2.3	0.76	0.8	2012	6.1	14.2	-2	0.48	2.9
2016	4.6	8	1.1	0.31	1.4	2016	16.2	29	3.5	0.3	5
2017	2.1	5.9	-1.7	0.65	1.4	2017	12.4	27.6	-2.7	0.44	5.4
2018	2.3	4.4	0.2	0.35	0.8	2018	3.6	7.6	-0.5	0.44	1.6
2019	0	0	0	NA	0	2019	8	22.3	-6.4	0.7	5.6
2020	0	0	0	NA	0	2020	0.1	0.3	0	0.97	0.1
2021	0	NA	NA	NA	0	2021	0	NA	NA	NA	0
2022	**NA**	**NA**	**NA**	**NA**	**NA**	**2022**	**NA**	**NA**	**NA**	**NA**	**NA**

Table 4. Stratified mean catch-per-tow of horseshoe crabs in **the lower Delaware Bay** survey area in 2010-2022, with the mean, standard deviation (sd), and coefficient of variation (CV), calculated using the **normal distribution** model by demographic group. Also included are the estimated upper and lower 95% confidence limits (UCL, LCL).

YEAR	MEAN	UCL	LCL	CV	SD	YEAR	MEAN	UCL	LCL	CV	SD
Immature Females						**Immature Males**					
2010	79.5	116.5	42.6	0.19	15.1	2010	60.4	95.7	25.1	0.25	15.3
2011	21.3	54.2	-11.5	0.55	11.8	2011	21.5	57.2	-14.3	0.6	12.9
2012	165.5	287.6	43.4	0.3	49.9	2012	183.9	360.1	7.8	0.34	63.4
2016	186.5	284.7	88.3	0.22	40.1	2016	167.9	249.7	86	0.21	34.6
2017	90.8	176	5.6	0.37	33.2	2017	58.2	109	7.5	0.36	20.7
2018	47.1	55.6	38.6	0.08	3.6	2018	54.9	69.6	40.2	0.11	6.2
2019	16	30.4	1.5	0.35	5.6	2019	10.7	21.7	-0.4	0.4	4.3
2020	0.3	0.8	0	0.97	0.3	2020	0.2	0.6	0	0.97	0.2
2021	3.1	NA	NA	0	0	2021	3.3	NA	NA	0	0
2022	**NA**	**NA**	**NA**	**NA**	**NA**	**2022**	**NA**	**NA**	**NA**	**NA**	**NA**
Mature Females						**Mature Males**					
2010	49.1	99.8	-1.7	0.4	19.7	2010	128	227.9	28.2	0.3	38.9
2011	28.6	49.9	7.4	0.27	7.7	2011	100.3	187.7	13	0.31	31.5
2012	18.7	46.2	-8.9	0.34	6.4	2012	65.3	111.7	18.8	0.28	18.1
2016	26.2	33.4	19	0.11	3	2016	161.8	192.4	131.1	0.08	13.3
2017	80.5	165	-4	0.38	30.4	2017	303.4	531.7	75.2	0.27	82.2
2018	36.2	47.2	25.1	0.12	4.3	2018	94.7	120.3	69	0.11	10.8
2019	29.3	54.8	3.8	0.34	9.9	2019	49.9	90	9.9	0.31	15.6
2020	0.2	0.5	0	0.97	0.2	2020	4.1	8.8	0	0.67	2.7
2021	1.6	NA	NA	0	0	2021	8.7	NA	NA	0	0
2022	**NA**	**NA**	**NA**	**NA**	**NA**	**2022**	**NA**	**NA**	**NA**	**NA**	**NA**
Newly Mature Females						**Newly Mature Males**					
2010	9.6	24.9	-5.7	0.62	5.9	2010	4.3	9.1	-0.5	0.43	1.9
2011	1.4	3.8	-0.9	0.58	0.8	2011	1.4	4.9	-2.2	0.94	1.3
2012	1	4.4	-2.3	0.76	0.8	2012	6.1	14.1	-1.9	0.47	2.9
2016	4.5	8	1.1	0.3	1.3	2016	16	27.2	4.9	0.27	4.3
2017	2.1	5.9	-1.7	0.65	1.4	2017	12.4	25.7	-1	0.42	5.2
2018	2.3	4.3	0.3	0.34	0.8	2018	3.6	7.6	-0.5	0.44	1.6
2019	0	0	0	NA	0	2019	8.5	22.9	-5.9	0.66	5.6
2020	0	0	0	NA	0	2020	0.1	0.3	0	0.97	0.1
2021	0	NA	NA	NA	0	2021	0	NA	NA	NA	0
2022	**NA**	**NA**	**NA**	**NA**	**NA**	**2022**	**NA**	**NA**	**NA**	**NA**	**NA**

Table 5. Results of correlation analyses of mean prosomal width (mm) and survey year for mature and newly mature males and females from the Delaware Bay area and lower Delaware Bay surveys. Statistics presented are number of years included: *n*; *T-score*; probability, *p*; and correlation coefficient, *r*. A negative correlation coefficient indicates a decreasing regression slope.

Maturity Group	n	T	p	r
Delaware Bay Area 2002 - 2022				**p**
Mature females	17	-8.51	<0.001	-0.905
Newly mature females	17	-5.07	0.001	-0.794
Mature males	17	-16.45	<0.001	-0.972
Newly mature males	17	-4.81	<0.001	-0.769
Lower Delaware Bay 2002 - 2021				
Mature females	9	-6.78	<0.001	-0.932
Newly mature females	9	-3.98	0.016	-0.894
Mature males	9	-6.32	<0.001	-0.922
Newly mature males	9	2.28	0.063	0.681

Table 6. Estimated population (in thousands) of horseshoe crabs in the coastal **Delaware Bay area** survey, 2002-2022, with the mean, standard deviation (sd), and coefficient of variation (CV), calculated using the **delta distribution model** by demographic group. Also included are the estimated upper and lower 95% confidence limits (UCL, LCL).

YEAR	MEAN	UCL	LCL	CV	SD	YEAR	MEAN	UCL	LCL	CV	SD
Immature Females						**Immature Males**					
2002	9470	15665	3275	0.31	2936	2002	5483	9284	1683	0.33	1809
2003	4585	8848	321	0.43	1972	2003	2303	4217	390	0.39	898
2004	7774	11770	3778	0.25	1944	2004	6810	10895	2725	0.29	1975
2005	5630	8856	2404	0.28	1576	2005	5260	8839	1681	0.33	1736
2006	12928	18691	7164	0.21	2715	2006	9327	14554	4100	0.24	2238
2007	13684	27486	-118	0.41	5610	2007	8966	18246	-314	0.42	3766
2008	10933	18650	3216	0.32	3499	2008	7841	13917	1766	0.35	2744
2009	39032	72868	5197	0.39	15222	2009	29864	47269	12460	0.28	8362
2010	3954	5220	2688	0.16	633	2010	2686	4144	1229	0.26	698
2011	4965	6945	2985	0.2	993	2011	3092	4547	1637	0.23	711
2016	11699	20462	2935	0.36	4212	2016	9102	16649	1555	0.39	3550
2017	7505	10708	4302	0.19	1426	2017	5091	8465	1717	0.27	1375
2018	10173	14285	6061	0.19	1933	2018	7507	11173	3842	0.23	1727
2019	3397	5516	1279	0.31	1053	2019	1487	2614	360	0.38	565
2020	9475	19779	0	0.65	6159	2020	5925	11967	0	0.61	3614
2021	4,174	7,947	400	0.53	2218	2021	2,574	4,634	513	0.47	1,199
2022	**9,930**	**15,493**	**4,366**	**0.33**	**3282**	**2022**	**7,652**	**12,192**	**3,112**	**0.35**	**2686**
Mature Females						**Mature Males**					
2002	4959	8084	1834	0.3	1488	2002	11584	17335	5834	0.24	2780
2003	3379	5160	1599	0.25	845	2003	8069	13029	3110	0.29	2340
2004	2735	4043	1426	0.23	629	2004	5150	7788	2511	0.25	1288
2005	3138	4942	1333	0.27	847	2005	5844	8461	3228	0.22	1286
2006	6611	14330	-1108	0.42	2777	2006	15825	26060	5589	0.27	4273
2007	7746	12704	2789	0.31	2401	2007	15795	25104	6487	0.28	4423
2008	6311	10202	2419	0.29	1830	2008	14647	24995	4299	0.33	4834
2009	2975	4971	979	0.32	952	2009	6240	10197	2283	0.3	1872
2010	5178	7616	2740	0.23	1191	2010	13963	21910	6015	0.28	3910
2011	5290	7282	3297	0.18	952	2011	15060	29000	1120	0.4	6024
2016	6024	8635	3413	0.21	1265	2016	21941	37216	6665	0.29	6363
2017	7185	10525	3844	0.23	1653	2017	20664	31208	10119	0.25	5166
2018	7326	10520	4131	0.21	1538	2018	15749	21880	9619	0.18	2835
2019	5110	8454	1767	0.32	1635	2019	8924	15202	2646	0.35	3108
2020	10803	15359	6247	0.25	2706	2020	31546	51050	12042	0.36	11583
2021	15,498	35,873	0	0.75	11,568	2021	38,538	85,949	0	0.7	26,925
2022	**11,421**	**17,179**	**5,662**	**0.30**	**3380**	**2022**	**19,921**	**31,447**	**8,395**	**0.34**	**6,806**
Newly Mature Females						**Newly Mature Males**					
2002	1537	2400	675	0.26	400	2002	548	869	227	0.28	153
2003	794	1633	-45	0.49	389	2003	78	221	-65	0.84	66
2004	358	575	141	0.29	104	2004	789	1127	451	0.21	166
2005	479	753	206	0.27	129	2005	597	1002	191	0.33	197
2006	2051	3509	594	0.31	636	2006	3113	5113	1113	0.31	965
2007	2373	4339	408	0.4	949	2007	3129	4972	1287	0.28	876
2008	2571	4984	158	0.43	1106	2008	757	1254	261	0.31	235
2009	885	1361	410	0.26	230	2009	725	1240	210	0.34	247
2010	1338	2990	-314	0.59	789	2010	1422	3070	-226	0.55	782
2011	845	1360	331	0.3	254	2011	749	1335	164	0.36	270
2016	1608	2357	860	0.23	370	2016	2608	4884	331	0.42	1095
2017	1480	2274	687	0.26	385	2017	1523	2392	654	0.28	426
2018	1773	2923	622	0.31	550	2018	3341	5367	1316	0.29	969
2019	242	472	12	0.47	114	2019	1271	2154	389	0.34	437
2020	133	330	0	0.87	117	2020	2492	4030	953	0.37	914
2021	0	NA	NA	NA	NA	2021	6,333	14,328	0	0.68	4309
2022	**115**	**207**	**23**	**0.46**	**53**	**2022**	**5,487**	**10,293**	**681**	**0.52**	**2,835**

Table 7. Estimated population (in thousands) of horseshoe crabs in the coastal **Delaware Bay area** survey, 2002-2022, with the mean, standard deviation (sd), and coefficient of variation (CV), calculated using the **normal distribution** model by demographic group. Also included are the estimated upper and lower 95% confidence limits (UCL, LCL).

YEAR	MEAN	UCL	LCL	CV	SD	YEAR	MEAN	UCL	LCL	CV	SD
Immature Females						**Immature Males**					
2002	8222	11875	4568	0.21	1727	2002	5076	7998	2155	0.28	1421
2003	4089	6860	1317	0.32	1308	2003	2114	3462	766	0.3	634
2004	7376	10616	4135	0.21	1549	2004	6033	8786	3281	0.22	1327
2005	5104	7521	2687	0.23	1174	2005	4673	7414	1932	0.28	1308
2006	13714	20988	6439	0.25	3429	2006	9378	13971	4786	0.23	2157
2007	13692	27335	48	0.41	5614	2007	9350	19735	-1035	0.45	4208
2008	10595	16578	4612	0.26	2755	2008	6897	10443	3350	0.23	1586
2009	27375	40519	14232	0.23	6296	2009	26435	38730	14140	0.23	6080
2010	4102	5706	2497	0.19	779	2010	2781	4423	1139	0.29	806
2011	5426	8433	2420	0.27	1465	2011	3301	5219	1382	0.28	924
2016	11292	18441	4144	0.3	3388	2016	8185	13512	2858	0.31	2537
2017	7948	11818	4077	0.23	1828	2017	5082	7829	2335	0.26	1321
2018	10115	13839	6391	0.18	1821	2018	7768	11653	3882	0.24	1864
2019	14855	15027	14682	0.33	4902	2019	66	236	-104	1.27	84
2020	6832	10559	3106	0.32	2213	2020	4610	7540	1679	0.38	1740
2021	4053	7670	436	0.51	2064	2021	2548	4389	707	0.42	1074
2022	**8,328**	**11,016**	**5,639**	**0.19**	**1580**	**2022**	**6,359**	**8,461**	**4,257**	**0.20**	**1243**
Mature Females						**Mature Males**					
2002	4779	7431	2128	0.26	1243	2002	10711	14972	6450	0.19	2035
2003	3308	4851	1764	0.22	728	2003	7454	10827	4082	0.21	1565
2004	2767	3919	1615	0.2	553	2004	5586	8875	2297	0.28	1564
2005	2957	4323	1592	0.22	651	2005	5408	7322	3494	0.17	919
2006	5867	10517	1218	0.31	1819	2006	14461	21734	7188	0.23	3326
2007	6553	9864	3243	0.25	1638	2007	13100	18506	7694	0.2	2620
2008	7172	13336	1008	0.4	2869	2008	14244	23240	5247	0.3	4273
2009	3230	5523	936	0.33	1066	2009	6319	10255	2383	0.29	1833
2010	5588	8698	2478	0.26	1453	2010	14396	22600	6192	0.27	3887
2011	5388	7629	3147	0.2	1078	2011	14858	25890	3825	0.33	4903
2016	5735	7770	3700	0.17	975	2016	24017	40197	7837	0.3	7205
2017	7785	12033	3537	0.27	2102	2017	19985	29245	10724	0.23	4597
2018	9463	18463	464	0.44	4164	2018	15264	19849	10680	0.15	2290
2019	6420	6506	6334	0.32	2054	2019	11660	11824	11497	0.37	4314
2020	10927	16014	5840	0.28	3021	2020	25200	34983	15416	0.23	5810
2021	21766	40665	2867	0.49	10750	2021	61879	109880	13877	0.45	27576
2022	**9,839**	**12,836**	**6,842**	**0.18**	**1770**	**2022**	**19,032**	**25,588**	**12,475**	**0.20**	**3859**
Newly Mature Females						**Newly Mature Males**					
2002	1509	2278	741	0.24	362	2002	561	925	196	0.31	174
2003	787	1547	26	0.45	354	2003	78	222	-66	0.84	66
2004	367	613	120	0.32	117	2004	786	1120	452	0.2	157
2005	531	908	154	0.34	181	2005	580	927	233	0.29	168
2006	2122	3705	540	0.33	700	2006	3377	6076	678	0.38	1283
2007	2129	3584	674	0.33	703	2007	2841	4214	1468	0.23	653
2008	2697	4780	613	0.36	971	2008	776	1315	237	0.33	256
2009	883	1366	399	0.26	230	2009	708	1157	259	0.31	219
2010	1770	4532	-992	0.74	1310	2010	1464	3180	-252	0.56	820
2011	882	1495	269	0.34	300	2011	766	1343	190	0.36	276
2016	1583	2304	863	0.22	348	2016	2939	5588	290	0.43	1264
2017	0.00	NA	NA	NA	NA	2017	1590	2623	557	0.32	509
2018	1780	2866	695	0.29	516	2018	3064	4466	1663	0.22	674
2019	77	225	-70	0.94	73	2019	112	267	-43	0.68	77
2020	134	330	0	0.87	117	2020	2430	3676	1184	0.3	740
2021	0	NA	NA	NA	NA	2021	6308	14299	0	0.68	4307
2022	**115**	**212**	**18**	**0.46**	**53**	**2022**	**6,370**	**11,143**	**1,597**	**0.44**	**2795**

Table 8. Estimated population (in thousands) of horseshoe crabs in the **lower Delaware Bay** survey area in 2010-2022, with the mean, standard deviation (sd), and coefficient of variation (CV), calculated using the **delta distribution** model by demographic group. Also included are the estimated upper and lower 95% confidence limits (UCL, LCL).

	YEAR	MEAN	UCL	LCL	CV	SD		YEAR	MEAN	UCL	LCL	CV	SD
Immature Females							**Immature Males**						
	2010	3510	5199	1822	0.2	702		2010	2632	4476	788	0.29	763
	2011	870	1931	-191	0.44	383		2011	881	2160	-397	0.52	458
	2012	8021	15084	958	0.32	2567		2012	9381	21965	-3204	0.42	3940
	2016	9046	15558	2534	0.29	2623		2016	8429	14813	2044	0.32	2697
	2017	4536	10029	-956	0.47	2132		2017	2920	6458	-618	0.47	1372
	2018	2211	2803	1619	0.1	221		2018	2597	3516	1678	0.15	390
	2019	525	1278	-229	0.56	294		2019	308	816	-201	0.64	197
	2020	12	33	0	0.97	12		2020	8	22	0	0.97	8
	2021	130	NA	NA	0.99	129		2021	140	NA	NA	0.78	109
	2022	**NA**	**NA**	**NA**	**NA**	**NA**		**2022**	**NA**	**NA**	**NA**	**NA**	**NA**
Mature Females							**Mature Males**						
	2010	2117	4260	-25	0.39	826		2010	5657	10247	1067	0.32	1810
	2011	1348	2599	96	0.33	445		2011	4829	10570	-912	0.43	2076
	2012	938	2522	-646	0.39	366		2012	3263	6864	-338	0.35	1142
	2016	1274	1710	837	0.15	191		2016	7735	9709	5761	0.1	774
	2017	3674	7501	-153	0.38	1396		2017	16794	40517	-6929	0.51	8565
	2018	1771	2588	953	0.18	319		2018	4616	6600	2631	0.18	831
	2019	1148	3011	-715	0.63	723		2019	5746	14583	-3092	0.6	3448
	2020	7	19	0	0.97	7		2020	152	332	0	0.68	103
	2021	65	NA	NA	0.99	64		2021	365	NA	NA	0.72	262
	2022	**NA**	**NA**	**NA**	**NA**	**NA**		**2022**	**NA**	**NA**	**NA**	**NA**	**NA**
Newly Mature Females							**Newly Mature Males**						
	2010	414	1087	-260	0.63	261		2010	187	409	-35	0.46	86
	2011	65	170	-40	0.58	38		2011	58	208	-93	0.94	55
	2012	50	214	-114	0.76	38		2012	301	710	-109	0.49	147
	2016	206	357	55	0.3	62		2016	727	1268	186	0.29	211
	2017	88	249	-73	0.66	58		2017	542	1100	-16	0.4	217
	2018	115	220	9	0.36	41		2018	148	290	7	0.4	59
	2019	0	0	0	NA	0		2019	361	1022	-299	0.71	257
	2020	0	0	0	NA	0		2020	4	11	0	0.97	4
	2021	0	NA	NA	NA	NA		2021	0	NA	NA	NA	NA
	2022	**NA**	**NA**	**NA**	**NA**	**NA**		**2022**	**NA**	**NA**	**NA**	**NA**	**NA**

Table 9. Estimated population (in thousands) of horseshoe crabs in the **lower Delaware Bay** survey area in 2010-2022, with the mean, standard deviation (sd), and coefficient of variation (CV), calculated using the **normal distribution** model by demographic group. Also included are the estimated upper and lower 95% confidence limits (UCL, LCL).

	YEAR	MEAN	UCL	LCL	CV	SD		YEAR	MEAN	UCL	LCL	CV	SD
Immature Females							**Immature Males**						
	2010	3503	5155	1851	0.18	631		2010	2588	4056	1120	0.24	621
	2011	938	2311	-435	0.53	497		2011	935	2437	-567	0.58	542
	2012	8125	14222	2027	0.31	2519		2012	9023	17690	356	0.35	3158
	2016	8618	13190	4046	0.22	1896		2016	7725	11638	3812	0.21	1622
	2017	4325	8829	-178	0.41	1773		2017	2731	5408	53	0.38	1038
	2018	2209	2780	1638	0.1	221		2018	2595	3529	1661	0.15	389
	2019	852	868	836	0.01	9		2019	566	566	566	0	0
	2020	12	33	0	0.97	12		2020	8	22	0	0.97	8
	2021	130	NA	NA	0	0		2021	140	NA	NA	0	0
	2022	**NA**	**NA**	**NA**	**NA**	**NA**		**2022**	**NA**	**NA**	**NA**	**NA**	**NA**
Mature Females							**Mature Males**						
	2010	2124	4340	-91	0.41	871		2010	5600	9916	1285	0.3	1680
	2011	1290	2239	340	0.27	348		2011	4479	8332	625	0.31	1388
	2012	915	2242	-412	0.34	311		2012	3188	5456	921	0.28	893
	2016	1264	1647	880	0.13	164		2016	7727	9570	5883	0.1	773
	2017	3654	7307	2	0.36	1315		2017	13805	23702	3908	0.26	3589
	2018	1782	2666	898	0.19	339		2018	4647	6901	2393	0.19	883
	2019	1932	1948	1916	0	0		2019	8356	8356	8356	0	0
	2020	7	19	0	0.97	7		2020	152	332	0	0.68	103
	2021	65	NA	NA	0	0		2021	365	NA	NA	0	0
	2022	**NA**	**NA**	**NA**	**NA**	**NA**		**2022**	**NA**	**NA**	**NA**	**NA**	**NA**
Newly Mature Females							**Newly Mature Males**						
	2010	418	1097	-260	0.63	263		2010	185	391	-22	0.43	80
	2011	65	170	-40	0.58	38		2011	58	208	-93	0.94	55
	2012	50	214	-114	0.76	38		2012	302	719	-114	0.5	151
	2016	205	355	55	0.28	57		2016	716	1176	256	0.25	179
	2017	88	249	-73	0.66	58		2017	541	1090	-9	0.4	216
	2018	114	226	3	0.35	40		2018	149	296	1	0.41	61
	2019	0	0	0	NA	0		2019	401	408	394	0	3
	2020	0	0	0	NA	0		2020	4	11	0	0.97	4
	2021	0	NA	NA	NA	NA		2021	0	NA	NA	NA	NA
	2022	**NA**	**NA**	**NA**	**NA**	**NA**		**2022**	**NA**	**NA**	**NA**	**NA**	**NA**

Table 10. Mean, minimum (min), and maximum (max) bottom water temperature (C°) and ordinal sampling date (numerical calendar date from 1 January) for survey collections in the Delaware Bay area and Lower Delaware Bay. For reference, 1 September is ordinal date 243 in non-leap years.

	Water Temperature			Ordinal Date		
	mean	**max**	**min**	**mean**	**max**	**min**
Delaware Bay Area						
2002	19.33	15	23.5	277.41	273	300
2003	17.41	13.5	20	286.60	278	296
2004	16.67	14.5	20.5	292.74	277	302
2005	20.94	14	24.5	261.23	250	306
2006	17.53	13	22.3	284.53	246	314
2007	19.69	14.3	23.3	294.96	282	311
2008	20.09	19.3	22.6	277.02	272	287
2009	15.54	14.3	17	315.24	307	324
2010	19.72	12.3	24.1	282.68	265	331
2011	21.60	18.6	23.8	265.44	254	296
2012	18.47	18.1	18.8	292.92	289	298
2016	22.82	18.6	24.8	274.02	260	299
2017	21.89	18.8	23.2	274.05	263	294
2018	22.48	13.9	24.8	276.41	253	315
2019	23.05	18.8	24.3	250.38	242	270
2020	21.79	17	25	231.15	219	252
2021	23.25	18.8	28	233.44	222	250
2022	**21.18**	**16.7**	**25.6**	**265.42**	**245**	**285**
Lower Delaware Bay						
2010	17.18	16.7	17.7	295.36	295	296
2011	18.32	18	18.6	294.27	294	295
2012	17.96	17.9	18	299.00	299	299
2016	19.56	19	20.1	288.40	288	289
2017	19.35	19.2	19.5	292.30	292	293
2018	12.16	11.3	12.8	321.44	321	322
2019	17.50	17.2	17.8	292.00	292	292
2020	24.00	23.2	25.4	248.00	248	248
2021	20.50	19	22	268.00	268	268
2022	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**

Table 11. Correlations between annual mean catches-per-tow of horseshoe crabs with mean bottom water temperature and ordinal sampling date in the Delaware Bay area survey and the lower Delaware Bay survey, by demographic group. The Delaware Bay area surveys included 15 years, and the lower Delaware Bay surveys included 8 years. Statistics presented include correlation coefficient, *r*; *T-score*; and probability, *p*. Data are from Tables 1, 3, and 10.

	Water Temperature			**Ordinal Date**		
Delaware Bay Area 2002 - 2022	***r***	***T***	***p***	***r***	***T***	***p***
Immature females	-0.531	-2.43	0.028	0.563	2.64	0.019
Immature males	-0.539	-2.48	0.026	0.578	2.74	0.015
Mature females	0.556	2.59	0.020	-0.692	-3.71	0.002
Mature males	0.581	2.76	0.014	-0.714	-3.95	0.001
Newly mature females	-0.164	-0.64	0.529	0.512	2.31	0.036
Newly mature males	0.452	1.96	0.068	-0.475	-2.09	0.054
Lower Delaware Bay 2002 - 2021						
Immature females	-0.116	-0.31	0.767	0.346	0.98	0.362
Immature males	-0.154	-0.41	0.692	0.36	1.02	0.341
Mature females	-0.371	-1.06	0.325	0.537	1.69	0.136
Mature males	-0.153	-0.41	0.694	0.37	1.05	0.327
Newly mature females	-0.273	-0.75	0.477	0.318	0.89	0.405
Newly mature males	-0.086	-0.23	0.826	0.303	0.84	0.428

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Red Knot Stopover Population Size and Migration Ecology at Delaware Bay, USA, 2023

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Abstract

Red Knots (*Calidris canutus rufa*) stop at Delaware Bay on the mid-Atlantic coast of North America during northward migration to feed on eggs of horseshoe crabs (*Limulus polyphemus*). We conducted a mark-recapture-resight investigation to estimate the passage population of Red Knots at Delaware Bay in 2023. The 2023 passage population size was estimated at 39,361 (95% credible interval: 33,724–47,556). Although there is broad overlap in the credible intervals for population estimates from 2020–2023, the population estimate for 2023 was below 40,000 birds for only the second time since 2011. Horseshoe crabs have been harvested for use as bait in eel (*Anguilla rostrata*) and whelk (*Busycon*) fisheries since at least 1990. In the late 1990s and early 2000s, the number of Red Knots counted during aerial surveys at Delaware Bay declined from ~50,000 to ~13,000 and some avian conservation biologists hypothesized that horseshoe crab harvest levels in the 1990s prevented sufficient refueling for successful migration to the Arctic breeding grounds, reproduction, and survival for the remainder of the annual cycle. Since 2013, the harvest of horseshoe crabs in the Delaware Bay region has been managed using an Adaptive Resource Management (ARM) framework. The objective of the ARM framework is to manage sustainable harvest of Delaware Bay horseshoe crabs while maintaining ecosystem integrity and supporting Red Knot recovery with adequate stopover habitat for Red Knots and other migrating shorebirds. For annual harvest recommendations, the ARM framework requires annual estimates of horseshoe crab population size and the Red Knot stopover population size. We used a Bayesian analysis of a Jolly-Seber model, which accounts for turnover in the population and the probability of detection during surveys to estimated the passage (stopover) population. The 2023 population size estimate will inform harvest recommendations in the next management cycle for decision making by the Atlantic States Marine Fisheries Commission.

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1. Introduction

Red Knots (*Calidris canutus rufa*) stop at Delaware Bay during northward migration to feed on eggs of horseshoe crabs (*Limulus polyphemus*). The northward migration of *C. c. rufa* coincides with the spawning of horseshoe crabs, whose eggs are an excellent food resource for a migrating Red Knots because they have a high energy content and are easily digestible (Karpantyet al. 2006, Haramis et al. 2007). Horseshoe crabs are therefore an important food resource for Red Knots as well as other shorebirds at Delaware Bay.

Horseshoe crabs have been harvested since at least 1990 for use as bait in American eel (*Anguilla rostrata*) and whelk (Busycon) fisheries (Kreamer and Michels 2009). In the late 1990s and early 2000s the estimated number of Red Knots counted at Delaware Bay declined from ~50,000 to ~13,000 (Niles et al. 2008). The number of horseshoe crabs harvested peaked in the late 1990s and then declined in the early 2000s. Avian conservation biologists hypothesized that unregulated harvest of horseshoe crabs from Delaware Bay in the 1990s prevented sufficient refueling during stopover for successful migration to the breeding grounds, nesting, and survival for the remainder of the annual cycle (Baker et al. 2004, McGowan et al. 2011).

The Atlantic States Marine Fisheries Commission (ASMFC) has managed the horseshoe crabs in the Delaware Bay region since 1998 and in 2012 adopted an Adaptive Resource Management (ARM) framework, which explicitly incorporates shorebird objectives in horseshoe crab (hereafter "crab" or "crabs") harvest regulation (McGowan et al. 2015b). The ARM framework was designed to constrain the harvest so that the number of spawning crabs would not limit the number of Red Knots stopping at Delaware Bay during migration. To achieve multiple objectives simultaneously, the ARM framework requires an estimate each year of both the crab population and the Red Knot stopover population size to inform harvest recommendations (McGowan et al. 2015a). Therefore, we estimated the stopover population size in 2023 using mark-resight data on individually-marked birds and a Jolly-Seber model for open populations, as we have each year since 2011.

2. Methods

Red Knots have been individually marked at Delaware Bay and other locations in the Western Hemisphere (e.g., Argentina, Brazil, Canada, Chile) with engraved leg flags since 2003. Each leg flag is engraved with a field-readable, unique 3-character alphanumeric code (Clark et al. 2005). Mark-resight data (i.e., sight records of individually-marked birds and counts of marked and unmarked birds) were collected on the Delaware and New Jersey shores of Delaware Bay in 2023 according to the methods for mark-resight investigations of Red Knots at Delaware Bay (Lyons 2016). This protocol has been used at Delaware Bay since 2011.

Surveys to locate leg-flagged birds were conducted on 20 beaches (Appendix 1) in 2023 according to the sampling plan, i.e., every three days in May and early June (Table 1). During these resighting surveys, agency staff and volunteers surveyed the beach and recorded the field- readable alphanumeric combinations detected on leg-flagged birds.

As in previous years (Lyons 2022), all flag resightings were validated with physical capture and banding data available in the data repository at http://www.bandedbirds.org/. Resightings without a corresponding record of physical capture and banding (i.e., "misread" errors) were discarded and not included in the analysis. However, banding data from Argentina are not available for validation purposes in bandedbirds.org; therefore, all resightings of orange engraved flags were included in the analysis without validation using banding data. We also omitted resightings of 12 flagged individuals in 2023 whose flag codes were accidentally deployed in both New Jersey and South Carolina (Amanda Dey, New Jersey Division of Fish and Wildlife, pers. comm., 31 May 2017) because it is not possible to confirm individual identity in this case. Section 4 "Summary of Mark-resight and Count Data Collected in 2023" describes additional quality control procedures and the potential for other types of errors in the mark- resight dataset.

While searching for birds marked with engraved leg flags, observers also periodically used a scan sampling technique to count marked and unmarked birds in randomly selected portions of Red Knot flocks (Lyons 2016). As part of the scan sampling protocol to estimate the marked-unmarked ratio (Lyons 2016), observers checked a random sample of birds for marks (leg flags), and recorded 1) the number of individually-marked birds, and 2) the number of birds checked for marks in each sample.

To estimate stopover population size, we used the methods of Lyons et al. (2016) to analyze 1) the mark-resight data (flag codes), and 2) data from the scan samples of the marked-unmarked ratio. Lyons et al. (2016) relied on the "superpopulation" approach developed by Crosbie and Manly (1985) and Schwarz and Arnason (1996). The superpopulation is defined as the total number of birds present in the study area on at least one of the sampling occasions over the entire

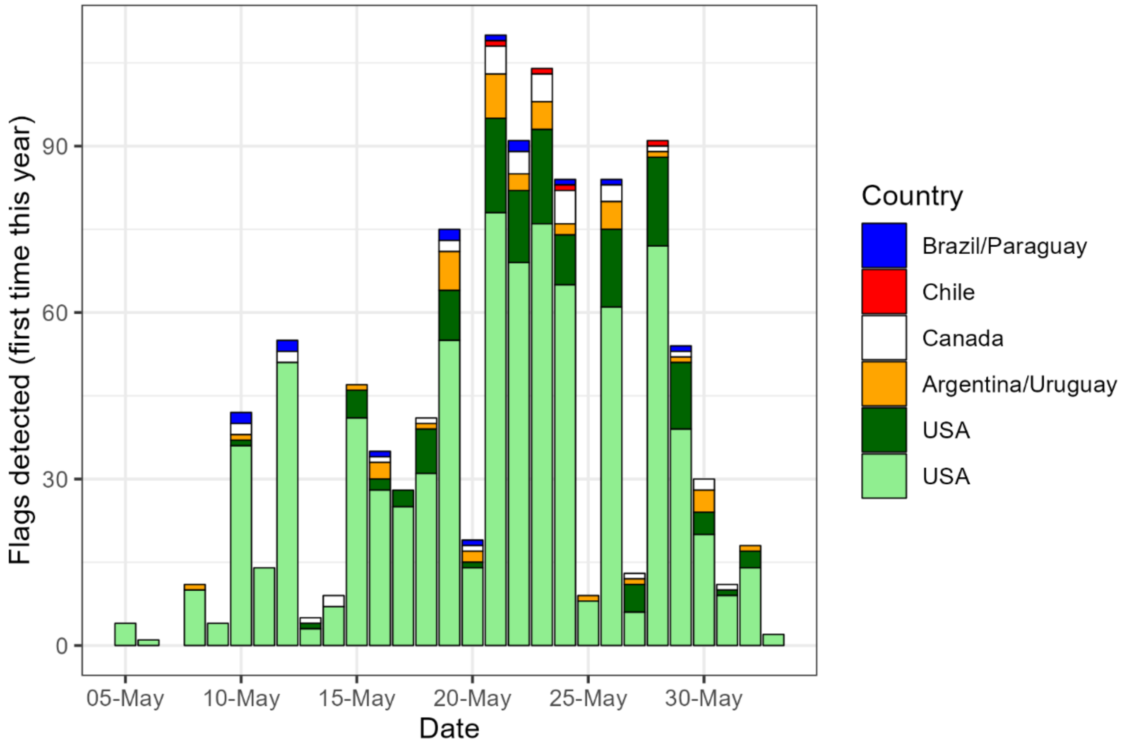

Figure 1 Number of flags detected for the first time in 2023 by flag color.

study, i.e., the total number of birds present in the study area at any time between the first and last sampling occasions (Nichols and Kaiser 1999). In this superpopulation approach, passage population size is estimated each year using the Jolly-Seber model for open populations, which accounts for the flow-through nature of migration areas and probability of detection during surveys.

In our analyses for Delaware Bay, the days of the migration season were aggregated into 3-day sampling periods (a total of 10 sample periods possible each season, Table 1). Data were aggregated to 3-day periods because this is the amount of time necessary to complete mark-resight surveys on all beaches in the study (a summary of the mark-resight data from 2023 is provided in Appendix 2).

With the mark-resight superpopulation approach, we first estimated the number of birds that were carrying leg flags, and then adjusted this number to account for unmarked birds using the estimated proportion of the population with flags. The estimated proportion with leg flags is thus an important statistic. We used the scan

Table 1. Dates for mark-resight survey periods (3-day sampling occasions) for Red Knots (*C. c. rufa*) at Delaware Bay in 2023. The same sampling periods have been used at Delaware Bay since 2011. Data from survey period 10 were not used in the 2023 analysis because the mark-resight data were sparse in this period.

Survey period	Dates	Survey period	Dates
1	≤10 May	6	23-25 May
2	11-13 May	7	26-28 May
3	14-16 May	8	29-31 May
4	17-19 May	9	1-3 June
5	20-22 May	10	4-6 June

sample data (i.e., the counts of marked birds and the number checked for marks) and a binomial model to estimate the proportion of the population that is marked. To account for the random nature of arrival of marked birds at the study area and the addition of new marks during the season, we implemented the binomial model as a generalized linear mixed model with a random effect for the sampling period. More detailed

Table 2. Number of Red Knot (*C. c. rufa*) flags detected at Delaware Bay from 2019–2023 by banding location (flag color).

	No. of flagged individuals detected				
Banding location (flag color)	2019	2020	2021	2022	2023
U.S. (lime green)	2,368	1,255	1,292	1,281	843
U.S. (dark green)	351	161	118	118	141
Argentina (orange)	216	89	81	66	48
Canada (white)	156	52	78	62	41
Brazil (dark blue)	35	21	17	14	14
Chile (red)	10	9	5	5	4
Total	3,136	1,587	1,591	1,546	1,091

methods are provided in Lyons et al. (2016) and Appendix 3.

3. Summary of Mark-resight and Count Data Collected in 2023

3.1 Mark-resight encounter data

The 2023 Red Knot mark-resight dataset included a total of 1,091 individual birds that were recorded at least once during mark-resight surveys at Delaware Bay in 2023; these birds were originally captured and banded with leg flags in five different countries (Table 2). This total is ~30% lower than the total detected at Delaware Bay in 2020 (1,587) and 2021 (1,591), and 2022 (1,546; Table 2).

There was sufficient data for analysis in 9 of the 10 sampling periods in 2023 (≤10 May to 3 June; Table 1). In 2023, data beyond 3 June were too sparse for analysis and were not included.

One assumption of the mark-resight approach is that individual identity of marked birds is recorded without error (see Lyons 2016 for discussion of all model assumptions). As noted above, some field-recording errors are evident when sight records are compared to physical capture records available from bandedbirds.org. Again, any engraved flag reported by observers that did not have a corresponding record of physical capture was omitted. Field observers submitted 3,379 resightings in 2023; 34 were not valid (i.e., no corresponding banding data), for an overall misread read of 1.1%. These invalid resightings were removed before analysis, but a second type of "false positive" is still possible, i.e., false positive detection of flags that were deployed prior to 2023 but were not in fact present at Delaware Bay in 2023. It is not possible to identify this second type of false positive with banding data validation or other quality assurance/quality control methods (Tucker et al. 2019).

3.2 Marked-ratio data ("scan samples")

In 2023, 504 marked ratio scan samples were collected: 326 and 178 samples in Delaware and New Jersey, respectively (Appendix 4). In 2020, 2021, and 2022, there were 734, 564, and 541 marked-ratio scan samples collected, respectively.

Table 3. Number of Red Knots (*C. c. rufa*) detected during aerial and ground surveys of Delaware Bay in 2023. Data were provided by W. Pitts, New Jersey Department of Environmental Protection, Division of Fish and Wildlife.

	Total
Aerial survey	
2023-05-16	5,029
2023-05-22	12,713
2023-05-26	11,785
Ground/Boat Surveys	
2023-05-22	22,266
2023-05-26	21,448

3.3 Aerial and ground count data

Aerial surveys of the Delaware and New Jersey shore were conducted on 16, 22, and 26 May 2023 (Table 3; data provide by W. Pitts, New Jersey Department of

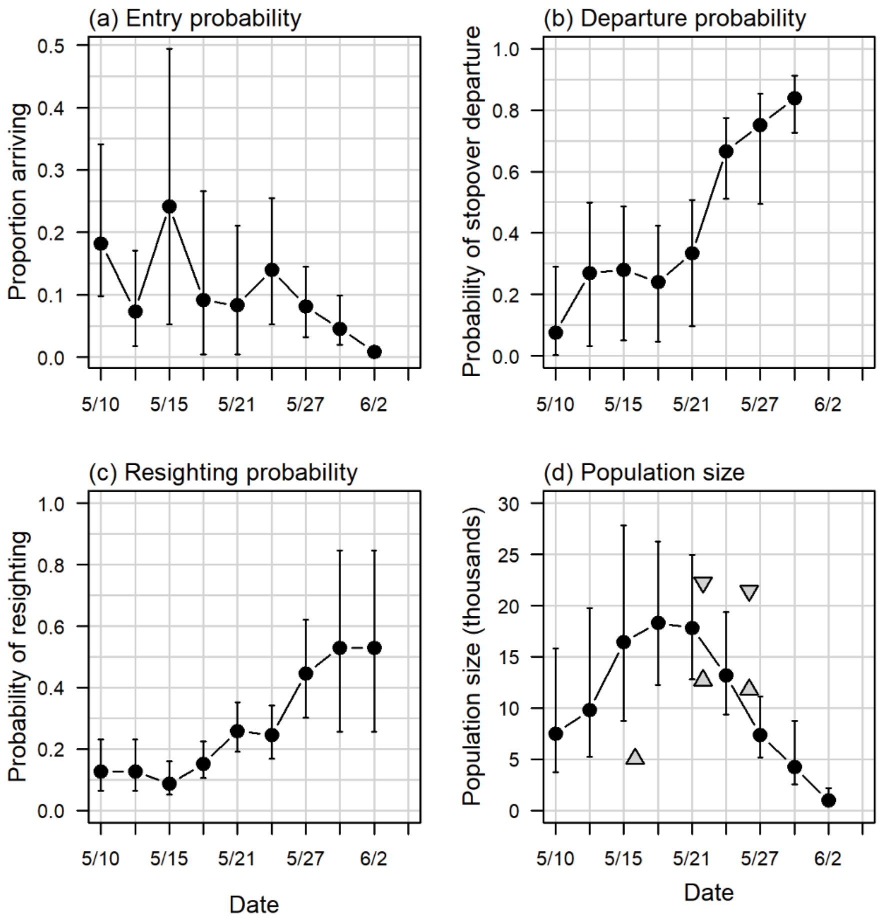

Figure 2 Estimated Jolly-Seber (JS) model parameters from a mark-resight study of Red Knots (*C. c. rufa*) at Delaware Bay in 2023: (a) proportion of stopover population arriving at Delaware Bay, (b) stopover departure probability, (c) probability of resighting, and (d) time-specific stopover population size. Dates on the x- axis represent sampling occasions (3-day survey periods, Table 1). Triangles in (d) are aerial survey (triangle point up) and ground counts (triangle point down).

Environmental Protection, Division of Fish and Wildlife). Ground and boat surveys of the Delaware and New Jersey shore also were conducted on 22 and 26 May 2023.

4. Summary of 2023 Migration

A substantial number of Red Knots arrived early in 2023, with ~20% of all birds that stopped in the bay this year arriving by 10 May (Fig. 1a). This is a larger proportion of early arrivals than last year: in 2022, <10% arrived before 14 May. Arrivals in 2023 peaked around 15 May, with another ~25% of all birds arriving between 13 and 16 May 2023. Approximately 50% of all birds in the 2023 stopover populations thus had arrived by 16 May, which is slightly earlier than the long-term pattern of arrivals; in many years the peak of arrivals has been closer to 18 May.

Stopover departure probability is the probability that a bird present at Delaware Bay during sampling period *i* departs before sampling period *i*+1. In 2023, departure probability was relatively high early in the season, indicating substantial turnover in the stopover population (Fig. 1b). In many years, departure probability is often ≤10% early in the season, indicating that early-arriving birds remain in the bay. In 2023, departure probability was above 20% by 12 May, relatively high for early in the season and indicating high turnover in the population. Departures continued at a steady pace until 24 May when mass depatures began and continued to the end of May (Fig. 1b).

Table 4. Red Knot (*C. c. rufa*) stopover (passage) population estimate using mark-resight methods compared to a peak-count index using aerial- or ground-survey methods at Delaware Bay. The mark-resight estimate of stopover (passage) population, *N, accounts for population turnover during migration. The peak-count index, a single count on a single day, does not account for turnover in the population. "AG" indicates a combination of aerial and ground counts used to formulate the peak-count index. "CI" stands for credible interval.**

Year	Stopover population[a] (mark-resight *N**)	95% CI stopover population *N**	Peak-count index (aerial [A]; ground [G])
2011	43,570	(40,880 – 46,570)	12,804 (A)[b]
2012	44,100	(41,860 – 46,790)	25,458 (G)[c]
2013	48,955	(39,119 – 63,130)	25,596 (A)[d]
2014	44,010	(41,900 – 46,310)	24,980 (A)[c]
2015	60,727	(55,568 – 68,732)	24,890 (A)[c]
2016	47,254	(44,873 – 50,574)	21,128 (A)[b]
2017	49,405[e]	(46,368 – 53,109)	17,969 (A)[f]
2018	45,221	(42,568 – 49,508)	32,930 (A)[b]
2019	45,133	(42,269 – 48,393)	30,880 (A)[g]
2020	40,444	(33,627 – 49,966)	19,397 (G)[c]
2021	42,271	(35,948 – 55,210)	6,880 (AG)[h]
2022	39,800	(35,013 – 51,355)	12,114 (AG)[g]
2023	39,361	(33,724 – 47,556)	22,266 (G)[g]

[a] passage population estimate for entire season, including population turnover

[b] 23 May

[c] 24 May

[d] 28 May

[e] Data management procedures to reduce bias from recording errors in the field; data from observers with greater than average misread rate were not included in the analysis.

[f] 26 May

[g] 22 May

[h] 27 May

Following Lyons et al. (2016), we used the Jolly-Seber model to estimate stopover duration. Stopover duration in 2023 was similar to 2022, but slightly lower than during 2019 – 2021. In 2023, estimated average stopover duration was 9.2 days (95% credible interval (CI), 8.2 – 10.4 days). The stopover duration estimate (and 95% CI) was 12.1 days in 2019 (11.6 – 12.5), 10.7 days in 2020 (9.9 – 11.7), 10.3 days in 2021 (9.0 – 12.1),and 9.4 days in 2022 (8.6 – 10.9 days). This method of estimating stopover duration provides a coarse measure in our Delaware Bay study, however, because it is derived from the estimated number of sampling periods (i.e., the time step in the mark-recapture model) that birds remained in the study area. Each sampling period in this analysis is 3 consecutive days in which the data are aggregated (Table 1). To estimate stopover duration in number of days at Delaware Bay with this method, we first estimate the number of sampling periods that each bird remained in the study area and then multiply this by 3 (the number of days in each period). The resolution of the stopover duration estimate is thus limited by the resolution of the sampling periods.

Probability of resighting in 2023 was relatively low for much of the season, remainging below 30% from 10 May until 24 May (Fig. 1c). Probability of resighting higher during 27 May to 2 June (~40–50%) at the end of the season.

In 2023, 6.8% of the stopover population carried engraved leg flags (95% CI: 5.9–7.9%; Appendix 5 Fig. A5). This is slightly lower than 2022 (8.4% , 95% CI: 7.4%–9.7%) and suggests a declining trend in the proportion with flags. The proportion of the population with leg flags has historically been closer to 10% and was as high as 9.6 percent (95% CI: 8.8%–10.3%) in 2020.

5. Stopover Population Estimation

The passage population size estimate for 2023 was 39,361 (95% credible interval: 33,724 – 47,556; Table 4). Unlike the aerial survey, this superpopulation estimate accounts for turnover in the population and probability of detection. The 2023 stopover population estimate is similar to the 2022 population estimate, lower than the 2021 estimate, and below 40,000 for the first time since 2011, the first year of our mark-resight estimation procedures were used at Delaware Bay (Table 4). However, there was wide overlap of the confidence intervals for the stopover population estimates in recent years (Table 4).

Like 2020–2022 population estimates, the 2023 estimate is slightly lower than the 2018 and 2019 estimates (Table 4) and the confidence interval is wider. The wide confidence intervals are due in part to the low probability of resighting for many of the sampling periods during 2020–2023 compared to earlier years (early 2021 notwithstanding).

The time-specific stopover population estimates in 2023 increased steadily from the beginning of the season and peaked around 18–21 May (~18,300), similar to 2022 (Fig. 1d). After the peak, time-specific estimates declined steadily until 2 June (Fig. 1d).

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References

Baker, A. J., P. M. González, T. Piersma, L. J. Niles, I. de Lima Serrano do Nascimento, P. W. Atkinson, N. A. Clark, C. D. T. Minton, M. K. Peck, and G. Aarts. 2004. Rapid population decline in Red Knots: fitness consequences of decreased refuelling rates and late arrival in Delaware Bay. Proceedings of the Royal Society of London. Series B: Biological Sciences 271:875–882.

Clark, N.A., S. Gillings, A.J. Baker, P.M. González, and R. Porter. 2005. The production and use of permanently inscribed leg flags for waders. Wader Study Group Bull. 108: 38–41.

Crosbie, S. F., and B. F. J. Manly. 1985. Parsimonious modelling of capture-mark-recapture studies. Biometrics 41:385–398.

Haramis, G. M., W. A. Link, P. C. Osenton, D. B. Carter, R. G. Weber, N. A. Clark, M. A. Teece, and D. S. Mizrahi. 2007. Stable isotope and pen feeding trial studies confirm the value of horseshoe crab Limulus polyphemus eggs to spring migrant shorebirds in Delaware Bay. Journal of Avian Biology 38:367–376.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration-stochastic model. Biometrika 52:225–248.

Karpanty, S. M., J. D. Fraser, J. Berkson, L. J. Niles, A. Dey, and E. P. Smith. 2006. Horseshoe crab eggs determine red knot distribution in Delaware Bay. Journal of Wildlife Management 70:1704–1710.

Kéry, M., and M. Schaub. 2012. Bayesian population analysis using WinBUGS: a hierarchical perspective. 1st ed. Academic Press, Boston.

Lyons, J.E. 2016. Study design guidelines for mark-resight investigations of Red Knots in Delaware Bay. Unpublished report. U.S. Fish and Wildlife Service Division of Migratory Bird Management, Laurel, MD. 13 pp.

Lyons, J.E., W.P. Kendall, J.A. Royle, S.J. Converse, B.A. Andres, and J.B. Buchanan. 2016. Population size and stopover duration estimation using mark-resight data and Bayesian analysis of a superpopulation model. Biometrics 72:262-271.

Lyons, J. E. 2022. Red Knot stopover population size and migration ecology at Delaware Bay, USA, 2022. Delaware Division of Fish and Wildlife, Dover, DE. 23 pp. Available at: https://dnrec.alpha.delaware.gov/fish-wildlife/conservation/shorebirds/research/

McGowan, C. P., J. E. Hines, J. D. Nichols, J. E. Lyons, D. R. Smith, K. S. Kalasz, L. J. Niles, A. D. Dey, N. A. Clark, P. W. Atkinson, C. D. T. Minton, and W. L. Kendall. 2011. Demographic consequences of migratory stopover: linking Red Knot survival to horseshoe crab spawning abundance. Ecosphere 2:Article 69.

McGowan, C. P., J. E. Lyons, and D. R. Smith. 2015a. Developing objectives with multiple stakeholders: Adaptive management of horseshoe crabs and red knots in the Delaware Bay. Environmental Management 55:972–982.

McGowan, C. P., D. R. Smith, J. D. Nichols, J. E. Lyons, J. Sweka, K. Kalasz, L. J. Niles, R. Wong, J. Brust, M. Davis, and B. Spear. 2015b. Implementation of a framework for multi-species, multi-objective adaptive management in Delaware Bay. Biological Conservation 191:759–769.

Kreamer, G., and S. Michels. 2009. History of horseshoe crab harvest on Delaware Bay. Pages 299–313 in J. T. Tanacredi, M. L. Botton, and D. R. Smith, editors. Biology and Conservation of Horseshoe Crabs. Springer, New York, NY.

Nichols, J. D., and A. Kaiser. 1999. Quantitative studies of bird movement: a methodological review. Bird Study 46:S289–S298.

Niles, L. J., H. P. Sitters, A. D. Dey, P. W. Atkinson, A. J. Baker, K. A. Bennett, R. Carmona, K. E. Clark, N. A. Clark, C. Espoz, P. M. González, B. A. Harrington, D. E. Hernández, K. S. Kalasz, R. G. Lathrop, R. N. Matus, C. D. T. Minton, R. I. G. Morrison, M. K. Peck, W. Pitts, R. A. Robinson, and I. L. Serrano. 2008. Status of the red knot (Calidris canutus rufa) in the Western Hemisphere. Studies in Avian Biology 36:xviii+185.

Royle, J. A., and R. M. Dorazio. 2008. Hierarchical modeling and inference in ecology: the analysis of data from populations, metapopulations and communities. Academic Press, Amsterdam.

Royle, J. A., and R. M. Dorazio. 2012. Parameter-expanded data augmentation for Bayesian analysis of capture–recapture models. Journal of Ornithology 152:521–537.

Schwarz, C. J., and A. N. Arnason. 1996. A general methodology for the analysis of capture- recapture experiments in open populations. Biometrics 52:860–873.

Seber, G. A. F. 1965. A note on the multiple-recapture census. Biometrika 52:249–259.

Tucker, A. M., C. P. McGowan, R. A. Robinson, J. A. Clark, J. E. Lyons, A. DeRose-Wilson, R. du Feu, G. E. Austin, P. W. Atkinson, and N. A. Clark. 2019. Effects of individual misidentification on estimates of survival in long-term mark–resight studies. The Condor: Ornithological Applications 121:1-13.

Appendix 1. Locations around Delaware Bay, USA, where mark-resight surveys were conducted to estimate Red Knot (*C. c. rufa*) stopover population size in 2023.

State	Beach	Longitude	Latitude
DE	Port Mahon	-75.4021	39.1831
DE	Pickering Beach	-75.4087	39.1377
DE	Kitts Hummock	-75.4048	39.1130
DE	Ted Harvey Wildlife Area	-75.4019	39.0864
DE	North Bowers	-75.3973	39.0630
DE	South Bowers	-75.3860	39.0498
DE	Brockenbridge	-75.3638	39.0359
DE	Mispillion	-75.3131	38.9519
DE	Slaughter Beach	-75.3146	38.9282
DE	Fowlers Beach	-75.2633	38.8766
DE	Prime Hook Beach	-75.2467	38.8604
NJ	Gandys/Money Island	-75.2417	39.2767
NJ	Fortescue	-75.1675	39.2233
NJ	North Reeds	-74.8908	39.1228
NJ	South Reeds	-74.8922	39.1138
NJ	Cooks	-74.8941	39.1082
NJ	Kimbles	-74.8948	39.1049
NJ	Bay Cove	-74.8965	39.1008
NJ	Pierces Point	-74.9013	39.0897
NJ	Villas and Norburys	-74.9298	39.0449

Appendix 2. Summary ("m-array") of Red Knot (*C. c. rufa*) mark-resight data from Delaware Bay, USA, 2023. NR = never resighted.

			Next resighted at sample								
Sample	Dates	Resighted	2	3	4	5	6	7	8	9	NR
1	≤10 May	62	9	1	1	9	3	3	0	0	36
2	11-13 May	83		7	4	7	1	1	0	0	63
3	14-16 May	99			17	9	2	4	0	0	67
4	17-19 May	166				32	17	6	2	0	109
5	20-22 May	277					49	17	4	0	207
6	23-25 May	269						42	6	0	221
7	26-28 May	261							35	2	224
8	29-31 May	142								13	129
9	1-3 June	35									

Appendix 3. Statistical Methods to Estimate Stopover Population Size of Red Knots (*C. c. rufa*) Using Mark-Resight Data and Counts of Marked Birds

We converted the observations of marked Red Knots into encounter histories, one for each bird, and analyzed the encounter histories with a Jolly-Seber (JS) model (Jolly 1965, Seber 1965, Crosbie and Manly 1985, Schwarz and Arnason 1996). The JS model includes parameters for recruitment (β), survival (ϕ), and capture (*p*) probabilities; in the context of a mark-resight study at a migration stopover site, these parameters are interpreted as probability of arrival to the study area, stopover persistence, and resighting, respectively. Stopover persistence is defined as the probability that a bird present at time *t* remains at the study area until time *t* + 1. The Crosbie and Manley (1985) and Schwarz and Arnason (1996) formulation of the JS model also includes a parameter for superpopulation size, which in our approach to mark-resight inferences for stopover populations is an estimate of the marked (leg-flagged) population size.

We chose to use 3-day periods rather than days as the sampling interval for the JS model given logistical constraints on complete sampling of the study area; multiple observations of the same individual in a given 3-day period were combined for analysis. A summary (m-array) of the mark-resight data is presented in Appendix 1.

We made inference from a fully-time dependent model; arrival, persistence, and resight probabilities were allowed to vary with sampling period [β_t ϕ_t p_t]. In this model, we set $p_1 = p_2$ and $p_{K-1} = p_K$ (where *K* is the number of samples) because not all parameters are estimable in the fully-time dependent model (Jolly 1965, Seber 1965, Crosbie and Manly 1985, Schwarz and Arnason 1996).

We followed the methods of Royle and Dorazio (2008) and Kéry and Schaub (2012, Chapter 10) to fit the JS model using the restricted occupancy formulation. Royle and Dorazio (2008) use a state-space formulation of the JS model with parameter-expanded data augmentation. For parameter-expanded data augmentation, we augmented the observed encounter histories with all-zero encounter histories (n = 2000) representing potential recruits that were not detected (Royle and Dorazio 2012). We followed Lyons et al. (2016) to combine the JS model with a binomial model for the counts of marked and unmarked birds in an integrated Bayesian analysis. Briefly, the counts of marked birds (m_s) in the scan samples are modeled as a binomial random variable:

$$m_s \sim Bin(C_s, \pi), \qquad (1)$$

where m_s is the number of marked birds in scan sample *s*, C_s is the number of birds checked for marks in scan sample *s*, and π is the proportion of the population that is marked. Total stopover population size $\widehat{N^*}$ is estimated by

$$\widehat{N^*} = \widehat{M^*}/_{\hat{\pi}} \qquad (2)$$

where $\widehat{M^*}$ is the estimate of marked birds from the J-S model and $\hat{\pi}$ is the proportion of the population that is marked (from Eq. 1). Estimates of marked subpopulation sizes at each resighting occasion *t* $\left(\widehat{M_t^*}\right)$ are available as derived parameters in the analysis. We calculated an estimate of population size at each mark-resight sampling occasion $\widehat{N_t^*}$ using $\widehat{M_t^*}$ and $\hat{\pi}$ as in equation 2.

To better account for the random nature of the arrival of marked birds and addition of new marks during the season, we used a time-specific model for proportion with marks in place of equation 1 above:

$$m_{s,t} \sim Binomial\left(C_{s,t}, \pi_t\right) \qquad (3)$$

$$for\ s\ in\ 1, \dots, n_{samples}\ and\ t\ in\ 1, \dots, n_{occasions}$$

$$logit(\pi_t) = \alpha + \delta_t$$

$$\delta_t \sim Normal(0, \sigma^2_{occasions})$$

where m_s is the number of marked birds in scan sample *s*, C_s is the number of birds checked for marks in scan sample *s*, δ_t is a random effect time of sample *s*, and π_t is the time-specific proportion of the population that is marked. Total stopover population size $\widehat{N^*}$ was estimated by summing time-specific arrivals of marked birds to the stopover (B_t) and expanding to include unmarked birds using estimates of proportion marked:

$$\widehat{N^*} = \sum \widehat{B_t} / \pi_t$$

Time-specific arrivals of marked birds are estimated from the Jolly-Seber model using $\widehat{B_t} = \widehat{\beta}_t \widehat{M^*}$ where $\widehat{M^*}$ is the estimate of the number of marked birds and $\widehat{\beta_t}$ is the fraction of the population arriving at time *t*.

Appendix 4. Marked-ratio scan samples of Red Knots (*C. c. rufa*).

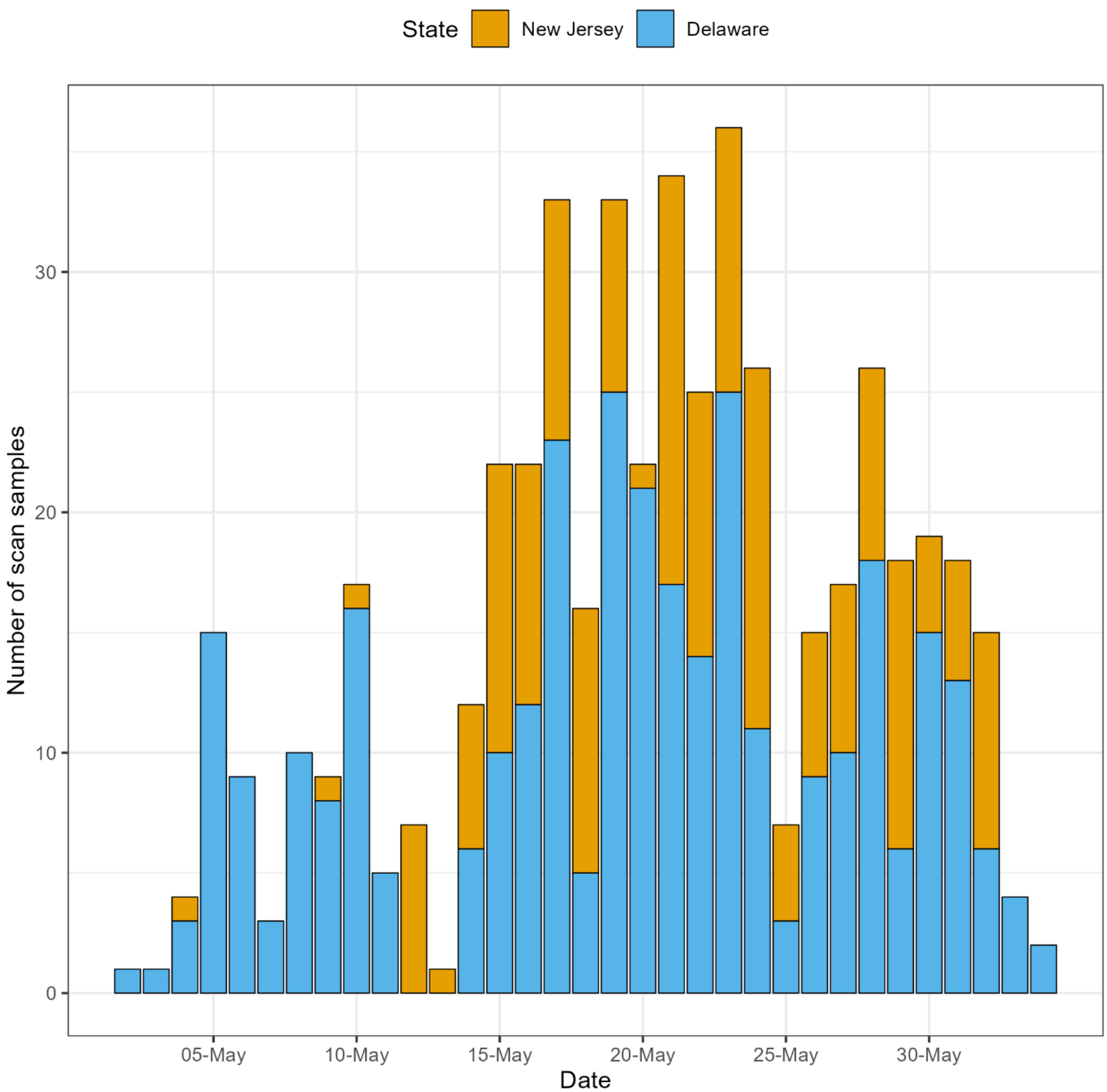

Figure A4. Number of Red Knot (*C. c. rufa*) marked-ratio scan samples (n =) collected in Delaware Bay in 2023 by field crews in Delaware (blue, n = scan samples) and New Jersey (orange, n = scan samples) and date.

Appendix 5. Marked proportion.

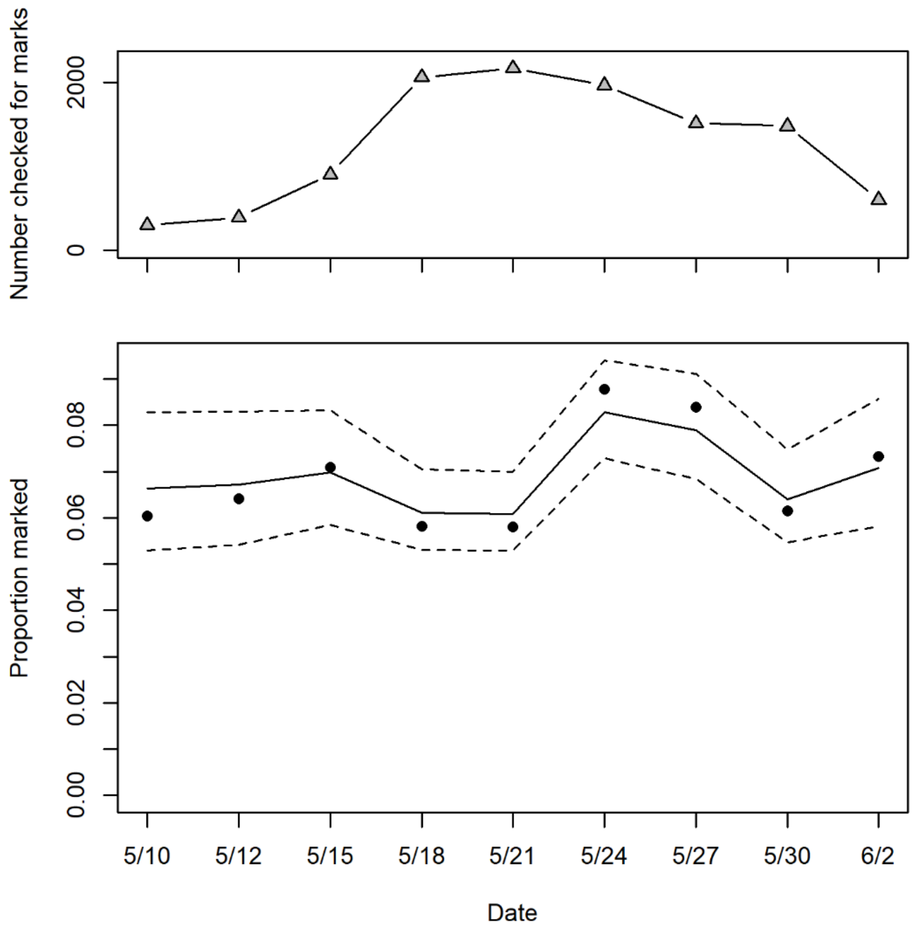

Figure A5. Estimated proportion of the Delaware Bay stopover population of Red Knots (*C. c. rufa*) carrying leg flags in 2023 (overall average and 95% credible interval: 0.068 [0.059, 0.079]). The marked proportion was estimated from marked-ratio scan samples for each 3-day sampling period. The dates for the sampling periods are shown in Table 1. The upper panel shows the sample size (number scanned, i.e., checked for marks) for each sample period. The bottom panel shows the estimated proportion marked for each sample occasion, which was estimated with the generalized linear mixed model described in Appendix 2. Solid and dashed lines are estimated median proportion marked and 95% credible interval, respectively; filled circles show (number with marks/number scanned).

ATLANTIC STATES MARINE FISHERIES COMMISSION

REVIEW OF THE INTERSTATE FISHERY MANAGEMENT PLAN

HORSESHOE CRAB
(*Limulus polyphemus*)

2022 Fishing Year

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Prepared by the Plan Review Team

October 2023

Sustainable and Cooperative Management of Atlantic Coastal Fisheries

Table of Contents

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I. Status of the Fishery Management Plan

Date of FMP Approval:	December 1998
Amendments	None
Addenda	Addendum I (April 2000) Addendum II (May 2001) Addendum III (May 2004) Addendum IV (June 2006) Addendum V (September 2008) Addendum VI (August 2010) Addendum VII (February 2012)
Management Unit:	Entire coastwide distribution of the resource from the estuaries eastward to the inshore boundary of the EEZ
States with Declared Interest:	Massachusetts – Florida, Potomac River Fisheries Commission
Active Boards/Committees:	Horseshoe Crab Management Board, Advisory Panel, Technical Committee, and Plan Review Team; Delaware Bay Ecosystem Technical Committee; Adaptive Resource Management Subcommittee

Goals and Objectives

The Interstate Fishery Management Plan for Horseshoe Crabs (FMP) established the following goals and objectives.

2.0. Goals and Objectives

The goal of this Plan is to conserve and protect the horseshoe crab resource to maintain sustainable levels of spawning stock biomass to ensure its continued role in the ecology of the coastal ecosystem, while providing for continued use over time. Specifically, the goal includes management of horseshoe crab populations for continued use by:

1) *current and future generations of the fishing and non-fishing public (including the biomedical industry, scientific and educational research);*
2) *migrating shorebirds; and,*
3) *other dependent fish and wildlife, including federally listed (threatened) sea turtles.*

To achieve this goal, the following objectives must be met:

(a) prevent overfishing and establish a sustainable population;

(b) achieve compatible and equitable management measures among jurisdictions throughout the fishery management unit;

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(c) establish the appropriate target mortality rates that prevent overfishing and maintain adequate spawning stocks to supply the needs of migratory shorebirds;
(d) coordinate and promote cooperative interstate research, monitoring, and law enforcement;
(e) identify and protect, to the extent practicable, critical habitats and environmental factors that limit long-term productivity of horseshoe crabs;
(f) adopt and promote standards of environmental quality necessary for the long-term maintenance and productivity of horseshoe crabs throughout their range; and,
(g) establish standards and procedures for implementing the Plan and criteria for determining compliance with Plan provisions.

Fishery Management Plan Summary
The framework for managing horseshoe crabs along the Atlantic coast was approved in October 1998 with the adoption of the Interstate Fishery Management Plan (FMP) for Horseshoe Crabs. The goal of this plan is to conserve and protect the horseshoe crab resource to maintain sustainable levels of spawning stock biomass to ensure its continued role in the ecology of coastal ecosystems while providing for continued use over time.

In 2000, the Horseshoe Crab Management Board approved Addendum I to the FMP. Addendum I established a state-by-state cap on horseshoe crab bait landings at 25 percent below the reference period landings (RPL's), and *de minimis* criteria for those states with a limited horseshoe crab fishery. Those states with more restrictive harvest levels (Maryland and New Jersey) were encouraged to maintain those restrictions to provide further protection to the Delaware Bay horseshoe crab population, recognizing its importance to migratory shorebirds. Addendum I also recommended that the National Marine Fisheries Service (NMFS) prohibit the harvest of horseshoe crabs in federal waters (3-200 miles offshore) within a 30 nautical mile radius of the mouth of Delaware Bay, as well as prohibit the transfer of horseshoe crabs in federal waters. A horseshoe crab reserve was established on March 7, 2001, by NMFS in the area recommended by ASMFC. This area is now known as the Carl N. Shuster Jr. Horseshoe Crab Reserve (Figure 1).

In 2001, the Horseshoe Crab Management Board approved Addendum II to the FMP. The purpose of Addendum II was to allow the voluntary transfer of harvest quotas between states to alleviate concerns over potential bait shortages on a biologically responsible basis. Voluntary quota transfers require Technical Committee review and Management Board approval.

In 2004, the Board approved Addendum III to the FMP. The addendum sought to further the conservation of horseshoe crab and migratory shorebird populations in and around the Delaware Bay. It reduced harvest quotas and implemented seasonal bait harvest closures in New Jersey, Delaware, and Maryland, and revised monitoring components for all jurisdictions.

Addendum IV was approved in 2006. It further limited bait harvest in New Jersey and Delaware to 100,000 crabs (male only) and required a delayed harvest in Maryland and Virginia.

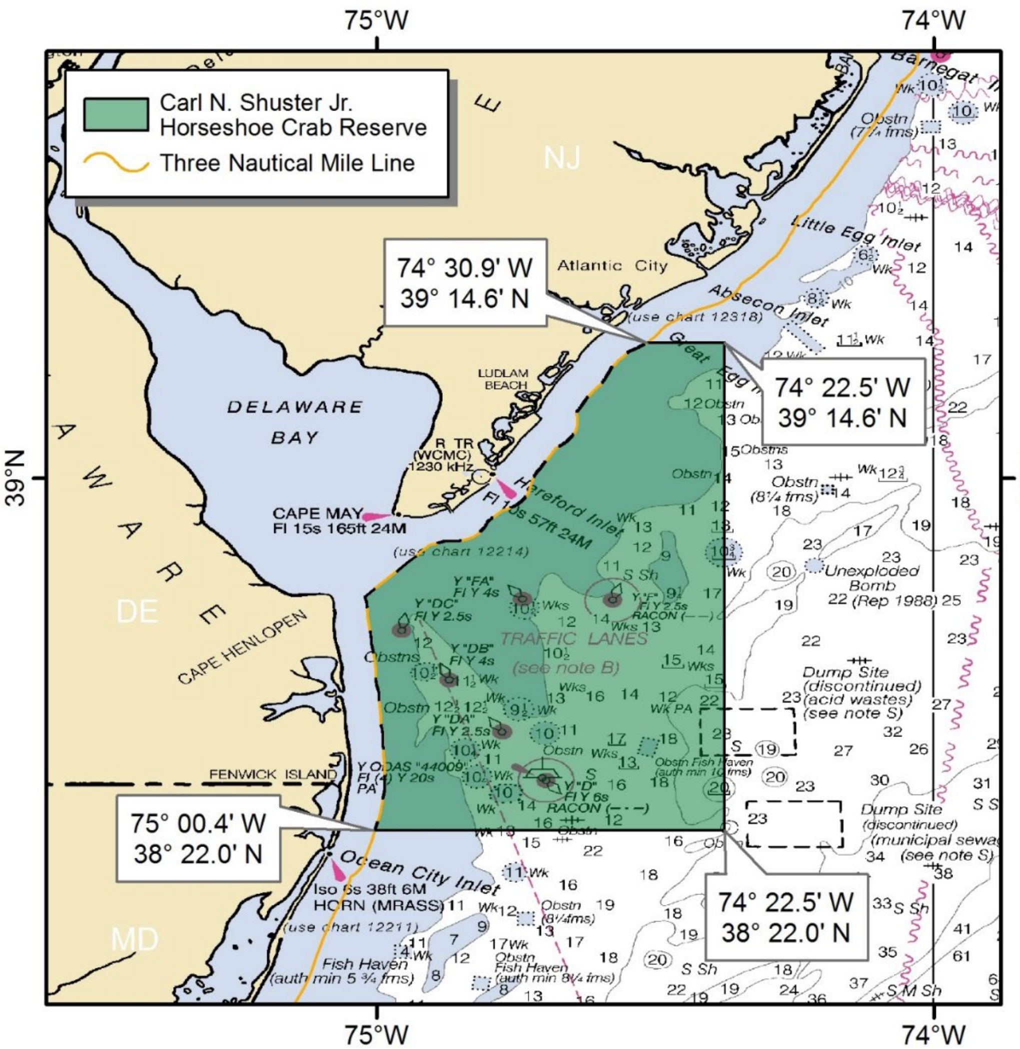

Figure 1. Carl N. Shuster Jr Horseshoe Crab Reserve.

Addendum V, adopted in 2008, extended the provisions of Addendum IV through October 31, 2010.

In early 2010, the Board initiated Draft Addendum VI to consider management options that would follow expiration of Addendum V. The Board voted in August 2010 to extend the Addendum V provisions, via Addendum VI, through April 30, 2013. The Board also chose to include language allowing them to replace Addendum VI with another Addendum during that time, in anticipation of implementing an Adaptive Resource Management (ARM) Framework.

The Board approved Addendum VII in February 2012. This addendum implemented an ARM framework for use during the 2013 fishing season and beyond. The framework considers the abundance levels of horseshoe crabs and shorebirds in determining the optimized bait harvest level for the Delaware Bay states of New Jersey, Delaware, Maryland, and Virginia (east of the COLREGS).

The ARM Framework underwent a revision process in 2021 to incorporate more available data and update the software platform. Several improvements were made to the ARM Framework during this revision. The ARM Revision improves the population models for horseshoe crabs and red knots by incorporating Delaware Bay region-specific data collected over the past few decades. Horseshoe crab population estimates from the Catch Multiple Survey Analysis (CMSA) model used in the 2019 Benchmark Stock Assessment were incorporated into the ARM Revision. Additionally, the ARM Revision includes more sources of horseshoe crab removals than the previous version, adding mortality in the biomedical industry and commercial discards from other fisheries. The maximum number of male and female horseshoe crabs the ARM Revision can recommend remains the same at 210,000 females and 500,000 males. However, harvest recommendations under the ARM Revision are now based on a continuous scale rather than the fixed harvest packages in the previous Framework. Also, the harvest of females is decoupled from the harvest of males so that each are determined separately. While additional data and model improvements are used in the ARM Revision, the conceptual model of horseshoe crab abundance influencing red knot survival and reproduction remains intact with the intent of ensuring the abundance of horseshoe crabs does not become a limiting factor in the population growth of red knots. The Board accepted the ARM Revision and Peer Review for management use in January 2022.

Addendum VIII was approved in November 2022. Addendum VIII adopts the changes to the ARM Framework as recommended in the peer-reviewed 2021 ARM Framework for use in setting annual specifications for horseshoe crabs of Delaware Bay-origin.

II. Status of the Stock and Assessment Advice

A benchmark stock assessment was completed and approved for management use in 2019. The assessment report is available at:
http://www.asmfc.org/uploads/file/5cd5d6f1HSCAssessment_PeerReviewReport_May2019.pdf

This assessment was the first to successfully apply a stock assessment model to a component of the horseshoe crab stock. A Catch Multiple Survey Analysis (CMSA) model, a stage-based model that tracks progression of crab abundances from pre-recruits to full recruits to the fishery, was applied to female crabs in the Delaware (DE) Bay region (New Jersey-Virginia). This model estimated regional female crab abundance using relative abundance information from the Virginia Tech Benthic Trawl Survey, New Jersey Ocean Trawl Survey, and Delaware Adult Trawl Survey, and estimates of mortality including natural mortality, commercial bait harvest, commercial discard mortality, and mortality associated with biomedical use. While reference points were not approved to determine stock status, the CMSA population estimates were recommended as the best estimates for female horseshoe crab abundance in the DE Bay region.

The base CMSA model population estimates show an increase in the number of female crabs in the DE Bay region since 2012, when the ARM Framework was established via Addendum VII.

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This increasing trend is supported by positive trends in regional fishery-independent surveys during this time period. Population estimates from the base model are not publicly available due to the inclusion of confidential biomedical data. However, a sensitivity run assuming no biomedical mortality is publicly viewable, and these estimates are not significantly different from the base model results. Estimates of discard mortality from the Northeast Fisheries Observer Program (NEFOP) were also included in the base CMSA model and indicate that discard mortality could be significant, of similar or greater magnitude than mortality due to bait harvest. Population estimates from the CMSA are currently being considered for incorporation into the ARM Framework, which is applied annually to specify bait harvest quotas for the DE Bay region.

Autoregressive Integrated Moving Average (ARIMA) models, similar to those used in previous assessments, were applied to all regions. ARIMA models were fit to fishery-independent survey indices trends of abundance in each of the regional horseshoe crab populations: Northeast (Massachusetts-Rhode Island), New York (Connecticut-New York), DE Bay, and Southeast (North Carolina-Florida). No definitions for overfishing or overfished status have been adopted by the Management Board. However, the assessment characterized the status of each regional and the coastwide population based on the percentage of surveys within a region (or coastwide) having a >50% probability of the terminal year being below the ARIMA reference point. The ARIMA reference point was the 1998 index for each survey. “Poor” status was defined as >66% of surveys meeting this criterion, “Good” status was defined as <33% of surveys, and “Neutral” status was defined as 34–65% of surveys. Based on these criteria, stock status was neutral for the Northeast region, poor for the New York region, neutral for the Delaware Bay region, and good for the Southeast region. Coastwide, abundance has fluctuated through time with many surveys decreasing after 1998 but increasing in recent years. The coastwide status includes surveys from all regions and indicates a neutral trend, likely due to a combination of positive and negative trends.

An assessment update is expected for completion in 2024.

III. Status of the Fishery

Bait Fishery

For most states, the bait fishery is open year-round. However, because of seasonal horseshoe crab movements (to the beaches in the spring; deeper waters and offshore in the winter), the fishery operates at different times along the coast. New Jersey has prohibited commercial harvest of horseshoe crabs in state waters since 2006. State waters of Delaware are closed to horseshoe crab harvest and landing from January 1st through June 7th each year, and other state horseshoe crab fisheries are regulated with various season/area closures.

The total reported bait landings in 2022 totaled 570,988 crabs. This is well below the ASMFC coastwide quota of 1,587,274 crabs (Table 1, Figure 2) and represents a 23% decrease from 2021 landings of 741,684 crabs. Landings increased in New York but decreased in most states.

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Reported coastwide landings since 1998 show more male than female horseshoe crabs were harvested annually. Several states presently have sex-specific restrictions in place which limit or ban the harvest of females. The American eel pot fishery prefers egg-laden female horseshoe crabs as bait, while the whelk (conch) pot fishery is less dependent on females. States with greater than 5% of coastal landings are required to report sex for at least a portion of their bait harvest; for 2022 these states include Massachusetts, New York, Delaware, Maryland, and Virginia. Within these states, 61% of reported bait landings were male, 17% were female, and 22% were unclassified in 2022.

The hand, trawl, and dredge fisheries accounted for the majority of reported commercial horseshoe crab bait landings in 2022. Other gears that account for the remainder of the harvest include rakes, hoes, and tongs, fixed nets, and gill nets.

Table 1. Reported commercial horseshoe crab bait landings by jurisdiction. "C" indicates confidential landings.

	MA	RI	CT	NY	NJ*	DE*	MD*	PRFC	VA**	NC	SC	GA	FL	TOTAL
ASMFC Quota 2022	330,377	26,053	48,689	366,272	162,136	162,136	255,980	0	172,828	24,036	0	29,312	9,455	1,587,274
State Quota 2022	165,000	8,398	48,689	150,000	0	151,345	255,980	-	172,828	24,036	0	29,312	9,455	1,020,820
Landings by Year														
2015	117,611	7,867	19,632	145,324	0	151,262	27,494	0	102,235	24,839	0	0	264	596,528
2016	110,399	20,676	21,945	176,632	0	109,836	157,013	0	128,848	25,197	0	0	689	751,235
2019	172,664	C	17,588	167,181	0	164,225	145,907	0	151,727	13,463	0	0	0	832,755
2020	163,695	C	15,942	63,367	0	124,803	61,165	0	24,031	3,672	0	0	0	456,675
2021	156,013	1,706	17,492	97,860	0	172,927	181,044	0	112,497	2,145	0	0	C	741,684
2022	135,731	C	1,343	111,481	0	147,558	84,627	0	89,748	500	0	0	C	570,988

*Male-only harvest

**Virginia harvest east of the COLREGS line is limited to 81,331 male-only crabs under the ARM harvest package #3. Virginia harvest east of the COLREGS in 2022 was 8,334 crabs.

Biomedical Use

The horseshoe crab is an important resource for research and manufacture of materials used for human health. There are five companies along the Atlantic Coast that process horseshoe crab blood for use in manufacturing Limulus Amebocyte Lysate (LAL): Associates of Cape Cod, Massachusetts; Lonza (formerly Cambrex Bioscience), Limuli Laboratories, New Jersey; Wako Chemicals, Virginia; and Charles River Endosafe, South Carolina. Addendum III requires states where horseshoe crabs are collected for biomedical purposes to collect and report total collection numbers, crabs rejected, crabs bled (by sex) and to characterize mortality.

The Plan Review Team (PRT) annually calculates total coastwide collections and estimates mortality associated with biomedical use. In 2022, 911,826 crabs were collected coastwide

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solely for biomedical purposes[1] (Table 2). This represents a 27% increase from 2021. Of the total biomedical collections in 2022, males accounted for 43.3%, females comprised 34.3%, and 22.4% were of unknown sex. Some crabs were rejected prior to bleeding due to mortality, injuries, slow movement, and size (mortality observed while crabs were going through the biomedical process is included under 'Observed Mortality' in Table 2). Approximately 2.4% of crabs collected solely for biomedical purposes were observed and reported as dead from the time of collection up to the point of bleeding.

During the 2019 benchmark stock assessment, a meta-analysis of literature estimates was performed to estimate post-bleeding mortality of horseshoe crabs. Although many of these studies did not implement biomedical best practices, these values are the only available estimates of mortality experienced after bleeding. Based on the literature review, post-bleeding mortality is estimated at 15%. Tagging data was used in the assessment to compare survivorship between crabs that were and were not bled. These results indicated some decrease in short-term survivorship, but greater long-term survivorship for bled crabs. These results are likely attributable to the culling process used by biomedical facilities to select healthy crabs for bleeding.

Post-bleeding mortality, calculated as 15% of the number of bled biomedical-only crabs (not from the bait market), for 2022 was estimated to be 124,227 crabs. Total mortality (observed mortality plus post-bleeding mortality) of biomedical crabs for 2022 was estimated at 145,920 crabs. The total estimated mortality from biomedical collections represents approximately 20% of the 2022 total directed use mortality (716,908 crabs), which includes both total biomedical mortality and removals for bait.

In 2023, a work group appointed by the Board reviewed and updated the *Best Management Practices for Handling Horseshoe Crabs for Biomedical Purposes*[2]. The work group included technical committee and advisory panel members with expertise in horseshoe crab biology, ecology, and biomedical processing. The purpose of the BMPs is to recommend broadly applicable industry standards that are expected to minimize mortality and injury of horseshoe crabs associated with the biomedical process.

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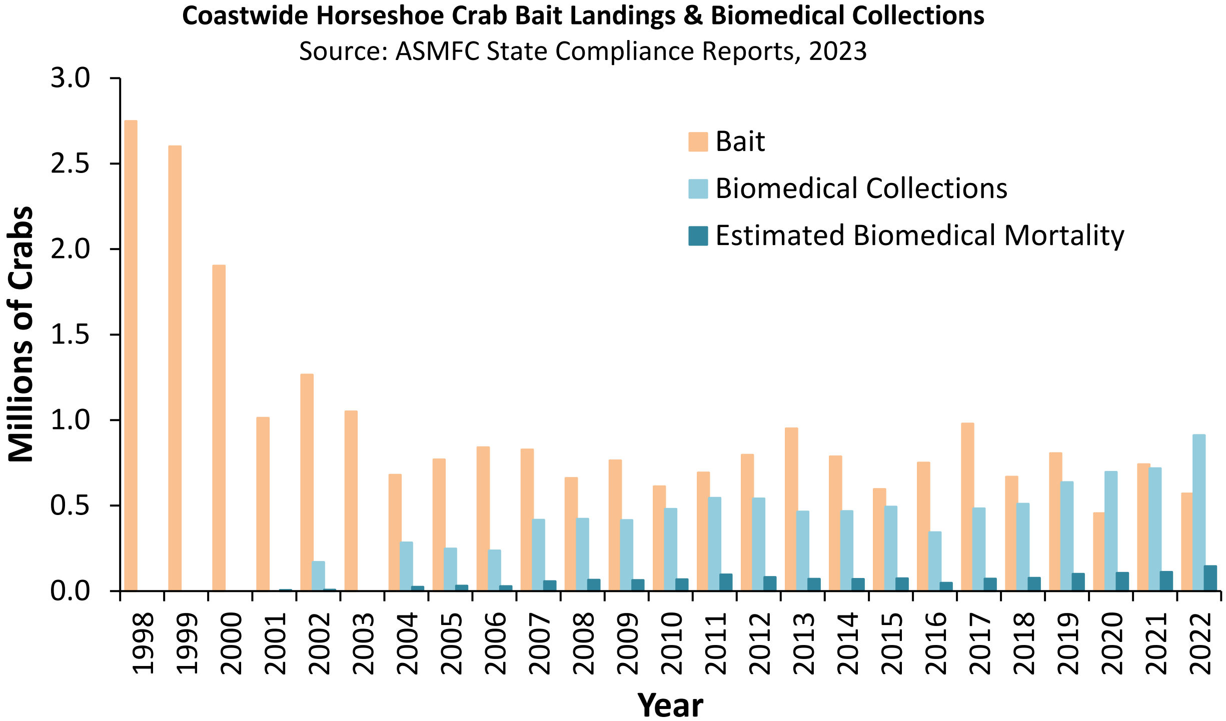
[1] This does not include bait crabs borrowed for bleeding and then returned to the bait market; these are counted against state bait quotas. The dual use of horseshoe crabs harvested for bait is encouraged as a conservation tool. Facilities that bleed horseshoe crabs to manufacture LAL can utilize crabs from the bait market in what is often referred to as the "rent a crab" program. Permitted bait harvesters and/or dealers can "rent" crabs caught for the bait industry to the bleeding facility; these crabs are returned to the bait vendor after bleeding. These crabs are caught under bait permits, are counted against the bait quota of the state of origin, and must comply with that state's regulations for bait harvest. The dual use of crabs in this program can reduce overall harvest, may decrease overall mortality, can provide the LAL manufacturers with an additional source of raw material, and may offer harvesters and dealers opportunity within this secondary market.

[2] Best Management Practices for Handling Horseshoe Crabs for Biomedical Purposes can be found here: https://asmfc.org/uploads/file/645bf065HSC_Biomedical_BMPs_2023.pdf

Figure 2. Number of horseshoe crabs harvested for bait and collected for biomedical purposes, 1998-2022.



*Biomedical collections are annually reported to the Commission and include all horseshoe crabs brought to bleeding facilities except those that were harvested as bait, "rented" by biomedical facilities and counted against state bait quotas.

*Crabs collected solely for biomedical crabs are returned to the water after bleeding; a 15% mortality rate is assumed for all bled crabs that are released. This number plus observed mortality reported annually by bleeding facilities via state compliance reports equals the 'Estimated Biomedical Mortality.'

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Figure 3. Total Horseshoe Crab Mortality from Bait and Estimated Biomedical Mortality, 1998-2022.

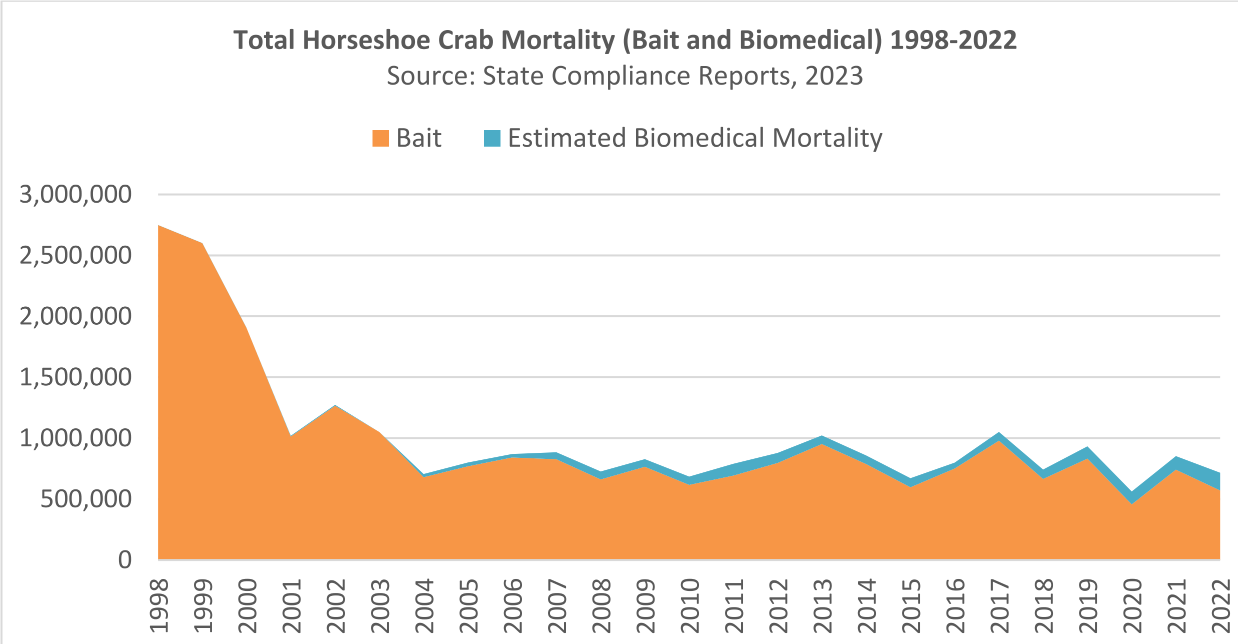

Table 2. Numbers of horseshoe crabs collected, bled, and estimated mortality for the biomedical industry. Numbers shown are for crabs collected solely for biomedical use. Mortality of bled crabs that later enter the bait industry is included in bait harvest.

Year	Crabs Collected	Crabs Bled	Post-Bleeding Mortality	Observed Mortality	Total Mortality
2010	480,914	412,781	61,917	6,829	68,746
2011	545,164	486,850	73,028	24,139	97,166
2012	541,956	497,956	74,693	7,370	82,063
2013	464,657	440,402	66,060	5,447	71,507
2014	467,897	432,340	64,851	5,658	70,509
2015	494,123	464,506	69,676	5,362	75,038
2016*	344,495	318,523	47,778	1,004	48,782
2017	483,245	444,115	66,617	6,056	72,674
2018	510,407	479,142	71,871	5,588	77,459
2019	637,029	589,361	88,404	12,789	101,193
2020	697,025	649,546	97,432	8,907	106,339
2021	718,809	667,951	100,193	11,911	112,104
2022	911,826	828,181	124,227	21,693	145,920

***Some biomedical collections were reduced in 2016 due to temporary changes in production.**

IV. Status of Research and Monitoring

The Horseshoe Crab FMP set forth an ambitious research and monitoring strategy in 1999 and again in 2004 to inform future management decisions. Despite limited time and funding there are many accomplishments since 1999. These accomplishments were largely made possible by forming partnerships between state, federal and private organizations, and the support of hundreds of public volunteers.

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Addendum III Monitoring Program

Addendum III requires affected states to carry out three monitoring components:

1. All states who do not qualify for *de minimis* status report monthly harvest numbers and subsample a portion of the catch for sex and harvest method. In addition, those states with annual landings above 5% of the coastwide harvest report all landings by sex and harvest method. Although states with annual landings less than 5% of annual coastwide harvest are not required to report landings by sex, the PRT recommends all states require sex-specific reporting for horseshoe crab harvest.
2. States with biomedical collections are required to monitor and report collection numbers and mortality associated with the transportation and bleeding of the crabs.
3. States must identify spawning and nursery habitat along their coasts. All states have completed this requirement, and a few continue active monitoring programs.

Virginia Tech Research Projects

The Virginia Tech Horseshoe Crab Trawl Survey (VT Survey) was not conducted in 2013-2015, due to a lack of funding, but was conducted in 2016-2022, and is in progress for 2023. Funding sources beyond 2023 continue to be explored. The 2022 surveys were conducted between August 2 and October 12. The lower Delaware Bay area of the survey was not sampled in 2022 as increased operational costs resulted in limitations to time on the water.

For the Delaware Bay Area (DBA), the 2022 survey resulted in an increase in the stratified catch-per-tow values for newly mature females and immature individuals, and decreases in the stratified catch-per-tow values for newly mature males and mature individuals. No estimates were significantly different from the previous year with the exception of newly mature females, as none were caught in 2021. Mean stratified catch-per-tow for all demographic groups in the DBA continues to be highly variable, although mature individuals have shown a positive trend over the time series. Prosomal widths of mature and newly mature males and females show decreasing trends over the time series in the DBA.

The indices from this survey, along with the New Jersey Ocean Trawl and Delaware Fish and Wildlife Adult Trawl Survey indices, were used to estimate horseshoe crab abundance in the 2021 ARM Framework Revision to produce optimal harvest limits for the upcoming year.

Spawning Surveys

The redesigned Delaware Bay spawning survey was completed for the twenty-fourth consecutive year in 2022. Twelve beaches in Delaware and ten beaches in New Jersey were sampled. Delaware is currently in the process of analyzing survey data.

Tagging Studies

The USFWS continues to maintain a toll-free telephone number and a website for reporting horseshoe crab tag returns and assists interested parties in obtaining tags. Tagging work continues to be conducted by biomedical companies, research organizations, and other parties involved in outreach and spawning surveys. Beginning with the 2013 tagging season, additional efforts were implemented to ensure that current tagging programs are providing data that benefits the management of the coastwide horseshoe crab population. All existing and new tagging efforts are required to submit an annual application to be considered for the USFWS tagging program and all participants must submit an annual report along with their tagging and resighting data to indicate how their tagging program addresses at least one of the following objectives: determine horseshoe crab sub-population structure, estimate horseshoe crab movement and migration rates, and/or estimate survival and mortality of horseshoe crabs. The PRT recommends all tagging programs approved by the states coordinate with the USFWS tagging program, in order to ensure a consistent coastwide program to support management.

Since 1999, over 409,859 crabs have been tagged and released through the USFWS tagging program along the Atlantic coast, and 49,993 unique crabs have been recaptured. Crabs have been tagged and released from every state on the Atlantic Coast from Florida to New Hampshire. In the early years of the program, tagging was centered around Delaware Bay; however, tagging has expanded and increased in Long Island Sound and the Southeast. Tagging information from this database has been used in the 2019 Benchmark Stock Assessment to define stock structure, estimate total mortality, and characterize impacts of biomedical use on crab mortality.

New York Region Monitoring
Following the 2019 Benchmark Stock Assessment, which characterized the status of the horseshoe crab population in the New York region as "Poor", the Board directed the PRT to monitor fishery-independent surveys in this area to track progress of state management actions toward improving this regional population. During the assessment, five surveys were included in the ARIMA model to characterize this population. One of these, the Northeast Area Monitoring and Assessment Program (NEAMAP), includes sample areas outside of the New York region, making it too data-intensive to specify the regional index on an annual basis. The most recent information from the state-conducted surveys used in the assessment is summarized below, but can be viewed in greater detail in the Connecticut and New York state compliance reports. The Western Long Island (WLI) Little Neck Bay and Manhasset Bay seine surveys were combined in the assessment to form a single index, but are shown below separately. None of these beach seine surveys were completed in 2020 due to the COVID-19 pandemic but resumed in 2021. Figures 5-8 show the annual index for each survey over the time series until 2021.

Connecticut

- Long Island Sound Trawl (LISTS) (Fall) – 2022 index – The 2022 survey was limited in April due to staff limitations and in June because of mechanical issues with the research vessel. The LISTS indices for 2022 were above average in both the spring and fall (0.78 and 1.85 kg/tow, respectively). The fall index was one of the highest in the time series.

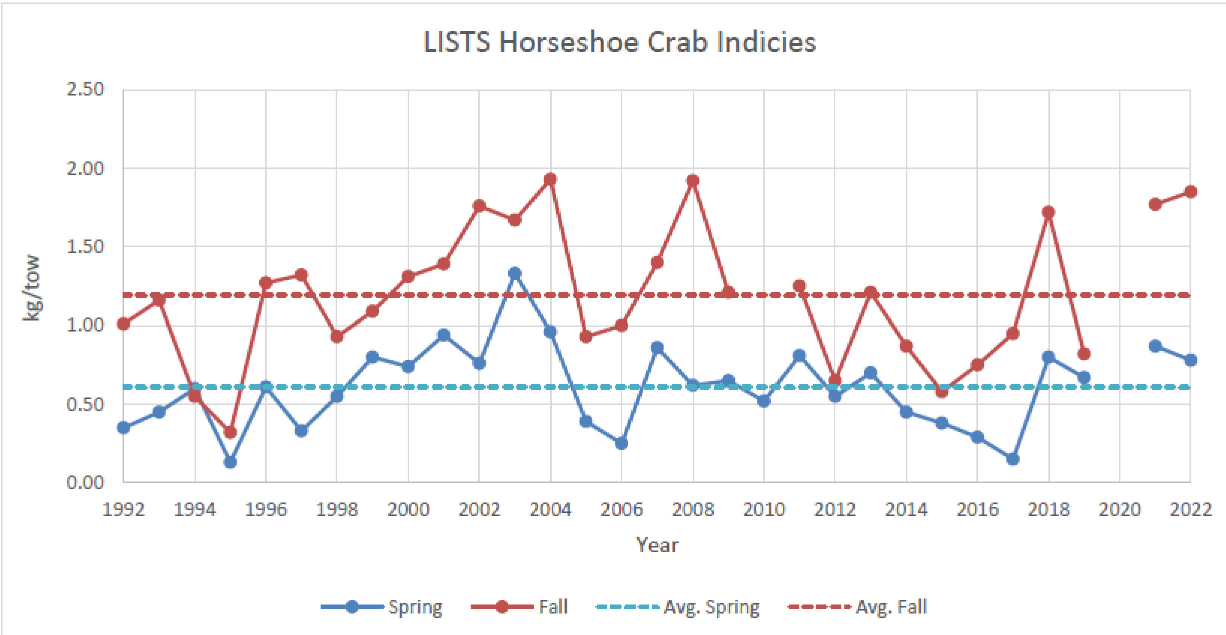

Figure 4. LISTS Horseshoe Crab Indices, 1992-2022.

New York

- Peconic Trawl – 2022 index = 0.14 (delta distribution average catch per unit effort [CPUE]), increase from 2021, below 2010-22 average.
- WLI Jamaica Bay Seine (all horseshoe crabs) – 2022 index = 0.06 (geometric mean), decrease from 2021, lowest value in time series.
- WLI Little Neck Bay Seine (all) – 2022 index = 1.23 (geometric mean), increase from 2021, below 2010-22 average.
- WLI Manhasset Bay Seine (all) – 2022 index = 0.89 (geometric mean), increase from 2019, below 2010-22 average.

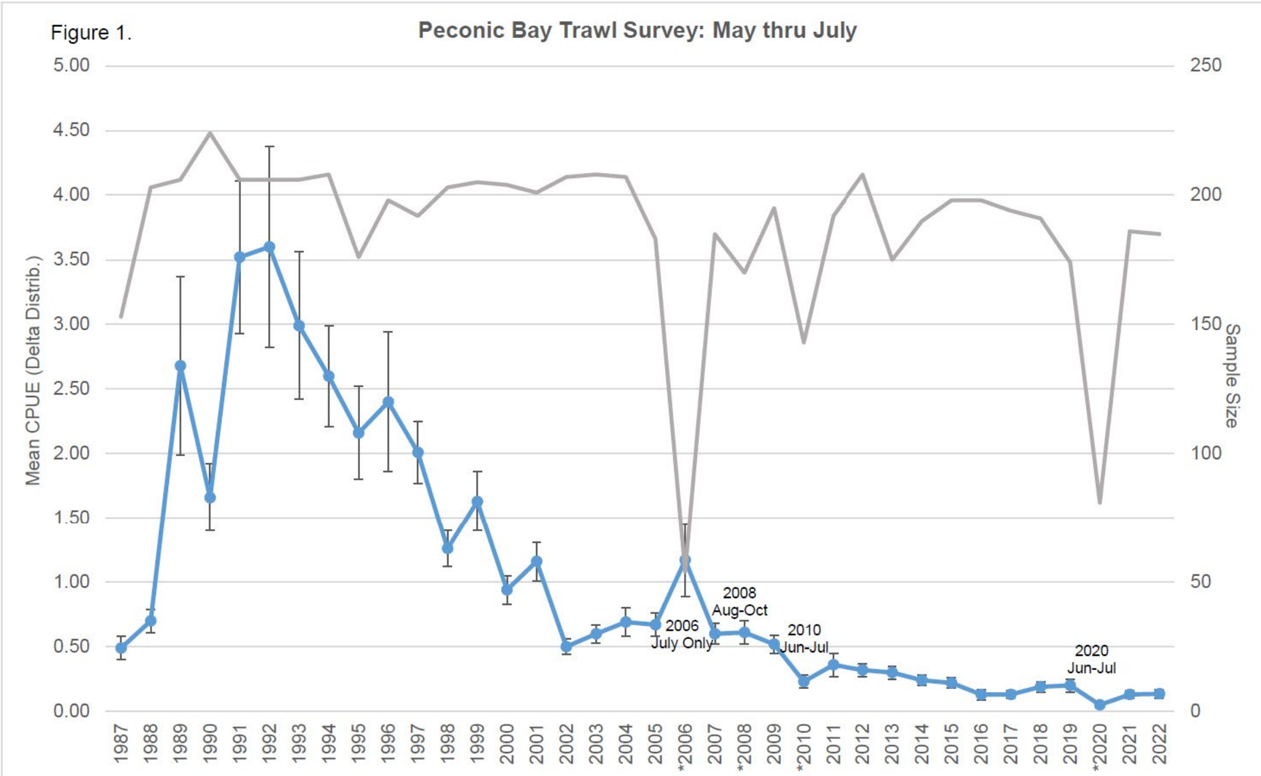

Figure 5. Peconic Bay Trawl Survey: May through July, 1987-2022. (Gray line=sample size, blue line=mean CPUE).

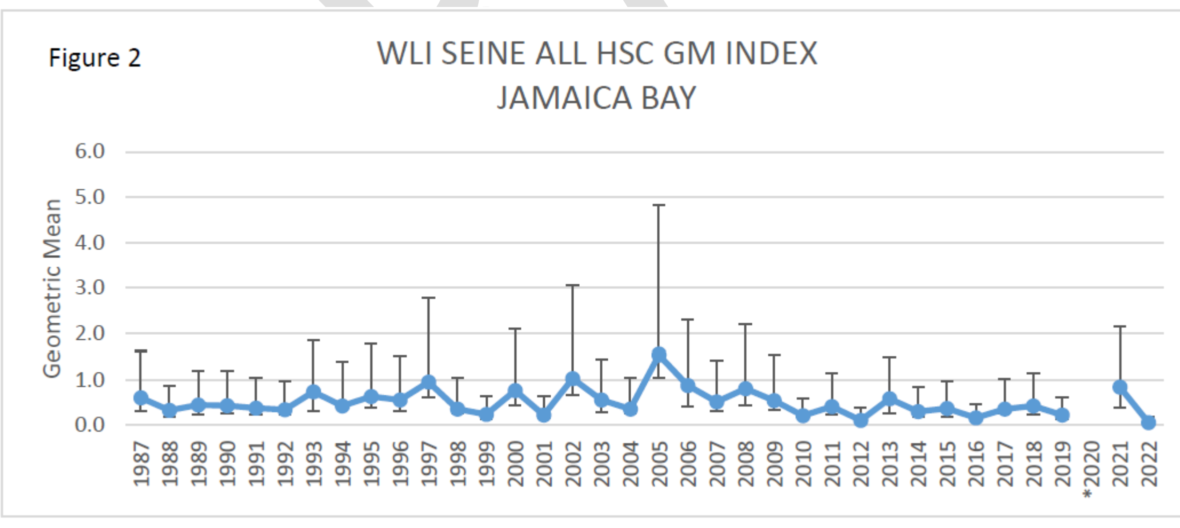

**Figure 6. NYSDEC WLI Jamaica Bay Beach Seine Survey All Horseshoe Crab GM Index, 1987-2022. ***Due to the COVID-19 pandemic, in 2020 sampling did not begin until July.

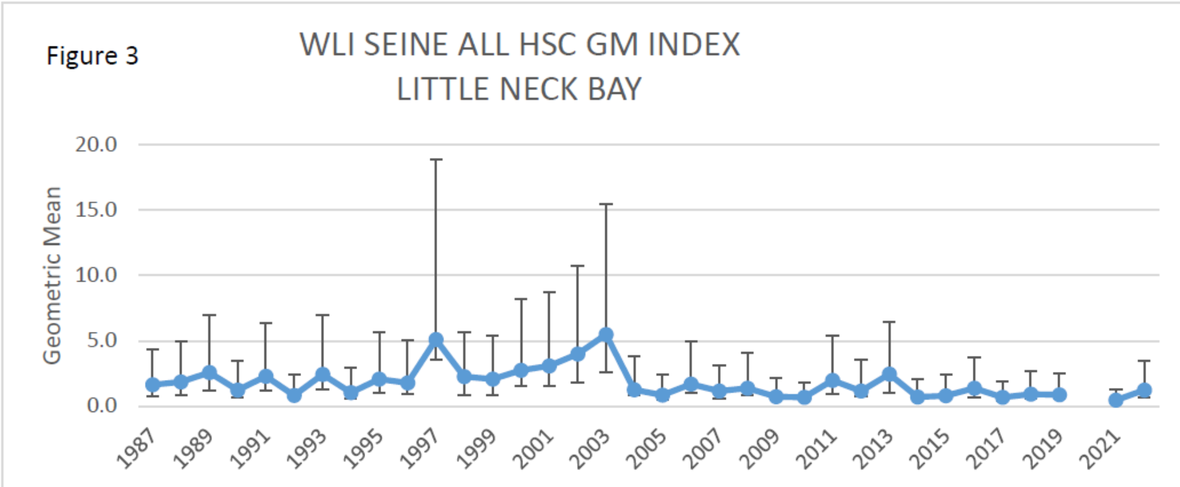

Figure 7. Little Neck Bay Seine Survey All Horseshoe Crab GM Index, 1987-2022. *Due to the COVID-19 pandemic, in 2020 sampling did not begin until July.

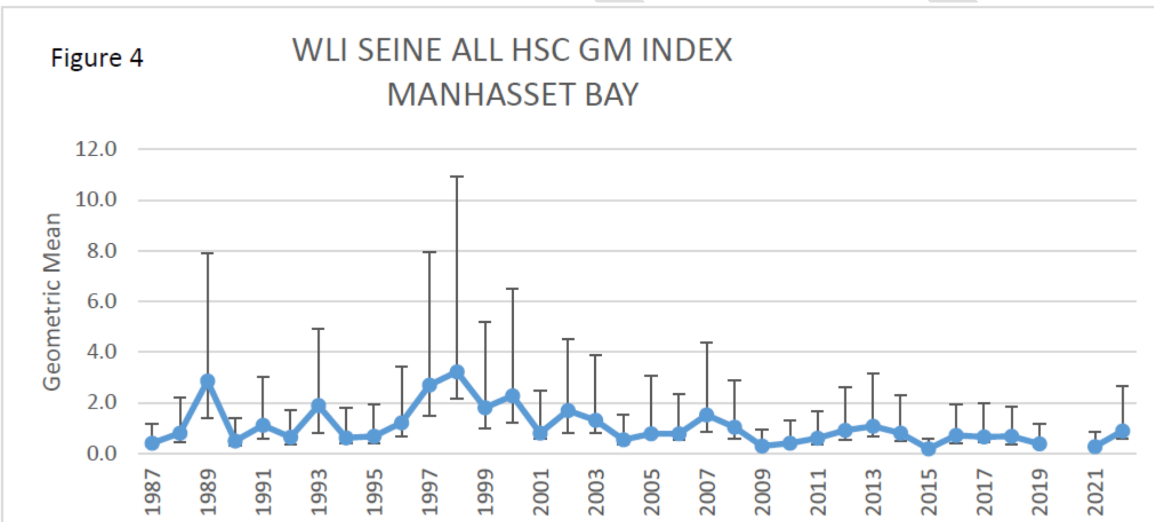

Figure 8. Manhasset Bay Seine Survey All Horseshoe Crab GM Index, 1987-2022. *Due to the COVID-19 pandemic, in 2020 sampling did not begin until July.

V. Status of Management Measures and Issues

ASMFC

Initial state harvest quotas were established through Addendum I. Addendum III outlined the monitoring requirements and recommendations for the states. Addendum IV set harvest closures and quotas, and other restrictions for New Jersey, Delaware, Maryland, and Virginia, which were continued in Addenda V and VI.

In February 2012 the Board approved Addendum VII to implement the ARM Framework; it was implemented in 2013. Addendum VII includes an allocation mechanism to divide the Delaware Bay optimized harvest output from the ARM Framework among the four Delaware Bay states

(New Jersey, Delaware, Maryland, and Virginia east of the COLREGS line). Season closures and restrictions present within Addendum VI remain in effect as part of Addendum VII.

State-specific charts outlining compliance and monitoring measures are included in Section VII. Issues noted by the PRT include:

- Massachusetts and Connecticut did not report to ASMFC by the required deadline.

The PRT finds that all other jurisdictions appear to be in compliance with the FMP and subsequent Addenda in 2022.

Changes to State Regulations

No changes were made to state regulations for fishing year 2022.

Alternative Baits

Trials testing effectiveness of alternative baits to horseshoe crab for the American eel and whelk fisheries have previously been conducted. Additionally, a survey of bait usage in the eel and whelk fisheries was conducted in 2017. This survey is available at: http://www.asmfc.org/uploads/file/5a04b785HSC_BaitSurveyTCReport_Oct2017.pdf.

Shorebirds

The USFWS received petitions in 2004 and 2005 to emergency list the red knot under the Endangered Species Act. In fall 2005, it determined that emergency listing was not warranted at the time. As part of a court settlement, the USFWS agreed to initiate proposed listings of over 200 species, including the red knot. In fall 2013, the USFWS released a proposal for listing the red knot as threatened. In January 2015 the USFWS designated the red knot as threatened under the Endangered Species Act.

In 2022 the USFWS conducted an analysis of the changes to horseshoe crab management that would occur under the 2021 ARM Revision to determine the likelihood of impacts to the red knot. The finding from analysis is that there is a < 1% chance of a red knot population decline due to the implementation of potential female harvest under the revised ARM. Therefore, the Service concluded that take, defined under the Endangered Species Act as killing or injuring, of red knots is not likely.

The red knot has been listed as an endangered species in the state of New Jersey since 2012.

VI. PRT Recommendations and Research Needs

De Minimis

States may apply for *de minimis* status if, for the last two years, their combined average horseshoe crab bait landings (by numbers) constitute less than one percent of coastwide horseshoe crab bait landings for the same two-year period. States may petition the Board at

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any time for *de minimis* status, if their fishery falls below the threshold level. Once *de minimis* status is granted, designated States must submit annual reports to the Board justifying the continuance of *de minimis* status.

States that qualify for *de minimis* status are not required to implement any horseshoe crab harvest restriction measures, but are required to implement components A, B, E and F of the monitoring program (Section 3.5 of the FMP; further modified by Addendum III). Since *de minimis* states are exempt from a harvest cap, there is potential for horseshoe crab landings to shift to *de minimis* states and become substantial, before adequate action can be taken. To control shifts in horseshoe crab landings, *de minimis* states are encouraged to implement one of the following management measures:

1. Close their respective horseshoe crab bait fishery when landings exceed the *de minimis* threshold;
2. Establish a state horseshoe crab landing permit, making it only available to individuals with a history of landing horseshoe crabs in that state; or
3. Establish a maximum daily harvest limit of up to 25 horseshoe crabs per person per day. States which implement this measure can be relieved of mandatory monthly reporting, but must report all horseshoe crabs harvests on an annual basis.

The following states have been removed from the Management Board since its formation: Pennsylvania (2007), Maine (2011), and New Hampshire (2014). South Carolina, Georgia, and Florida are requesting *de minimis* status for the 2023 fishing season based on the 2021-22 season landings and meet the FMP requirements for being granted this status (Table 1). The PRT recommends granting these jurisdictions *de minimis* status.

Biomedical Threshold
The 1998 FMP established a biomedical mortality threshold of 57,500 crabs that, if exceeded, requires the Board to consider management action. This threshold has been exceeded in all but one year since 2008. Results of the 2019 Benchmark Stock Assessment indicate that levels of biomedical mortality prior to 2017 (the terminal year of data used in the assessment) did not have a significant effect on horseshoe crab population estimates or fishing mortality in the Delaware Bay region.

In 2020 the Board tasked the PDT to review the threshold for biomedical use to develop biologically-based options for the threshold and to develop options for action when the threshold is exceeded. It also tasked the PDT to review the best management practices (BMPs) for handling biomedical catch and suggest options for updating and implementing BMPs. The PDT concluded that given the lack of coastwide population estimates for horseshoe crabs, it is not possible to develop a biologically-based threshold for biomedical mortality. Thus, the PDT did not recommend a change to the threshold. Based on this information the Board determined no action is warranted, but agreed to form a work group to review and update the best

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management practices for biomedical handling to further reduce stress, injury, and mortality to horseshoe crabs collected for biomedical purposes if possible.

Funding for Research and Monitoring Activities

The PRT strongly recommends the funding and continuation of the VT benthic trawl survey. 2022 sampling had to be reduced due to increased costs. This effort provides a statistically reliable estimate of horseshoe crab relative abundance that is essential to continued ARM implementation and use of the CMSA stock assessment model.

Discard Mortality Estimation

Results of the 2019 Benchmark Stock Assessment indicate that discard mortality may be significant, of similar or greater magnitude than bait harvest. The Review Panel's report indicated that these estimates could be further refined to reduce their uncertainty and more precisely characterize this mortality source. The PRT recommends the Board take steps to increase access to and use of data from the NEFOP, allowing for improved monitoring and estimation of discard mortality.

Improvement of the New York Regional Population

Results of the 2019 Benchmark Stock Assessment indicate a "Poor" status for the New York regional population, due to negative trends in regional abundance indices. New York and Connecticut have indicated that they will take actions within their states to improve this population. The PRT and Board have recommended such actions so that this population's status may improve.

In 2022, Connecticut implemented measures to reduce harvest in response to the Board's request. These changes include the commercial fishing season moving from May 22 to the calendar date three days after the last full or new moon (whichever is later) in May, and a new 5-day closure centered on the first moon phase in June. The daily possession limit for commercial hand-harvest was decreased from 500 to 150 crabs. These changes were implemented prior to the 2022 Spring season.

The PRT will continue to annually report regional indices of abundance so that progress of management actions may be tracked through the annual FMP Reviews.

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VII. State Compliance and Monitoring Measures

MASSACHUSETTS		
	2022 Compliance	**2023 Management Proposal**
***De minimis* status**	Did not request *de minimis*	Did not request *de minimis*
Bait Harvest Restrictions and Landings		
- ASMFC Quota (Voluntary State Quota)	330,377 (165,000)	330,377 (165,000)
- Other Restrictions	Bait: 300 crab daily limit year round; limited entry; Biomedical: 1,000 crab daily limit; Conch pot and eel fishermen: no possession limit Mobile gear: 75 crab trip limit, exempted from "no-fishing days" starting 10/9/2020; All: May and June 5-day lunar closures; 7" PW minimum size; Pleasant Bay Closed Area	Bait: 300 crab daily limit year round; Biomedical: 200,000 crab quota; 1,000 crab daily limit; Conch pot and eel fishermen: no possession limit All: May and June 5-day lunar closures; No mobile gear harvest Fri-Sat during summer flounder season; 7" PW minimum size; Pleasant Bay Closed Area
- Landings	135,731	--
Monitoring Component A_1		
- Mandatory monthly reporting	Yes, plus weekly dealer reporting through SAFIS	Yes, plus weekly dealer reporting through SAFIS
- Characterize commercial bait fishery	Yes	Yes
Monitoring Component A_2		
- Biomedical reporting	Yes	Yes
- Required information for biomedical use of crabs	Yes	Yes
Monitoring Component A_3 Identify spawning and nursery habitat	Yes	Not Applicable
Monitoring Component B_1 Coastwide benthic trawl survey	Yes, VT Trawl Survey was conducted in 2022	Yes, VT Trawl Survey will be conducted in 2023; future years and spatial scope unknown at this time
Monitoring Component B_2 Continue existing benthic sampling programs	Yes	Yes
Monitoring Component B_3 Implement spawning survey	Yes	Yes
Monitoring Component B_4 Tagging program	Yes – w/NPS and USFWS; Pleasant Bay, Monomy NWR, Waquoit Bay	Yes – w/NPS and USFWS; Pleasant Bay, Monomy NWR, Waquoit Bay

RHODE ISLAND		
	2022 Compliance	**2023 Management Proposal**
***De minimis* status**	Did not request *de minimis*	Did not request *de minimis*
Bait Harvest Restrictions and Landings		
- ASMFC Quota (Voluntary State Quota)	26,053 (8,398)	26,053 (8,398)
- Other Restrictions	State Restrictions: - Daily possession limit: 60 crabs per permit - Bait Fishery Closure: May 1-May 31 - Biomedical Fishery Closure: 48 hours prior to and 48 hours following new and full moons during May. - Biomedical quota and best management practices	State Restrictions: - Daily possession limit: 60 crabs per permit - Bait Fishery Closure: May 1-May 31 - Biomedical Fishery Closure: 48 hours prior to and 48 hours following new and full moons during May - Biomedical quota and best management practices
- Landings	Confidential	--
Monitoring Component A_1		
- Mandatory monthly reporting	Yes, weekly call in and monthly on paper	Yes, weekly call in and monthly on paper
- Characterize commercial bait fishery	Yes	Yes
Monitoring Component A_2		
- Biomedical reporting	Yes	Yes
- Required information for biomedical use of crabs	Yes, included in Massachusetts' biomedical reports	Captured in Massachusetts' biomedical reports
Monitoring Component A_3 Identify spawning and nursery habitat	Yes	Not Applicable
Monitoring Component B_1 Coastwide benthic trawl survey	Yes, VT Trawl Survey was conducted in 2022	Yes, VT Trawl Survey will be conducted in 2023; future years and spatial scope unknown at this time
Monitoring Component B_2 Continue existing benthic sampling programs	Yes	Yes
Monitoring Component B_3 Implement spawning survey	Yes, since 2000	Yes
Monitoring Component B_4 Tagging program	No	No

CONNECTICUT		
	2022 Compliance	**2023 Management Proposal**
***De minimis* status**	Did not request *de minimis*	Did not request *de minimis*
Bait Harvest Restrictions and Landings		
- ASMFC Quota	48,689	48,689
- Other Restrictions	- Limited entry program - Hand-harvest possession limit of 150 crabs - seasonal and lunar closures	Prohibit hand harvest of horseshoe crabs or eggs in state waters, effective Oct. 1, 2023
- Landings	1,343	--
Monitoring Component A_1		
- Mandatory monthly reporting	Yes	Yes
- Characterize commercial bait fishery	No – exempt under Addendum III because landings are < 5% of coastwide total	No – exempt under Addendum III because landings are < 5% of coastwide total
Monitoring Component A_2		
- Biomedical reporting	Not Applicable	Not Applicable
- Required information for biomedical use of crabs	Not Applicable	Not Applicable
Monitoring Component A_3 Identify spawning and nursery habitat	Not provided	Not Applicable
Monitoring Component B_1 Coastwide benthic trawl survey	Yes, VT Trawl Survey was conducted in 2022	Yes, VT Trawl Survey will be conducted in 2023; future years and spatial scope unknown at this time
Monitoring Component B_2 Continue existing benthic sampling programs	Yes	Yes
Monitoring Component B_3 Implement spawning survey	Yes, since 1999 (methods differ from DE Bay survey)	Yes
Monitoring Component B_4 Tagging program	Yes, in collaboration with local universities (Sacred Heart University since 2015)	Yes

NEW YORK		
	2022 Compliance	**2023 Management Proposal**
***De minimis* status**	Did not request *de minimis*	Did not request *de minimis*
Bait Harvest Restrictions and Landings		
- ASMFC Quota (Voluntary State Quota)	366,272 (150,000)	366,272 (150,000)
- Other Restrictions	Ability to close areas to harvest; seasonal quotas and daily harvest limits Five-day lunar closures around the full moon in May and the new moon in June. Initial trip limit dropped to 150 crabs in period 2.	Ability to close areas to harvest; seasonal quotas and daily harvest limits - Five-day lunar closures around the full moon in May and the new moon in June. -Initial trip limit dropped to 150 crabs in period 2.
- Landings	111,481	--
Monitoring Component A_1		
- Mandatory monthly reporting	Yes	Yes
- Characterize commercial bait fishery	Yes	Yes
Monitoring Component A_2		
- Biomedical reporting	Yes	Yes
- Required information for biomedical use of crabs	Not Applicable	Not Applicable
Monitoring Component A_3 Identify spawning and nursery habitat	Yes	Not Applicable
Monitoring Component B_1 Coastwide benthic trawl survey	Yes, VT Trawl Survey was conducted in 2022	Yes, VT Trawl Survey will be conducted in 2023; future years and spatial scope unknown at this time
Monitoring Component B_2 Continue existing benthic sampling programs	Yes	Yes
Monitoring Component B_3 Implement spawning survey	Yes	Yes
Monitoring Component B_4 Tagging program	Yes	Yes

NEW JERSEY		
	2022 Compliance	**2023 Management Proposal**
***De minimis* status**	Did not request *de miminis*	Does not request *de miminis*
Bait Harvest Restrictions and Landings		
- ASMFC Quota (Voluntary state quota)	162,136 [male only] (0)	162,136 [male only] (0)
- Other Restrictions	Bait harvest moratorium	Bait harvest moratorium
- Landings	0	--
Monitoring Component A_1		
- Mandatory monthly reporting	Not Applicable	Not Applicable
- Characterize commercial bait fishery	Not Applicable	Not Applicable
Monitoring Component A_2		
- Biomedical reporting	Yes	Yes
- Required information for biomedical use of crabs	Yes	Yes
Monitoring Component A_3 Identify spawning and nursery habitat	Yes	Not Applicable
Monitoring Component B_1 Coastwide benthic trawl survey	Yes, VT Trawl Survey was conducted in 2022	Yes, VT Trawl Survey will be conducted in 2023; future years and spatial scope unknown at this time
Monitoring Component B_2 Continue existing benthic sampling programs	Yes	Yes
Monitoring Component B_3 Implement spawning survey	Yes	Yes
Monitoring Component B_4 Tagging program	No	No
Monitoring Component B_5 Egg abundance survey	Yes, no longer mandatory	Yes
Monitoring Component B_6 Shorebird monitoring program	Yes	Yes

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DELAWARE		
	2022 Compliance	**2023 Management Proposal**
***De minimis* status**	Did not request *de minimis*	Did not request *de minimis*
Bait Harvest Restrictions and Landings		
- ASMFC Quota (State Quota)	162,136 [male only] 151,345 [male only]	164,364 [male only] 164,364 [male only]
- Other Restrictions	Closed season (January 1 – June 7)	Closed season (January 1 – June 7)
- Landings	147,558 (male only)	--
Monitoring Component A_1		
- Mandatory monthly reporting	Yes (daily call-in reports & monthly logbooks)	Yes
- Characterize commercial bait fishery	Yes	Yes
Monitoring Component A_2		
- Biomedical reporting	Not Applicable	Not Applicable
- Required information for biomedical use of crabs	Not Applicable	Not Applicable
Monitoring Component A_3 Identify spawning and nursery habitat	Yes –updates once every 5 years or as needed	Yes – updates once every 5 years or as needed
Monitoring Component B_1 Coastwide benthic trawl survey	Yes, VT Trawl Survey was conducted in 2022	Yes, VT Trawl Survey will be conducted in 2023; future years and spatial scope unknown at this time
Monitoring Component B_2 Continue existing benthic sampling programs	Yes	Yes
Monitoring Component B_3 Implement spawning survey	Yes	Yes
Monitoring Component B_4 Tagging program	No state program but has assisted in the past with various Delaware Bay horseshoe crab tagging initiatives	No
Monitoring Component B_5 Egg abundance survey	Removed as component	Removed as component
Monitoring Component B_6 Shorebird monitoring program	Yes	Yes

Note: The egg abundance survey has been discontinued as a mandatory monitoring element. Delaware will include information on the survey if it continues, but is no longer required to perform the survey.

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MARYLAND		
	2022 Compliance	**2023 Management Proposal**
***De minimis* status**	Did not request *de minimis*	Did not request *de minimis*
Bait Harvest Restrictions and Landings		
- ASMFC Quota	255,980 (male only)	255,980 (male only)
- Other Restrictions	Delayed harvest and closed season/area combinations, catch limits	Delayed harvest and closed season/area combinations, catch limits
- Landings	84,627 (male only)	--
Monitoring Component A_1		
- Mandatory monthly reporting	Yes (weekly reports for permit holders; monthly for non-permit holders)	Yes (weekly reports for permit holders; monthly for non-permit holders)
- Characterize commercial bait fishery	Yes	Yes
Monitoring Component A_2		
- Biomedical reporting	Yes	Yes
- Required information for biomedical use of crabs	Yes	Yes
Monitoring Component A_3 Identify spawning and nursery habitat	Yes	Not Applicable
Monitoring Component B_1 Coastwide benthic trawl survey	Yes, VT Trawl Survey was conducted in 2022	Yes, VT Trawl Survey will be conducted in 2023; future years and spatial scope unknown at this time
Monitoring Component B_2 Continue existing benthic sampling programs	Yes	Yes
Monitoring Component B_3 Implement spawning survey	Yes	Yes
Monitoring Component B_4 Tagging program	Yes – through biomedical use	Yes – through biomedical use

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POTOMAC RIVER FISHERIES COMMISSION		
	2022 Compliance	**2023 Management Proposal**
***De minimis* status**	Did not request *de minimis*	Did not request *de minimis*
- Ability to close fishery if *de minimis* threshold is reached	No horseshoe crab fishery	No horseshoe crab fishery
- Daily possession limit <25 for *de minimis* state		
- HSC landing permit		
Bait Harvest Restrictions and Landings		
- ASMFC Quota	0	0
- Other Restrictions	None	None
- Landings	0	0
Monitoring Component A_1		
- Mandatory monthly reporting	Yes - weekly	Yes - weekly
- Characterize commercial bait fishery	Not Applicable	Not Applicable
Monitoring Component A_2		
- Biomedical reporting	Not Applicable	Not Applicable
- Required information for biomedical use of crabs	Not Applicable	Not Applicable
Monitoring Component A_3 Identify spawning and nursery habitat	Not Applicable	Not Applicable
Monitoring Component B_1 Coastwide benthic trawl survey	Yes, VT Trawl Survey was conducted in 2022	Yes, VT Trawl Survey will be conducted in 2023; future years and spatial scope unknown at this time
Monitoring Component B_2 Continue existing benthic sampling programs	Not Applicable	Not Applicable
Monitoring Component B_3 Implement spawning survey	Not Applicable	Not Applicable
Monitoring Component B_4 Tagging program	Not Applicable	Not Applicable

VIRGINIA		
	2022 Compliance	**2023 Management Proposal**
***De minimis* status**	Did not request *de minimis*	Did not request *de minimis*
Bait Harvest Restrictions and Landings		
- ASMFC Quota	172,828 (81,331 male-only east of COLREGS line)	172,828 (81,331 male-only east of COLREGS line)
- Other Restrictions	Closed season (January 1 – June 7) for federal waters. Effective January 1, 2013 harvest of horseshoe crabs, from east of the COLREGS line, is limited to trawl gear and dredge gear only.	Closed season (January 1 – June 7) for federal waters. Effective January 1, 2013 harvest of horseshoe crabs, from east of the COLREGS line, is limited to trawl gear and dredge gear only.
- Landings	89,748 (60,693 males)	--
Monitoring Component A_1		
- Mandatory monthly reporting	Yes	Yes
- Characterize commercial bait fishery	Yes	Yes
Monitoring Component A_2		
- Biomedical reporting	Yes	Yes
- Required information for biomedical use of crabs	Yes	Yes
Monitoring Component A_3 Identify spawning and nursery habitat	Yes	Not Applicable
Monitoring Component B_1 Coastwide benthic trawl survey	Yes, VT Trawl Survey was conducted in 2022	Yes, VT Trawl Survey will be conducted in 2023; future years and spatial scope unknown at this time
Monitoring Component B_2 Continue existing benthic sampling programs	Not Applicable	Not Applicable
Monitoring Component B_3 Implement spawning survey	No	No
Monitoring Component B_4 Tagging program	No	No

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NORTH CAROLINA		
	2022 Compliance	**2023 Management Proposal**
***De minimis* status**	Did not request *de minimis*	Did not request *de minimis*
Bait Harvest Restrictions and Landings		
- ASMFC Quota	24,036	24,036
- Other Restrictions	Trip limit of 50 crabs; Proclamation authority to adjust trip limits, seasons, etc.	Trip limit of 50 crabs; Proclamation authority to adjust trip limits, seasons, etc.
- Landings	500	--
Monitoring Component A_1		
- Mandatory monthly reporting	Yes	Yes
- Characterize commercial bait fishery	Yes	Yes
Monitoring Component A_2		
- Biomedical reporting	Not Applicable	Not Applicable
- Required information for biomedical use of crabs	Not Applicable	Not Applicable
Monitoring Component A_3 Identify spawning and nursery habitat	Little information available; Survey discontinued after 2002 and 2003 due to low levels of crabs recorded	Not Applicable
Monitoring Component B_1 Coastwide benthic trawl survey	Yes, VT Trawl Survey was conducted in 2022	Yes, VT Trawl Survey will be conducted in 2023; future years and spatial scope unknown at this time
Monitoring Component B_2 Continue existing benthic sampling programs	Yes	Yes
Monitoring Component B_3 Implement spawning survey	No	No
Monitoring Component B_4 Tagging program	No	No

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SOUTH CAROLINA		
	2022 Compliance	**2023 Management Proposal**
***De minimis* status**	*De minimis* status granted for 2022.	*De minimis* requested for 2023 and meets criteria.
- Ability to close fishery if *de minimis* threshold is reached	No horseshoe crab bait fishery	No horseshoe crab bait fishery
- Daily possession limit <25 for *de minimis* state		
- HSC landing permit		
Bait Harvest Restrictions and Landings		
- ASMFC Quota	0	0
- Other Restrictions	None	None
- Landings	0	--
Monitoring Component A_1		
- Mandatory monthly reporting	Yes (Biomedical)	Yes (Biomedical)
- Characterize commercial bait fishery	Not Applicable	Not Applicable
Monitoring Component A_2		
- Biomedical reporting	Yes	Yes
- Required information for biomedical use of crabs	Yes	Yes
Monitoring Component A_3 Identify spawning and nursery habitat	Completed	No
Monitoring Component B_1 Coastwide benthic trawl survey	Yes, VT Trawl Survey was conducted in 2022	Yes, VT Trawl Survey will be conducted in 2023; future years and spatial scope unknown at this time
Monitoring Component B_2 Continue existing benthic sampling programs	Yes	Yes
Monitoring Component B_3 Implement spawning survey	Yes	Yes
Monitoring Component B_4 Tagging program	Yes	Yes

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GEORGIA		
	2022 Compliance	**2023 Management Proposal**
***De minimis* status**	*De minimis* status granted in 2022.	*De minimis* requested for 2023 and meets criteria.
- Ability to close fishery if *de minimis* threshold is reached	Yes	Yes
- Daily possession limit <25 for *de minimis* state	25/person; 75/vessel with 3 licensees	25/person; 75/vessel with 3 licensees
- HSC landing permit	Must have commercial shrimp, crab, or whelk license; LOA permit required	Must have commercial shrimp, crab, or whelk license; LOA permit required
Bait Harvest Restrictions and Landings		
- ASMFC Quota	29,312	29,312
(State Quota)	29,312	29,312
- Other Restrictions	None	None
- Landings	0	--
Monitoring Component A_1		
- Mandatory monthly reporting	Yes	Yes
- Characterize commercial bait fishery	Not Applicable	Yes
Monitoring Component A_2		
- Biomedical reporting	Not Applicable	Not Applicable
- Required information for biomedical use of crabs	Not Applicable	Not Applicable
Monitoring Component A_3 Identify spawning and nursery habitat	Completed	Not Applicable
Monitoring Component B_1 Coastwide benthic trawl survey	Yes, VT Trawl Survey was conducted in 2022	Yes, VT Trawl Survey will be conducted in 2023; future years and spatial scope unknown at this time
Monitoring Component B_2 Continue existing benthic sampling programs	Yes	Yes
Monitoring Component B_3 Implement spawning survey	No	No
Monitoring Component B_4 Tagging program	No	No

FLORIDA		
	2022 Compliance	**2023 Management Proposal**
***De minimis* status**	*De minimis* status granted in 2022.	*De minimis* requested for 2023 and meets criteria.
- Ability to close fishery if *de minimis* threshold is reached	Yes	Yes
- Daily possession limit <25 for *de minimis* state	25/person w/ valid saltwater products license; 100/person with marine life endorsement	25/person w/ valid saltwater products license; 100/person with marine life endorsement
- HSC landing permit	See above	See above
Bait Harvest Restrictions and Landings		
- ASMFC Quota	9,455	9,455
- Other Restrictions	Daily possession limit	Daily possession limit
- Landings	Confidential	--
Monitoring Component A_1		
- Mandatory monthly reporting	Yes	Yes
- Characterize commercial bait fishery	Yes	Yes
Monitoring Component A_2		
- Biomedical reporting	Not Applicable	Not Applicable
- Required information for biomedical use of crabs	Not Applicable	Not Applicable
Monitoring Component A_3 Identify spawning and nursery habitat	Yes	Yes
Monitoring Component B_1 Coastwide benthic trawl survey	Yes, VT Trawl Survey was conducted in 2022	Yes, VT Trawl Survey will be conducted in 2023; future years and spatial scope unknown at this time
Monitoring Component B_2 Continue existing benthic sampling programs	Yes	Yes
Monitoring Component B_3 Implement spawning survey	Yes	Yes
Monitoring Component B_4 Tagging program	No	No

Chapter <86>: Frequently Asked Questions

1 **What is the animal-free alternative to Limulus amebocyte lysate (LAL)?**

Alternatives to naturally sourced LAL are commercially available or currently in development. These recombinant reagents utilize one (rFC) or more (rCR) recombinant zymogen proteases cloned from the natural clotting cascade of horseshoe crabs to detect and quantify endotoxins activity.

2 **What is the purpose of Chapter <86>?**

Chapter <86> provides additional tests to the Bacterial Endotoxins Test <85> using recombinant Factor C or recombinant cascade reagents to detect or quantify endotoxins.

3 **What kind of data was gathered and reviewed to inform Chapter <86>?**

The USP Microbiology Expert Committee, which includes eight FDA representatives, gathered and reviewed scientific data obtained from literature review and submissions from stakeholders, as well as from USP-generated experimental data gathered during reference standard qualification.

4 **Does this proposal replace LAL for endotoxin testing?**

No, manufacturers that currently use LAL for endotoxin testing can continue to do so and Chapter <86> has no impact on them. The Bacterial Endotoxins Tests (BET) described in the new chapter are additional techniques to the current *Bacterial Endotoxins Test* described in Chapter <85>. The new chapter is intended to allow manufacturers to use non-animal derived reagents, in line with USP's commitment to reduce the use of animal-derived materials.

5 **From a compendial perspective, how does Chapter <86> allow for the use of rFC and other cascade reagents?**

This chapter provides methods for the use of rFC or rCR and steps for how to verify their use for a specific product. Under the provisions of the chapter, manufacturers of new biopharmaceuticals can choose to use rFC or rCR without the need to demonstrate comparability to the current method using LAL. Manufacturers of existing products that want to switch to animal-free reagents need to show this comparability. This is a normal approach and information on how to do this is readily and freely available. Please note that regulatory authorities may require supplemental data prior to acceptance, and users are encouraged to consult each regulatory authority. An example of supplemental data may include a comparative study of the material tested by techniques described in this chapter and those in <85>.

6 **Will FDA require additional validation to use rFC or rCR?**

The new Chapter <86> outlines steps to use endotoxin testing with rFC or rCR. It is a normal requirement for any method that it needs to be validated and shown that it is fit for use. Regulatory authorities may require supplemental data and users are encouraged to discuss with each regulatory authority.

Chapter <86>: FAQ, continued...

7

How does this proposal differ from other global pharmacopeias?

This proposal is similar to the European Pharmacopeia's and the Japanese Pharmacopeia's approach. USP is additionally proposing to add rCR and the associated method, which is not in the current EP chapter, as we considered it a suitable addition based their recent commercial availability by multiple manufacturers.

USP	***European Pharmacopeia***	***Japanese Pharmacopeia***
Unless specified in an individual monograph or General Notices, the tests in this chapter are considered alternative tests and users must meet the requirements in *General Notices* 6.30.	The replacement of an LAL-based method prescribed in a monograph by an rFC-based method is considered as the use of an alternative method as described in the Ph. Eur. General Notices.	<G4-4-180> describes procedures and consideration in measurement when using recombinant protein-reagents for endotoxin assay as alternative methods, in addition to lysate reagents and test methods in Bacterial Endotoxins Test.
A test for bacterial endotoxins using rFC or rCR can be used in the same way as LAL-based methods, after demonstration of its fitness for use for the specific substance or product. Regulatory authorities may require supplemental data and users are encouraged to discuss with each regulatory authority.	A test for bacterial endotoxins using rFC can be used in the same way as LAL-based methods, after demonstration of its fitness for use for the specific substance or product.	If these reagents for endotoxin assay are used as an alternative method, confirm that accuracy, precision, sensitivity, specificity, etc. are equal or better compared to Bacterial Endotoxins Test <4.01> using lysate reagents.
To use recombinant reagents, supplier's primary validation data can be used.	The rFC can be used in the same way as LAL-based methods, after demonstration of fitness for use for the specific substance or product.	The recombinant protein-reagents for endotoxin assay are not identical to "an amoebocyte lysate prepared from blood corpuscle extracts of horseshoe crab" specified in Bacterial Endotoxins Test <4.01>.
Includes methods for rFC and rCR.	Includes methods for rFC.	Includes methods for rFC and rCR.
Reference	Reference	Reference

Chapter <86>: FAQ, continued...

8 **Will Chapter <86> be harmonized?**

This is a topic for discussion between several pharmacopeias. The proposed Chapter contains many similarities with the European and Japanese pharmacopeia. If Chapter <86> becomes an official standard, it will be further discussed among pharmacopeias with the intent to obtain harmonization as much as possible.

9 **Will there be an opportunity for stakeholders to comment on the proposed chapter?**

The Chapter comment period will be open from Nov. 1, 2023, through Jan. 31, 2024. We welcome questions or comments through our pre-publication on USP's website in advance of the official comment process.

10 **When will Chapter <86> be included in the *USP–NF*?**

At the end of the comment period, all comments on the proposed monograph are collected and sent to the relevant Expert Bodies for review. The Expert Committee may revise the document based on feedback and send it to the Expert Committee for review. Our USP scientific liaisons review all the public comments, organize the information received and provide science-based recommendations to the Expert Committee. Depending on the comments received, the draft Chapter may be republished for another round of comments, or the chapter may be balloted by the Expert Committee for incorporation into the *United States Pharmacopeia–National Formulary* (*USP–NF*).

11 **Does USP's reference standard apply to bacterial endotoxin testing using rFC and rCR?**

There is no impact on USP's Reference Standard for Endotoxins. Tests described in the new Chapter <86> utilize the standard in the same manner as <85>.

Atlantic States Marine Fisheries Commission

1050 N. Highland Street • Suite 200A-N • Arlington, VA 22201
703.842.0740 • www.asmfc.org

MEMORANDUM

September 28, 2023

To: Horseshoe Crab Management Board

From: Tina Berger, Director of Communications

RE: Advisory Panel Nomination

Please find attached a nomination to the Horseshoe Crab Advisory Panel – Sam Martin, a commercial mobile tending gear fisherman for Maryland. While Sam's nomination says that he has been found in violation of a criminal or civil federal fishery law or regulation. He incorrectly said yes to the answer and this has also been confirmed by the appointing state. Please review this nomination for action at the next Board meeting.

If you have any questions, please feel free to contact me at (703) 842-0749 or tberger@asmfc.org.

Enc.

cc: Caitlin Starks

M23-79

HORSESHOE CRAB ADVISORY PANEL

Bolded names await approval by the Horseshoe Crab Management Board

September 28, 2023

Massachusetts

David Meservey (comm/inshore otter trawl)
P.O. Box 128
South Chatham, MA 02659
Phone: 508.237.4366
dmese@yahoo.com
Appt Confirmed 8/2/22

Jay A. Harrington (comm/handpicker/raker)
#6 Sherman Road
P.O. Box 321
South Orleans, MA 02662
Phone: 508.255.0582
indeepH2O@gmail.com
Appt. Confirmed 4/7/98
Appt. Reconfirmed 10/02; 10/06; 5/10; 8/18

Chair, Brett Hoffmeister (biomedical)
Associates of Cape Cod
331 Barlows Landing Row
Pocasset, MA 02559
Phone (day): 508.444.1426
BHoffmeister@acciusa.com
Appt Confirmed 2/3/16
Appt. Reconfirmed 8/18

Rhode Island

Vacancy (comm/otter trawl)

New York

John L. Turner (conservation)
10 Clark Boulevard
Massapequa, NY 11762
Phone (day): 631.451.6455
Phone (eve): 516.797.9786
jturner@seatuck.org
Appt. Confirmed 2/10/05
Appt Reconfirmed 5/10

Vacancy – commercial pot

New Jersey

Benjie Swan (biomedical)
Limuli Laboratories
Dias Creek, 5 Bay Avenue
Cape May Courthouse, NJ 08210-2556
Phone: 609.465.6552
Swan24@verizon.net
Appt. Confirmed 8/5/10

Delaware

Lawrence Voss (comm./pot)
3215 Big Oak Road
Smyrna, DE 19977
Phone: (302)359-0951
shrlyvss@aol.com
Appt. Confirmed 10/24/18

2 vacancies - dealer/processor & conservation/environmental

Maryland

George Topping (comm/trawl)
32182 Bowhill Road
Salisbury, MD 21804
Phone: 443.497.2141
george@zztopping.com
Appt. Confirmed 5/16

Jeffrey Eutsler (comm/trawl)
11933 Gray's Corner Road
Berlin, MD 21811
Phone: 443.497.3078
jeffeutsler@me.com
Appt. Confirmed 2/4/98
Appt. Reconfirmed 10/02; 10/06; 5/10

Allen L. Burgenson (biomedical)
8875 Hawbottom Road
Middletown, MD 21769
Phone: 301.378.1263
allen.burgenson@lonza.com
Appt. Confirmed 8/21/08
past chair

Sam Martin (comm mobile tending/biomedical harvest)
985 Ocean Drive
Cape May, NJ 08204
Phone: 609.381.8892
smartin@atlanticcapes.com

HORSESHOE CRAB ADVISORY PANEL

Bolded names await approval by the Horseshoe Crab Management Board

September 28, 2023

Virginia

Richard B. Robins, Jr. (processor/dealer)
3969 Shady Oaks Drive
Virginia Beach, VA 23455
Phone (day): 757.244.8400
Phone (eve): 757.363.9506
richardbrobins@gmail.com
Appt. Confirmed: 2/9/00
Appt. Reconfirmed 1/2/06; 5/10

Christina M. Lecker
FUJIFILM Wako Chemicals U.S.A. Corporation,
LAL Division
Plant Manager - Cape Charles Facility
301 Patrick Henry Avenue
Cape Charles, VA 23310
Phone: 757-331-4240, 757-331-2026
FAX: 757-331-2046
christina.lecker@fujifilm.com
Appt. Confirmed 10/21/2020

1 vacancy - comm/pot/conch

South Carolina

Nora Blair (biomedical)
Charles River Laboratories Microbial Solutions
1852 Cheshire Drive
Charleston, SC 29412
843.276.7819
Nora.Blair@crl.com
Appt. Confirmed 5/1/19

Vacancy - comm/pot/trawl

Nontraditional Stakeholders

Jeff Shenot
7900 McClure Road
Upper Marlboro, MD 20772
Phone: 301.580.4524
JUGBAY@msn.com
Appt. Confirmed 8/2018

Walker Golder
Executive Director, Coastal Land Trust
3 Pine Valley Dr.
Wilmington, NC 28412
Office: 910.790.4524 x2060
Cell: 910.619.6244
walker@coastallandtrust.org
Appt. Confirmed 8/2018

ATLANTIC STATES MARINE FISHERIES COMMISSION

Advisory Panel Nomination Form

This form is designed to help nominate Advisors to the Commission's Species Advisory Panels. The information on the returned form will be provided to the Commission's relevant species management board or section. Please answer the questions in the categories (All Nominees, Commercial Fisherman, Charter/Headboat Captain, Recreational Fisherman, Dealer/Processor, or Other Interested Parties) that pertain to the nominee's experience. If the nominee fits into more than one category, answer the questions for all categories that fit the situation. **Also, please fill in the sections which pertain to All Nominees (pages 1 and 2). In addition, nominee signatures are required to verify the provided information (page 4), and Commissioner signatures are requested to verify Commissioner consensus (page 4). Please print and use a black pen.**

Form submitted by: Michael Luisi State: MD
(your name)

Name of Nominee: Sam Martin

Address: 985 Ocean Drive

City, State, Zip: Cape May, NJ 08204

Please provide the appropriate numbers where the nominee can be reached:

Phone (day): 609-381-8892 Phone (evening): same

FAX: 609-884-3261 Email: smartin@atlanticcapes.com

FOR ALL NOMINEES:

1. Please list, in order of preference, the Advisory Panel for which you are nominating the above person.
   1. Horseshore Crab
   2. ______
   3. ______
   4. ______

2. Has the nominee been found in violation of criminal or civil federal fishery law or regulation or convicted of any felony or crime over the last three years?

   yes YES no ______

3. Is the nominee a member of any fishermen's organizations or clubs?

   yes YES no ______

   If "yes," please list them below by name.

Garden State Seafood Association | Science Center for Marine Fisheries

Fishery Survival Fund

Responsible Offshore Development Association

4. What kinds (species) of fish and/or shellfish has the nominee fished for during the past year?

Horseshoe Crab | Squid
Black Sea Bass | Summer Flounder
Scallops | Surf Clams

5. What kinds (species) of fish and/or shellfish has the nominee fished for in the past?

same

FOR COMMERCIAL FISHERMEN:

1. How many years has the nominee been the commercial fishing business? 25 years
2. Is the nominee employed only in commercial fishing? yes YES no ____
3. What is the predominant gear type used by the nominee? Mobile Tending
4. What is the predominant geographic area fished by the nominee (i.e., inshore, offshore)? Inshore and Offshore - Mid-Atlantic and New England

FOR CHARTER/HEADBOAT CAPTAINS:

1. How long has the nominee been employed in the charter/headboat business? 25 years
2. Is the nominee employed only in the charter/headboat industry? yes YES no ____

   If "no," please list other type(s)of business(es) and/occupation(s): ____

3. How many years has the nominee lived in the home port community? 25 years

   If less than five years, please indicate the nominee's previous home port community.

FOR RECREATIONAL FISHERMEN:

1. How long has the nominee engaged in recreational fishing? 25________ years

2. Is the nominee working, or has the nominee ever worked in any area related to the fishing industry? yes YES_____ no ________

   If "yes," please explain.

____

____

____

FOR SEAFOOD PROCESSORS & DEALERS:

1. How long has the nominee been employed in the business of seafood processing/dealing? 25________________years

2. Is the nominee employed only in the business of seafood processing/dealing?

   yes YES_____ no ______ If "no," please list other type(s) of business(es) and/or occupation(s):

____

____

____

3. How many years has the nominee lived in the home port community? 25______ years

   If less than five years, please indicate the nominee's previous home port community.

____

FOR OTHER INTERESTED PARTIES:

1. How long has the nominee been interested in fishing and/or fisheries management? 25______ years

2. Is the nominee employed in the fishing business or the field of fisheries management? yes YES___ no _____

   If "no," please list other type(s) of business(es) and/or occupation(s):

____

____

____

FOR ALL NOMINEES:

In the space provided below, please provide the Commission with any additional information which you feel would assist us in making choosing new Advisors. You may use as many pages as needed.

I ALSO AM ON THE ADVISORY PANELS OF THE MAMFC FOR SURFCLAM/OCEAN QUAHOG, SPINY DOGFISH AND SQUID, MAC, BUTTERFISH I SIT ON THE MONKFISH AP FOR NEFMC.

I THINK IT IS IMPORTANT TO HAVE ADVISORS THAT ARE FULLY ENGAGED IN A BROAD RANGE OF REGULATORY BODIES. WITH A FOCUS ON ECOSYSTEM MANAGEMENT THE GIVES ENHANCED PERSPECTIVE IN SUSTAINING FISHERIES AND FISHING COMMUNITIES.

I WOULD LIKE TO SIT ON THE AP FOR HORSESHOE CRAB AS WE ARE FULLY ENGAGED IN THE FISHERY COMMERCIALLY AS WELL AS IN BIO-MEDICAL.

Nominee Signature: [signature] Date: 5/4/2023

Name: Sam Martin
(please print)

COMMISSIONERS SIGN-OFF (not required for non-traditional stakeholders)

[signature: Michael Luisi for Lynn Fegley]
State Director

State Legislator

Governor's Appointee

*Confirmed support from Dave and Russell via email/txt.