Atlantic States Marine Fisheries Commission

Horseshoe Crab Management Board

October 29, 2019
9:45 – 11:45 a.m.
New Castle, New Hampshire

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 *(M. Rhodes)* — 9:45 a.m.
2. Board Consent — 9:45 a.m.
   - Approval of Agenda
   - Approval of Proceedings from August 2019
3. Public Comment — 9:50 a.m.
4. Review Delaware Bay Ecosystem Technical Committee and Adaptive Resource Management Subcommittee Report (*J. Sweka*) — 10:00 a.m.
   - Recommended Updates to the ARM Model
5. Consider Re-initiation of Postponed Draft Addendum VIII (*M. Rhodes*) **Possible Action** — 10:40 a.m.
6. Set 2020 Harvest Specifications **Final Action** — 11:10 a.m.
   - Review Horseshoe Crab and Red Knot Abundance Estimates and 2019 ARM Model Results (*J. Sweka*)
   - Set 2020 Harvest Specifications (*M. Rhodes*)
7. Consider 2019 Fishery Management Plan Review and State Compliance (*M. Schmidtke*) **Action** — 11:30 a.m.
8. Other Business/Adjourn — 11:45 a.m.

The meeting will be held at Wentworth by the Sea, 588 Wentworth Road, New Castle, NH; 603.422.7322

MEETING OVERVIEW

Horseshoe Crab Management Board Meeting
Tuesday, October 29, 2019
9:45 – 11:45 a.m.
New Castle, New Hampshire

Chair: Dr. Malcolm Rhodes (SC) Assumed Chairmanship: 10/17	Horseshoe Crab Technical Committee Chair: Jeff Brunson (SC)	
Vice Chair: Joe Cimino (NJ)	Horseshoe Crab Advisory Panel Chair: Allen Burgenson (MD)	Law Enforcement Committee Representative: Doug Messeck (DE)
Delaware Bay Ecosystem Technical Committee Chair: Wendy Walsh (FWS)	Adaptive Resource Management Subcommittee Chair: Dr. John Sweka (FWS)	Previous Board Meeting: August 6, 2019
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 August 6, 2019 Board Meeting

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. Review Delaware Bay Ecosystem Technical Committee and Adaptive Resource Management Subcommittee Report (10:00 - 10:40 a.m.) Possible Action
Background • In September 2019, the Delaware Bay Ecosystem Technical Committee (DBE TC) and Adaptive Resource Management (ARM) Subcommittee met to discuss incorporation of horseshoe crab population estimates from the Catch Multiple Survey Analysis (CMSA) model, used in the 2019 Benchmark Stock Assessment, into the ARM Framework. • During this meeting, the DBE TC and ARM Subcommittee developed consensus recommendations for incorporating the CMSA estimates and updating other aspects of the ARM Framework. These recommendations were submitted for Board review in a memo from the committee chairs (**Briefing Materials**).
Presentations

Horseshoe Crab

Activity level: Medium

Committee Overlap Score: Low (SAS overlaps with BERP)

Committee Task List
• TC – Communicate with Kepley Biosystems' to determine whether trials should be conducted for OrganoBait • ARM & DBETC – Incorporate Catch Multiple Survey Analysis horseshoe crab population estimates into the ARM model • TC – March 1st: Annual compliance reports due • ARM & DBETC – Fall: Annual ARM model to set Delaware Bay specifications, review red knot and VT trawl survey results

TC Members: Jeff Brunson (SC, TC Chair), Derek Perry (MA), Natalie Ameral (RI, Vice Chair), Deb Pacileo (CT), Catherine Ziegler (NY), Samantha Macquesten (NJ), Jordan Zimmerman (DE), Steve Doctor (MD), Ellen Cosby (PRFC), Adam Kenyon (VA), Jeffrey Dobbs (NC), Eddie Leonard (GA), Claire Crowley (FL), Linda Stehlik (NMFS), Chris Wright (NMFS), Joanna Burger (Rutgers), Gregory Breese (USFWS), Mike Millard (USFWS), Kristen Anstead (ASMFC), Michael Schmidtke (ASMFC)

Delaware Bay Ecosystem TC Members: Wendy Walsh (USFWS, DBE TC Chair), Amanda Dey (NJ), Henrietta Bellman (DE, DBE TC Vice Chair), Jordan Zimmerman (DE), Steve Doctor (MD), Adam Kenyon (VA), Jim Fraser (VA Tech), Eric Hallerman (VA Tech), Mike Millard (USFWS), Greg Breese (USFWS), Kristen Anstead (ASMFC), Michael Schmidtke (ASMFC)

ARM Subcommittee Members: John Sweka (USFWS, ARM SC Chair), Larry Niles (NJ), 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 SC Vice Chair), Jim Nichols (USGS), Kristen Anstead (ASMFC), Michael Schmidtke (ASMFC)

DRAFT PROCEEDINGS OF THE

ATLANTIC STATES MARINE FISHERIES COMMISSION

HORSESHOE CRAB MANAGEMENT BOARD

The Westin Crystal City
Arlington, Virginia
August 6, 2019

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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2. **Approval of Proceedings of May 2019** by Consent (Page 1).

3. **Move to adjourn** by Consent (Page 7).

ATTENDANCE

Board Members

Dan McKiernan, MA, proxy for D. Pierce (AA)
Raymond Kane, MA (GA)
Sarah Ferrara, MA, proxy for Rep. Peake (LA)
Bob Ballou, RI, proxy for J. McNamee (AA)
Eric Reid, RI, proxy for Sen. Sosnowski (LA)
David Borden, RI (GA)
Sen. Craig Miner, CT (LA)
Justin Davis, CT (AA)
Bill Hyatt, CT (GA)
John McMurray, NY, proxy for Sen. Kaminsky (LA)
Jim Gilmore, NY (AA)
Emerson Hasbrouck, NY (GA)
Joe Cimino, NJ (AA)
Russ Allen, NJ, proxy for T. Fote (GA)
Stewart Michels, DE, proxy for D. Saveikis (AA)
Roy Miller, DE (GA)
Craig Pugh, DE, proxy for Rep. Carson (LA)
Lynn Fegley, MD, proxy for B. Anderson (AA)
Robert Brown, MD, proxy for R. Dize (GA)
Phil Langley, MD, proxy for Del. Stein (LA)
Pat Geer, VA, proxy for S. Bowman (AA)
Bryan Plumlee, VA (GA)
Chris Batsavage, NC, proxy for S. Murphey (AA)
Malcolm Rhodes, SC (GA)
Mel Bell, SC, proxy for Sen. Cromer (LA)
Doug Haymans, GA (AA)
Spud Woodward, GA (GA)
Erika Burgess, FL, proxy for J. McCawley (AA)
Rep. Thad Altman (FL) LA
Chris Wright, NMFS
Martin Gary, PRFC

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

Ex-Officio Members

Staff

Robert Beal
Toni Kerns
Dustin Colson Leaning
Mike Schmidtke
Kristen Anstead

Guests

Nora Blair, Charles River Labs
Syma Ebbin, UCONN

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; Tuesday, August 6, 2019, and was called to order at 3:00 o'clock p.m. by Chairman Malcolm Rhodes.

CALL TO ORDER

CHAIRMAN MALCOLM RHODES: All right let's everyone take our seats. My name is Malcolm Rhodes; I'm the Chairman of the Horseshoe Crab Management Board. To my immediate right is Dr. Mike Schmidtke; who is the ASMFC staffer in charge of this area. I want to welcome everyone here.

APPROVAL OF AGENDA

CHAIRMAN RHODES: Everyone should have gotten previous notes on the agenda. Are there any changes to the agenda? Seeing none, we'll take that as accepted.

APPROVAL OF PROCEEDINGS

CHAIRMAN RHODES: And we received the minutes from the last meeting. Emerson.

MR. EMERSON HASBROUCK: I would like to correct the proceedings from the May meeting to show that Emerson Hasbrouck was present as a Board member. I'm not listed here under the attendance, but in the body of the minutes there are my comments that are in there, so I was here.

PUBLIC COMMENT

CHAIRMAN RHODES: Excellent, so noted. With that change, any others, seeing none we'll accept those. Are there any public comments on matters that are not coming before the Board? There was no one signed up for it, so we'll move on to the fourth order of business.

CONSIDER MANAGEMENT RESPONSE TO 2019 HORSESHOE CRAB BENCHMARK STOCK ASSESSMENT

CHAIRMAN RHODES: At the last meeting Joe Cimino ran it beautifully, we got through the 2019 Horseshoe Crab Benchmark Stock Assessment.

It sounded like there was a lot of great discussion about what went on with that. Because of the lengths of those discussions and some salient points, the management response, certain parts of the management response had been touched on. But the Board as a whole did not come up with any plans at that point. That is where we are right now. At this point I'm going to turn the meeting over to Mike, and we will move forward from there.

DR. MIKE SCHMIDTKE: I don't have a lengthy presentation, it really is just one slide, and it's a reminder of some of the points that were brought up at the last meeting, after going through the benchmark stock assessment. These were some of the potential responses based off of the information from the assessment itself, as well as some actions that were delayed prior to the assessment taking place.

First of all, incorporation of the catch survey analysis population estimates into the ARM model. That direction was given by the Board and that process is underway. The ARM Subcommittee and the Delaware Bay Technical Committee will be meeting in person in September, to discuss exactly how this will take place, as well as how to present this information to the public, taking into account all of the aspects of that estimate related to confidentiality of biomedical information. The next point had to do with management changes in the New York region, if the Board would want any to be made. The New York region, as a reminder was given a poor status by the stock assessment.

This status reflected declining indices in that region, nearly all of the indices that were looked at from the New York region were declining. As a reminder to the Board there is this poor status, but it's not the same thing as overfishing necessarily, because an overfishing threshold has not been established for this population.

In addition, the quotas that have been established for the states have not been exceeded for New York and Connecticut during that time. It's not necessarily the same thing as overfishing, but it is a poor status that indicates a declining population in that area. The next part is draft Addendum VIII, which was postponed.

The plan initially is to take this up at the October, 2019 meeting when there is a bit more time for discussion if that's necessary, and finally if the Board wants to consider any form of a review to the ARM model, the most recent ARM review was conducted in 2016, and that was a short term review.

Addendum VII defines a long term review that could be conducted of the ARM model that has not been done since the ARM Management Framework has been put into place. If the Board wanted to consider that that is a direction you all could go, but with the knowledge that there would need to be a significant investment of time and/or Commission funds, in order to make something like that happen. That is all I have, Mr. Chair and I'll turn it back over to you.

CHAIRMAN RHODES: Okay thank you for that synopsis, and kind of an idea of where we're going. In the intervening time I know the New York region has had several visits. We've had some phone conferences, and at this point if you all are ready, would New York or Connecticut have any state responses they would like to put before the Board?

MR. JAMES J. GILMORE: We've been talking with Connecticut, but let me give a little background on this. It's what we understand is going on. New York's harvest quota is 360,000 crabs a year. We reduced that several years ago, first down to about 175,000, we've gone down to 150,000. We've done about a 60 percent reduction in our harvest quota.

In addition to that we've incorporated significant monitoring. We have trip limits, we have essentially adjustments to those trip limits quite frequently during the year, and in fact I just closed the fishery last week, so there will be no fall fishery this year. We're getting to the point right now that the problem of trying to continue to reduce harvest in New York is really probably not at the root of what the problem is.

One thing and I've stated this before at this Board, well let me say it more generically, because I do teach fisheries management. Moratoriums on healthy species are the worst thing you can do, because this is the problem it creates. When the moratorium was put into New Jersey, and I'm not faulting Jersey, because it was done by their Legislature, so the other reason why we never want Legislature to manage fisheries is because they create problems like this. When the crabs were essentially open in both states, they were going for about $0.25 a pound. When the fishery was closed in Jersey they shot up to about $3.00 a pound. Anybody that knows this fishery, you get a pickup truck and a refrigerator and you're in the fishery.

We had quite a significant amount of poaching. We increased our law enforcement activities, in fact we were doing coordination with some of the County helicopters to catch these guys, but it's just such a big fishery, and it's such a good way to make profits. That all being said we're looking at ways to do additional management.

The first thing that we can add on at this point is that we were essentially going to go what Jersey is already doing, and require bait bags, and see if that can essentially reduce the amount of harvest that we're going to need. We are looking at some possible closures, but we don't really know how to do that yet, particularly around the big spawning period.

We're working on that right now, and our preference obviously is to do this as just a state action without having to do an addendum, so everyone has to do a lot of work. But again, I'm not optimistic that anything we do at this point is going to help, until we get a better sense of how to manage this fishery with a moratorium in it.

I've talked to Jersey, and again they understand this is a Legislative action, and they've done things to try to help out. I'm not sure if there are other things they do, and I'll let them talk to that. But the data when we dissect it a little bit it's very, very clear. The closer you get to the western part of Long Island in towards New Jersey, the numbers get worse.

It's clearly that action that was done by their Legislature is having an effect on the population. My final statement, and I'll give it over to Justin to add into it is that the action that the Jersey Legislature did, did exactly the opposite of what we needed to do. It's having a negative effect on the population. Maybe in Delaware Bay it's helping them, in terms of keeping the population up, but on the entire regional area right now it's having a detriment. I'll turn it over to Justin.

CHAIRMAN RHODES: Justin.

DR. JUSTIN DAVIS: I think my remarks will largely mirror a lot of what Jim just said. We don't share a boarder with New Jersey, so we don't necessarily have the same concerns relative to that in the moratorium in New Jersey. But we do, I guess sort of feel that our fishery and imposing further restrictions on our fishery is probably not going to produce a significant effect on the horseshoe crab population.

We have a very small scale fishery. It's really about a dozen fishermen participating in the fishery. Our harvest has been constant at about half of our quota for a number of years now. That being said, we also would prefer to approach this from a state level action. We have begun taking a look at measures that might potentially reduce harvest, such as reducing possession limits, or reducing the amount of time that we're open.

We are open for a pretty restricted period as is. We're open for about six weeks and we're closed on the weekends during that period, so we already have a very short season. We've begun taking a look at potential measures that might help reduce harvest. We would approach that through our state regulatory process, which could take anywhere from six months to a year, depending on how lucky we get and how the chips fall out.

That is where we're at right now. In Connecticut we're starting to take a look at measures that might reduce harvest and hopeful for the next year to continue those discussions and move our regulatory process to address it. I will also say that we're working in conjunction with New York on developing regulations for the whelk fishery in Long Island Sound. We would also be looking to mandate bait bags in that fishery, and hopefully reduce the amount of bait required.

CHAIRMAN RHODES: Thank you both very much, I'll open it up to the rest of the Board for any questions or thoughts or concerns. Chris.

MR. CHRIS WRIGHT: Jim, when you closed the fishery this year how much harvest was there at that point?

MR. GILMORE: I don't know the exact number, but it was around 150,000. I think we might have been slightly over. But it's shut down now.

CHAIRMAN RHODES: Dan.

MR. DANIEL McKIERNAN: Yes for the record, Massachusetts adopted the Rhode Island lunar closures about ten years ago, and we think that this has had a real positive impact on recruitment. It was originally just May and June, and we even backed it up into April. For the better part of ten weeks we don't allow any harvest over a five day period of the new and full moons.

CHAIRMAN RHODES: Stewart.

MR. STEWART MICHELS: Jim, that 150,000 horseshoe crab cap, I guess several questions; one is that sex specific at all? Then the other one is that in regulation, or is that just kind of an administrative policy of yours? Are there mandatory paybacks?

MR. GILMORE: Let me take them one at a time. It's not a sex fishery, because in New York it's different than Delaware Bay, it's pretty much a 50/50 split, so a male only fishery would make no sense. Essentially those numbers are not specifically in regulations, but the ability to manage it is. We've had great success keeping it around that 150.

I think one year it got a little bit ahead of us, and we went up to 170,000, but we've generally stayed at that 150,000. Sorry, the last one Stew was? Yes there is no payback provision in it whatever. I will add as Justin had said about the bait bags. We've already put a rulemaking in place to implement those in New York, so that is already in process.

CHAIRMAN RHODES: Joe.

MR. JOE CIMINO: Just to address some of Jim's comments. As you mentioned there was a conference call with Connecticut and New York. New Jersey sat in on that. New Jersey does require bait bags in the whelk fishery. They also require receipts. Anyone that is using horseshoe crab as bait needs to have receipts. I spoke to our law enforcement division and they said in both of those instances on their stops there is really good compliance, especially for the bait bags, since as Jim mentioned, these crabs are quite expensive.

The other thing that they noted was that in general these guys are already using less than a horseshoe crab, or whatever they feel is effective. I don't know what else New Jersey can do. On that conference call the only other suggestion was consideration of alternative baits, but I think this Board is very familiar with that and it doesn't seem like a viable option at this time. I'll leave it at that.

CHAIRMAN RHODES: Dan.

MR. McKIERNAN: Yes what we've discovered in Massachusetts is a lot of the whelk potters were using green crabs. The legislature had put a bounty on green crabs with funding that we distributed to the towns to remove invasive green crabs, and those became one of the bait components. A lot of our whelk fishermen are using kind of a buffet of baits; a piece of horseshoe crab, some green crabs, a dogfish head, a herring. Some guys use mussels. We've sort of evolved. We think our use of horseshoe crabs is down because of that.

CHAIRMAN RHODES: Thank you, great time, very nonselective snails. Do any other people want to address? Seeing that I guess the Board at this point has to decide what sort of response. Our choices will be looking at the measures the two states have implemented, and follow up with them, or do we want to have something more statutory from the Board? I'm going to turn that over to the Board. Bob.

MR. ROBERT BALLOU: I'll take the bait, Mr. Chair. I feel comfortable allowing New York and Connecticut initiate state action. Tracking that action, I think it is incumbent upon the Board to track that action, and to continue tracking the monitoring, trawl survey results to see if there is any cause and effect. I would be comfortable with that approach.

CHAIRMAN RHODES: Any further? Is everyone comfortable with that approach seeing no objection, Toni?

MS. TONI KERNS: There is no objection. I think that if we can make the timing work out we can provide that report to the Board when we do our annual compliance reports. I can work with Jim and Justin and Mike to see if that would line up well to having the annual tracking of those measures.

CHAIRMAN RHODES: Fantastic, thank you. Dan.

MR. McKIERNAN: I have a question. Is it New York and Connecticut's intent to have rules in place by next spring?

MR. GILMORE: Yes, New York is like I said. The bait bag issue is already in our rulemaking process, and then if we're going to do the additional measures like I said we're considering some sort of a seasonal closure. We have an order that we're doing. We're trying to do whelk and this at the same time. The whole idea would be to have this in place for the next year.

DR. DAVIS: I'm cautiously optimistic that Connecticut might be able to have rules in place by spring 2020 as well.

CHAIRMAN RHODES: Fantastic. Other responses from the report were Addendum VIII, which specifically deals with two points. One is accounting for the mortality from biomedical harvest, and then for possible female horseshoe crab harvest in Delaware Bay when certain triggers are hit. Does anyone have any feel for either of those at this point?

DR. MIKE SCHMIDTKE: We don't need to necessarily address Addendum VIII within this meeting here. Like it's on the screen it can be taken up at the 2019 meeting. But just to give some background on the points that Mr. Chair just brought up. For the incorporation of the biomedical mortality there were a couple of different looks at this from the ARM Subcommittee.

Both indicated that whether biomedical mortality is incorporated or not incorporated into the ARM model, and regardless of which way it is incorporated of reducing the harvest packages, or adding it as a mortality term in the model itself it has not changed the results. It would not have changed any of the results from the harvest packages that were produced from that model.

In looking at kind of additional points from the stock assessment, in looking at how the Catch Survey Analysis population estimates are going to be incorporated into the ARM model, really if the best population estimate from that analysis is used in the ARM model, then that would incorporate biomedical information inherently from that estimate, because it would be there as part of the model.

One of the tricky parts, and one of the things that the ARM Subcommittee and Delaware Bay TC would need to discuss is how that information could be incorporated and conveyed in some way publicly, so that can be used in management. That is something that will be taken up at that September meeting. On the points of the harvest packages and the potential for female harvest in the Delaware Bay that is something that was looked at a few times in the interim as well.

The bottom line of is it that unless the horseshoe crab females or the red knots hit their population thresholds, no matter how many additional packages get put into the mix, there will be no female harvest unless those thresholds get exceeded. That is kind of the takeaways of some of the analysis that has been done since draft Addendum VIII was initiated, and then to the point that we currently are, since it was postponed and potentially being taken back up in October.

CHAIRMAN RHODES: Are there any questions? Is everyone comfortable with that? Stew.

MR. MICHELS: I'm sorry, so the question as to whether the catch survey model should be incorporated into the ARM process that's going to happen in September?

DR. SCHMIDTKE: It's kind of already a work in progress, like we're planning the meeting right now, but the meeting will occur in September for the Subcommittee and the TC to discuss exactly how to do that and how to present that information for the Board.

CHAIRMAN RHODES: All right, is everyone comfortable with where we are right now, with the response and where we're moving forward? Chris.

MR. WRIGHT: The peer review of the stock assessment, the Chair specifically mentioned that the bycatch really needs to be addressed. He suggested that the Board figure out a way of getting to that number. It seems like the significance that he stressed in his report was pretty alarming to me. I think we need to discuss that and just figure out, how do we get to those numbers so we can make better decisions in the future?

CHAIRMAN RHODES: Is the Board comfortable if we task the TC to look at that as they go over this data, and see if they can come up with a way of modeling that into it? Roy.

MR. ROY W. MILLER: Mr. Chairman, what would be the assignment, to examine the discard mortality rate or to suggest ways to reduce the discard mortality rate, which is it?

CHAIRMAN RHODES: I think at this point it's going to be trying to get a number for the discard mortality rate, before we can affect that it would be having a number that they're comfortable with that we can use for our analyses.

DR. SCHMIDTKE: I think one point that would need to be considered with that as far as like the timeline that the TC would be working with, and the possibility of completing the task is the access to the data. Somebody that is involved in the TC would need to be able to have access to the Northeast Fishery Observer Program data, because that was the primary data from which the discards were estimated in the assessment. One of the big difficulties for why those estimates were so broad and not as well defined as we maybe would have liked them to be, was because there wasn't anybody on the SAS that had ready access to those data.

DR. KRISTEN ANSTEAD: Just for some clarification. As part of the stock assessment we did use the Northeast Science Fishery Centers data to do bycatch estimates. There were a lot of comments during the peer review that they thought that some of those methods could be refined to be better, and that it would take some work and some collaboration with the Northeast Fishery Science Center.

I think certainly the TC could examine, maybe at a state level and make some suggestions about what they think the mortality rates are for each of the gears that could be encountering horseshoe crabs. But as far as the methods and the analysis of the data that is going to be a partnership really with the Northeast Fisheries Science Center to kind of work together to get that data to be in better shape for a similar analysis.

CHAIRMAN RHODES: Okay. Mike.

DR. MICHAEL ARMSTRONG: A question for Mike, or maybe Kristen, jumping to the last bullet. If we were to at some meeting go down the long term ARM review. My understanding is that all the fundamental parts of the ARM would be reassessed and open to change, including those thresholds that Mike, you just spoke about. We can have all the harvest packages we want, but based on where the thresholds are right now, you're not going to open up female harvest. But if we go into the long term review, are those thresholds also open for reassessment?

DR. SCHMIDTKE: I need one second just to check the language of the Addendum and make sure.

MS. KERNS: If I remember correctly, and I did not go back and double check the document. But the thresholds in the document were based on some scientific information that was provided to us. Yes, we could go back and review the scientific information and change the thresholds, but it would still be based on scientific information.

I think whether or not those would change much is if the information that backed them changed. If there hasn't been much change in the information that is the source for that threshold, then probably not much change would occur. But through the addendum process, if you change the entire ARM modeling, then we would go through the Addendum to do that. Does that make sense, Mike?

DR. ARMSTRONG: Yes, thanks. I'm just reflecting that those were created ten years ago or more, I think. Maybe some things have changed.

CHAIRMAN RHODES: Stew.

MR. MICHELS: I think among the things that have changed are some of the surveys that are being used to provide those estimates of just exactly where we are, relative to those utility functions. It might be a good time to take a shot at that long term ARM review.

CHAIRMAN RHODES: Well those are good points. I know the ARM Working Group is going to meet in September, and although they're not set up to go along with that I'm sure the discussion will work towards that. There may be some clear answers for everybody.

OTHER BUSINESS

CHAIRMAN RHODES: Is there any other business to come before this Board? Yes, Stew.

MR. MICHELS: I'm sorry, are we going to charge the TC then with investigating some of these issues, like the bycatch and digging a little bit deeper into that? One of the issues I'm a little concerned with are the conversion factors that have been applied along the coast. If we could drill down on that I think it would be helpful.

CHAIRMAN RHODES: Those have all been noted and will be looked at. Any other business, all right and Mike has one more bit.

DR. SCHMIDTKE: Just giving the Board an update. When the initial agenda went out it did include an item for the FMP review, and we typically tried to do that within a meeting or two of when the Compliance Reports are due. That is delayed this year. We have not received all of the Compliance Reports yet. But we are hoping to have all of the data that we need to conduct the FMP review in October. I just wanted to let the Board know.

ADJOURNMENT

CHAIRMAN RHODES: Great, if there is no other business, then we can stand adjourn, and we're back on time. Thank you all.

(Whereupon the meeting adjourned at 3:30 o'clock p.m. on August 6, 2019)

Atlantic States Marine Fisheries Commission

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MEMORANDUM

October 8, 2019

To: **Horseshoe Crab Management Board**

From: **John Sweka (Adaptive Resource Management Subcommittee Chair) and Wendy Walsh (Delaware Bay Ecosystem Technical Committee Chair)**

RE: **Update and Review of the ARM Framework**

On September 11-12, 2019, the Adaptive Resource Management (ARM) Subcommittee and Delaware Bay Ecosystem Technical Committee (DBETC) met in Arlington, VA, to discuss how to accomplish the Horseshoe Crab Management Board's (Board) task to incorporate horseshoe crab population estimates from the Catch Multiple Survey Analysis (CMSA) model into the ARM Framework. During this meeting, John Sweka proposed a suite of potential revisions to the Framework that incorporate new information and data that was used in the benchmark assessment in addition to the CMSA population estimates. These revisions generally shift aspects of the ARM model from being theoretical or based on older literature values to being based on empirical and more recent data.

The committees discussed these potential revisions and formed consensus recommendations that they believe are necessary for the ARM Framework to move forward in managing horseshoe crabs in the Delaware Bay using the best science available. These recommendations are listed below for the Board's consideration:

1. **For input into the ARM Framework annually, combine the primiparous and multiparous abundances from the Virginia Tech Trawl Survey with a half year of mortality applied to the estimates. This would apply to the ARM Framework immediately.**

2. **Move forward with using CMSA model for estimation and projection as the underlying horseshoe crab population model in the ARM Framework. Reassess ARM utility of female horseshoe crab harvest as a function of female abundance.**

3. **Update red knot survival and mass gain model with most recent data. Evaluate red knot model weights.**

4. **Use of CMSA accounts for biomedical mortality in the ARM Framework (a previous Board task).**

5. **First, request the disclosure of confidential biomedical data for use in the base run CMSA estimate. If Board does not agree with making the request or the companies say**

no to the disclosure: Run the CMSA with the confidential biomedical data with 15% applied mortality, without biomedical data, and with non-confidential coastwide biomedical data with 15% applied mortality. The harvest package will be made based on the population estimates from the CMSA that includes confidential data, as it represents the best data set available. Publish 0% biomedical and coastwide biomedical population estimates as population bounds.

6. **Reevaluate definition of Delaware Bay crabs and the implications towards the population estimates and harvest allocations.**

The proposed changes to the ARM Framework would be conducted over a year or two and would require an external peer review.

John Sweka, the ARM Subcommittee Chair, will be attending the 2019 ASMFC Annual Meeting to discuss these recommendations in greater detail and answer questions. For additional information on discussions surrounding these recommendations, please reference the September 11-12 Meeting Summary, which will be included in the 2019 Annual Meeting Briefing Materials and may be found on the Commission's horseshoe crab species webpage.

Atlantic States Marine Fisheries Commission

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Horseshoe Crab Adaptive Resource Management Subcommittee
Meeting Summary

September 11, 2019

Adaptive Resource Management Subcommittee Members: Jim Lyons (Chair, USGS), Lindy Barry (NJ), Jason Boucher (DE), Steve Doctor (MD), Larry Niles (CWF), Dave Smith (USGS), John Sweka (USFWS), Wendy Walsh (USFWS)

ASMFC Staff: Michael Schmidtke, Kristen Anstead

Public: Brett Hoffmeister (HSC AP Vice Chair, ACC), Nora Blair (Charles River), Joe Smith, Jordan Zimmerman (DE), Mike Millard (DBETC, USFWS), Amanda Dey (DBETC, NJ)

On the Phone: Greg Breese (DBETC Chair, USFWS)

The Adaptive Resource Management (ARM) Subcommittee (SC) met on September 11, 2019, in Arlington, Virginia. The meeting's goals were to define the value used for horseshoe crab abundance in the ARM Framework, discuss how to incorporate horseshoe crab population estimates from the Catch Multiple Survey Analysis (CMSA) model used in the 2019 benchmark stock assessment into the ARM Framework, discuss other potential revisions to the ARM Framework, compile a set of recommendations based on these discussions for consideration by the Delaware Bay Ecosystem Technical Committee (DBETC), and elect a new Chair and Vice Chair.

Following the comments by the peer review panel for the 2019 benchmark stock assessment for horseshoe crab, the Board tasked the ARM SC with considering the incorporation of population estimates for horseshoe crab in the Delaware Bay from the CMSA and the estimate of natural mortality into the ARM Framework since both values represent the best available data. Previously, the Board had tasked the ARM SC with accounting for biomedical mortality in the Framework, but tabled the proposed options until after the benchmark assessment.

The ARM SC discussed the definition of the current ARM Framework. Kristen Anstead presented aspects of the Framework that are not clearly defined in Addendum VII or previous ARM reports. One of these is the inclusion of primiparous crabs in annual adult abundance estimates from the Virginia Tech (VA Tech) Benthic Trawl Survey, which are used as an input to the ARM Framework. The ARM SC concluded that from a biological standpoint, primiparous crabs caught by the VA Tech Survey (conducted annually in the fall) would contribute to the number of eggs available to red knots the following spring and should be included in the adult population estimate. However, the ARM Framework currently does not account for mortality that occurs during the time lag between the VA Tech Survey and the red knot stopover. The ARM SC agreed that this should be accounted for moving forward by applying half of the annual total adult mortality rate estimated from the benchmark stock assessment (0.274) to primiparous and multiparous male and female crab abundance estimates from the VA Tech Survey. The ARM SC also determined that population estimates made using the swept area delta distribution are those that are and will be used as inputs for the ARM Framework.

John Sweka presented potential changes to the ARM Framework that would more directly connect it to the CMSA model and replace several of the current Framework's theoretical assumptions with empirical estimates. One of these changes is to estimate a spawner-recruit relationship for horseshoe crabs and use it to project the assessment's CMSA model into the future to estimate male, female, and total carrying capacities (K). This relationship would view primiparous crabs as recruits, thus estimating the number of primiparous crabs based on the number of spawners (multiparous and primiparous females) from 10 years (female age of maturity) earlier. Initially, due to limited data, a hockey-stick spawner-recruit model could be used. However, each additional year abundance data would provide an additional data point that could eventually lead to the use of a Ricker model, which is probably more representative of horseshoe crab reproductive biology and behavior. Use of the CMSA population estimates includes other changes to the ARM such as inclusion of bait harvest, discard, and biomedical mortality and improved estimates of natural mortality. Currently, the CMSA model is only applied to females due to convergence issues in fitting a model for males. However, further efforts to model males can be made, and they can be estimated and projected in the interim using sex ratio information. Sweka also suggested an update of red knot information used in the ARM model, including survival rates, mass gain, and model weighting.

The ARM SC discussed several aspects of the potential revisions. The SC noted that egg survival is likely more contingent on weather conditions during and shortly after spawning than the number of spawners. At the same time, the SC recognized that a certain number of spawners must be present to produce recruits. Limited data and poor fitting models are common for spawner-recruit relationships for many species, but the value of being able to project recruitment forward based on even this limited data has value for estimating population characteristics such as K. The model fit could also improve over time with data from additional years of all surveys in the CMSA and stage information now being collected by NJ and DE state surveys. Inclusion of actual removals information in the ARM model is an improvement, which can be made even better through improved estimates of discards and associated mortality. The SC discussed the possibility that use of this method could change K and influence harvest package selection. This could lead to the same, increased, or decreased bait harvest. However, the SC agreed that the proposed methodology is an improvement because it is more defensible. The SC recommended to move forward with using the CMSA model for estimation and projection as the underlying horseshoe crab population model in the ARM Framework. The SC also recommended reassessment of the ARM utility of female horseshoe crab harvest as a function of female abundance.

Dave Smith informed the ARM SC of a project that will be undertaken at the USGS Leetown Science Center to transfer the ARM Framework from its current software (ASDP) to MDPSolve, a software written in the more widely used MATLAB programming language. This project could incorporate the proposed ARM revisions. After completion, the model could be housed with the Commission and staff could be trained to run it.

The ARM SC discussed inclusion of biomedical data in the ARM Framework. Two methods for doing so had been discussed and tested in earlier meetings. However, through the use of the CMSA horseshoe crab population estimates, the ARM SC considers biomedical use of horseshoe crabs and associated mortality adequately accounted for.

The ARM SC discussed how to publicly present ARM information including population estimates and harvest package results, given the use of confidential information in CMSA abundance estimates. The ARM SC agreed that the ability to publish population estimates from the CMSA base run would be most accurate, and that the Commission should request permission to publish this estimate from the biomedical companies. Given denials of past requests for this permission, the ARM SC also considered other options for presenting results if this request is not made by the Board or is denied by the companies.

The ARM SC considered use of a moving average of biomedical mortality over multiple years, as well as a simulation based on a moving average and standard deviation. Use of the coastwide biomedical mortality applied to the Delaware Bay region was also considered. While this would underestimate the population in the region it would produce a publicly viewable number that could be recognized as a lower bound. Given the small impact of biomedical use observed by the stock assessment, this conservative estimate still likely would not change harvest package selection. The ARM SC also discussed use of 0% biomedical mortality, which would also give a publicly viewable upper abundance estimate and likely the same harvest package as the CMSA base run. Use of either the coastwide or 0% biomedical mortality was not preferred because of known directional bias. Therefore, the ARM SC recommended that the ARM model be run with the CMSA using both the 0% biomedical mortality and the coastwide biomedical mortality attributed to the Delaware Bay region. Population estimates from both methods would be published as population bounds and the resulting harvest package, if the same, would be used in management. If the harvest package differed, the more conservative harvest package would be used in management. This recommendation was revised after further discussion with the DBETC.

The ARM SC discussed the definition of Delaware Bay-origin crabs and the current use of abundance estimates from the VA Tech Survey, given the survey's sampling area relative to stock structure and movement information used in the assessment. The ARM SC noted that crabs that spawn in Delaware Bay may also spawn in other areas, such as coastal bays of Maryland or Virginia, in other years. Tagging information shows movement and exchange among different parts of the Delaware Bay region. The ARM SC discussed coverage of the Delaware Bay region (considered from the Virginia-North Carolina state line through New Jersey). The VA Tech Survey does not cover the northernmost and southernmost extremes of this region, but does cover a large majority of the region. Also, the majority of horseshoe crabs observed in New Jersey's Ocean Trawl Survey are in strata that are within the VA Tech Survey sampling area. The ARM SC decided that the population estimate from VA Tech should not be altered due to spatial coverage. The ARM SC did discuss movement of crabs south of the Delaware Bay and current consideration of portions of Maryland and Virginia crabs to not be of Delaware Bay origin. Given new information on horseshoe crab movement in this region since the ARM Framework was established, the ARM SC recommended that the percentages of Maryland and Virginia crabs considered to be of Delaware Bay origin or part of the Delaware Bay regional population be reevaluated.

The ARM SC elected a new Chair, John Sweka, and Vice Chair, Jim Lyons.

Horseshoe Crab Adaptive Resource Management Subcommittee and Delaware Bay Ecosystem Technical Committee
Joint Meeting Summary

September 12, 2019

Delaware Bay Ecosystem Technical Committee Members: Greg Breese (Chair, USFWS), Henrietta Bellman (DE), Amanda Dey (NJ), Steve Doctor (MD), Mike Millard (USFWS), Wendy Walsh (USFWS), Jordan Zimmerman (DE)

On the phone: Eric Hallerman (VT), Adam Kenyon (VA)

Adaptive Resource Management Subcommittee Members: Jim Lyons (Chair, USGS), Lindy Barry (NJ), Henrietta Bellman (DE), Jason Boucher (DE), Steve Doctor (MD), Larry Niles (CWF), Dave Smith (USGS), John Sweka (USFWS), Wendy Walsh (USFWS)

ASMFC Staff: Michael Schmidtke, Kristen Anstead

Public: Brett Hoffmeister (HSC AP Vice Chair, ACC), Nora Blair (Charles River), Joe Smith

A joint meeting of the Delaware Bay Ecosystem Technical Committee (DBETC) and Adaptive Resource Management (ARM) Subcommittee (SC) took place on September 12, 2019, in Arlington, Virginia. The meeting's goals were to review and discuss the ARM SC's proposed changes to the ARM Framework, develop recommendations for the Horseshoe Crab Management Board (Board) about the proposed changes, review 2018 horseshoe crab and 2019 red knot surveys, and elect a new Chair and Vice Chair.

Jim Lyons and John Sweka presented the ARM SC's recommended changes to the ARM Framework for the DBETC's review and consideration for approval. Following a presentation of the proposed revisions, the DBETC asked questions and made some revisions. The consensus recommendations by the DBETC and ARM SC to the Board are:

1. **For input into the ARM Framework annually, combine the primiparous and multiparous abundances from the Virginia Tech Trawl Survey with a half year of mortality applied to the estimates. This would apply to the ARM Framework immediately.**

2. **Move forward with using CMSA model for estimation and projection as the underlying horseshoe crab population model in the ARM Framework. Reassess ARM utility of female horseshoe crab harvest as a function of female abundance.**

3. **Update red knot survival and mass gain model with most recent data. Evaluate red knot model weights.**

4. **Use of CMSA accounts for biomedical mortality in the ARM Framework (a previous Board task).**

5. **First, request the disclosure of confidential biomedical data for use in the base run CMSA estimate. If Board does not agree with making the request or the companies say no to the disclosure: Run the CMSA with the confidential biomedical data with 15% applied mortality, without biomedical data, and with non-confidential coastwide biomedical data with 15%**

applied mortality. The harvest package will be made based on the population estimates from the CMSA that includes confidential data, as it represents the best data set available. Publish 0% biomedical and coastwide biomedical population estimates as population bounds.

6. **Reevaluate definition of Delaware Bay crabs and the implications towards the population estimates and harvest allocations.**

The proposed changes to the ARM Framework would be conducted over a year or two and would require a peer review.

The committees reviewed the results of the 2018 Virginia Tech Trawl Survey by Eric Hallerman, New Jersey Ocean Trawl and Delaware Bay Trawl by Lindy Barry, and Delaware 16' and 30' Trawls by Jordy Zimmerman. As in previous years, the immature and newly mature male and female horseshoe crabs show variability and no trend. Mature males and females in the coastal area show an increasing trend since 2002, although the committee members had some disagreement about the interpretation of that trend and what statistical test was used. The swept area estimate of mature female horseshoe crabs in the region for fall 2018 was 7.3 (95% CI: 4.1- 10.5) million.

Jim Lyons presented the 2019 red knot mark-resight survey conclusions and population estimates. The pattern of red knot arrivals in the Delaware Bay in 2019 suggested an early arrival and a relatively high persistence probability. The estimated stopover population was 45,133 (95% CI: 42,269–48,393), similar to the estimate in 2018 of 45,221 (95% CI: 42,568–49,508). This superpopulation estimate accounts for turnover in the population and probability of detection. Mandy Dey gave an update on the status of red knot which stated that peak stopover in the Delaware Bay has been low and stable for a decade and horseshoe crab eggs have not shown an increase. Both reports noted that there has been a shift of red knot distribution to New Jersey beaches and few birds detected on Delaware beaches.

The horseshoe crab population estimates from the Virginia Tech Trawl Survey and the red knot estimates from mark-resight have been forwarded to Conor McGowan, who runs the current ARM model, to generate the 2020 fishing season's harvest package. Additionally, Joe Smith discussed some recent work his research group has conducted regarding horseshoe crab egg density trends which indicates that beaches are not saturated with eggs to levels that compare with previous (1990s) estimates.

The DBETC elected a new Chair, Wendy Walsh, and Vice Chair, Henrietta Bellman.

Horseshoe Crab Harvest Recommendations Based on Adaptive Resource Management (ARM) Framework and Most Recent Monitoring Data

Report to the Delaware Bay Ecosystem Technical Committee by the ARM Subcommittee

September 2019

This report summarizes annual harvest recommendations. Detailed background on the ARM framework and data sources can be found in previous technical reports[1].

Objective statement
Manage harvest of horseshoe crabs in the Delaware Bay to maximize harvest but also to maintain ecosystem integrity and provide adequate stopover habitat for migrating shorebirds.

Alternative harvest packages
These harvest packages were compared to determine which will best meet the above objective given the most recent monitoring data. Harvest is of adult horseshoe crabs of Delaware Bay origin.

Harvest package	Male harvest (×1,000)	Female harvest (×1,000)
1	0	0
2	250	0
3	500	0
4	280	140
5	420	210

Population models
Population dynamics models that link horseshoe crabs and red knots were used to predict the effect of harvest packages. Three variations in the models represent the amount and type of dependence between horseshoe crabs and red knots. Stochastic dynamic programming was used to create a decision matrix to identify the optimal harvest package given the most recent monitoring data.

Monitoring data
Sources of data for horseshoe crab abundance were a set of trawl surveys conducted by Virginia Tech university.[2] Red Knot abundance estimates are taken from a mark-resight estimate for red knot abundance[3]. These data and methods can be evaluated in the respective reports from those studies.

Horseshoe crab abundance (millions)			Red knot abundance (×1,000)	
Year	Male	Female	Year	Male and female
2018 (Fall)	16.6	7.9	2019 (Spring)	4.5133

Harvest recommendations

Decision matrix was optimized incorporating recommendations on red knot stopover population estimates and associated calibration of red knot threshold[4]. I followed the accepted procedure used in all past years where the empirical abundance estimates did not exactly fit the discretized population size "bins." For each empirical estimate I use the closest discretized abundance "bin" that was not larger than the estimate, in other words I rounded down to the nearest bin.

Recommended harvest package	Male harvest (×1,000)	Female harvest (×1,000)
3	500	0

Quota of horseshoe crab harvest for Delaware Bay region states. Allocation of allowable harvest under ARM package 3 (500K males, 0 females) was conducted in accordance with management board approved methodology in *Addendum VII to the Interstate Fishery Management Plan for Horseshoe Crabs*. Note: Maryland and Virginia total quota refer to that east of the COLREGS line.

	Delaware Bay Origin HSC Quota		**Total Quota**	
State	**Male**	**Female**	**Male**	**Female**
Delaware	162,136	0	162,136	0
New Jersey	162,136	0	162,136	0
Maryland	141,112	0	255,980	0
Virginia	34,615	0	81,331	0

References

[1] McGowan, C. P., D. R. Smith, J. D. Nichols, J. Martin, J. A. Sweka, J. E. Lyons, L. J. Niles, K. Kalasz, R. Wong, J. Brust, M. Davis. 2009. A framework for the adaptive management of horseshoe crab harvests in the Delaware Bay constrained by Red Knot conservation. Report to the Atlantic States Marine Fisheries Commission Horseshoe Crab Technical Committee.

ASMFC Horseshoe Crab Stock Assessment Subcommittee. 2009. Horseshoe crab 2009 stock assessment report. Report to the Atlantic States Marine Fisheries Commission Horseshoe Crab Technical Committee.

ASMFC 2009. Terms of Reference and Advisory Report to the Horseshoe Crab Stock Assessment Peer Review. Stock Assessment Report No. 09-02.

[2] Virginia Tech Trawl Survey report, January 15, 2019

[3] Jim Lyons' 2019 estimate in the 10 September, 2019 Memo

[4] ARM's recommendations for improved estimates of red knot stopover population size and associated calibration of red knot threshold

Results of the 2018 Horseshoe Crab Trawl Survey:

Report to the Atlantic States Marine Fisheries Commission Horseshoe Crab and Delaware Bay Ecology Technical Committees

David Hata and Eric Hallerman

Department of Fish and Wildlife Conservation
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

15 January 2019

Abstract

To properly manage the mid-Atlantic horseshoe crab (*Limulus polyphemus*) fishery, a time-series of data on relative abundance of all demographic groups is needed. We conducted a trawl survey in the coastal Delaware Bay area and the lower Delaware Bay, quantifying mean catch per 15-minute tow and comparing relative abundance of demographic groups with results from previous years. Mean catch-per-tow of immature and newly mature horseshoe crabs in the coastal Delaware Bay area have been variable since 2002 with no trend. Mean catch-per-tow of mature females and males are correlated, and both appear to display an increasing trend over time. Mean catches of immature and mature crabs in lower Delaware Bay are generally larger than catches in the coastal area, although usually not statistically significantly so. Mean catch-per-tow and population estimates of newly mature males are correlated with values for newly mature females of the same year-class the following year. Our findings will be used to parameterize the Adaptive Resource Management model used to set annual harvest levels for horseshoe crabs.

Introduction

To properly 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. 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 2018 trawl survey.

In summer 2017, we provided the Adaptive Resource Management (ARM) Subcommittee population estimates of horseshoe crabs in the DBA and LDB surveys to inform the ARM model runs. Herein, we present the population estimates through the 2018 survey, incorporating the station location and stratum assignment corrections described in the 2017 report. Gear catchability has not been evaluated for these estimates, so they should be considered conservative.

Methods

The 2018 horseshoe crab trawl survey was 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 in 2016 and 2017. The lower Delaware Bay (LDB) survey area extended from the Bay mouth to a line between Egg Island Point, New Jersey and Kitts Hummock, Delaware. The LDB was previously sampled from 2010 to 2012 and in 2016 and 2017. Due to frequent and prolonged weather delays, the surveys were conducted over a protracted period from 11 September to 19 November 2018.

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 and 9 stations in the LDB.

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 are 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 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 lognormal delta-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 lognormal delta-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 calculate 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 then would represent the stratified mean catch per tow at each size interval.

The average 15-minute tow in the DBA was 1.23 kilometers at 4.9 KPH. The average 15-minute tow in the LDB was 1.22 km at 4.9 KPH. Valid net-spread measurements were obtained from 45 tows and averaged 9.8 meters. We used the net-spread (S, in meters)/tow speed (C, in KPH) relationship developed from previous trawl surveys to estimate net-spread for collections in which net-spread was not measured ($S = 13.84 - 0.858 \times C$).

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):

$$\text{catch/km}^2 = \text{catch/[tow distance (km)} \times \text{net-spread (km)]}.$$

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

Delaware Bay area

Stratified mean catches-per-tow for all demographic categories were relatively consistent from 2016 to 2018 (Tables 1 and 2; Figure 2). Stratified mean catches of mature females and males have been variable over the time-series, but are significantly correlated ($r = 0.866$; $T = 5.75$; $p < 0.001$; $n = 13$). Mean catches of mature males and females appear to be increasing over the time-series (males: $r = 0.729$; $T = 3.54$; $p = 0.005$; $n = 13$, females: $r = 0.599$; $T = 2.48$; $p = 0.031$), although males were relatively less abundant in 2018 than in the previous two years. Yearly trends from the delta- and normal-distribution models followed similar patterns for all demographic groups.

Mean catches of newly mature males are correlated with mean catches of immature females 171-230 mm PW and approximately the same age ($r = 0.762$; $T = 3.90$; $p = 0.002$; $n = 13$), and with mean catches of newly mature females the following year ($r = 0.749$; $T = 3.39$; $p = 0.008$). However, mean catches of immature females 171-230 mm are not correlated with mean catches of newly mature females the following year ($T = 2.08$; $p = 0.068$; $n = 11$), nor with the combined catches of newly mature females and immature females 231-300 mm the following year ($T = 1.61$; $p = 0.141$; $n = 11$).

Lower Delaware Bay

This was the sixth year of sampling within the Delaware Bay. Stratified mean catches of immature female crabs in 2018 were about half of those in 2016, the largest means observed, but were not significantly less, based on overlapping confidence limits (Tables 3 and 4; Figure 3). In addition, mean catches of mature females and males were much lower than in 2017, although again not significantly different based on overlapping confidence limits.

Size distributions

Size-frequency distributions of immature horseshoe crabs in the DBA survey display considerable variability (Figure 4). Modal groups are generally indistinct, except for one large group of both females and males in 2009. However, that modal group, which would presumably be larger in size the following year, becomes indistinct again in

2010. Size-frequency distributions from the lower Delaware Bay do not show that modal group in 2010 either (Figure 5).

We had previously reported that mean prosomal widths of mature male and female crabs in the DBA survey displayed slight but detectable decreases over time (Hata and Hallerman 2017). Those trends appear to continue through the 2018 survey, and also include newly mature females and males (Table 5; Figure 6). In addition, decreasing trends in mean PW were observed for mature females and males in the lower Delaware Bay survey, but an increasing trend was detected for newly mature males.

<u>Sex ratios</u>

Mature males were typically more than twice as numerous as mature females throughout the survey time-series. Sex ratios (M:F) from mean catch-per-tow in the DBA surveys ranged from 1.84 in 2005 to 3.63 in 2016, averaging 2.47 over all years. The ratio of newly mature males to females was highly variable, ranging from 0.10 in 2003 to 2.25 in 2004, and averaged 1.12. 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.

Sex ratios of mature horseshoe crabs were higher within the lower Delaware Bay than on the coast. Sex ratios (M:F) ranged from 2.61 in 2010 to 6.15 in 2016, averaging 3.84. As on the coast, sex ratios of newly mature crabs within the Bay were variable, and ranged from 0.45 to 5.97, averaging 3.07. The higher sex ratios within Delaware Bay may reflect a tendency for male horseshoe crabs to remain near the spawning beaches.

<u>Population estimates</u>

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 7 and 8). Similarly, population estimates of newly mature crabs increased from 2002 to 2008, but have remained consistently low since 2009. Estimated numbers of mature males and females have significantly increased over the time-series (males: $r = 0.708$; $T = 3.33$; $p = 0.007$; $n = 13$, females: $r = 0.567$, $T = 2.28$; $p = 0.043$).

Population estimates of newly mature females are significantly correlated with estimates of newly mature males the previous year ($r = 0.745$; $T = 3.35$; $p = 0.009$; $n = 11$), as observed for mean catches per tow above. Assuming males entering the newly mature category are of the same year-class as females entering that category the following year, annual trends for males may forecast similar trends for females.

Population estimates of immature crabs in lower Delaware Bay have been consistent with coastal estimates since the LDB survey began in 2010 (Tables 9 and 10). On average, 32% of the total number of immature females and 36% of immature males occurred within Delaware Bay, although the LDB sampling area composed only 9.3% of the total combined area. In 2018, 18% of immature females and 26% of immature males occurred within the Bay. Considerably fewer newly mature and mature crabs were in the Bay compared to the coast. About 11% of the combined population of newly mature females occurred within the Bay, while 14% of newly mature males were in the Bay. In 2018, only 6 and 4% of newly mature females and males, respectively, occurred within Delaware Bay. About 24% of mature females and 29% of mature males occurred within the Bay on average, with 19 and 23%, respectively, occurring within the Bay in 2018. Within the combined survey population, the sex ratio of mature males:females ranged from 2.24 to 4.07, and averaged 3.09, with a ratio of 2.24 in 2018.

<u>Effects of sampling period</u>

The 2018 DBA survey was conducted from mid-September to mid-November, although most sampling was completed by mid-October. The average bottom water temperature in 2018 was the highest in the time series (Table 6; Figure 7). Because of adverse weather, the 2018 lower Delaware Bay survey was completed nearly a month later than in previous years, and a month later than the majority of the DBA survey. As a result, the average LDB water temperature was 10 C° cooler than the average DBA temperature. Horseshoe crabs that were within the Bay during most of the DBA survey because of the warm temperature, and not enumerated, may have moved out of the Bay by the time the LDB survey was conducted, and again not enumerated. This may have resulted in underestimates of horseshoe crabs in both survey areas and contributed to the apparent decrease in mature M:F ratios in both survey areas since 2016.

When comparing survey time-frames and water temperatures, it appears that the mean catches of immature crabs are correlated with mean sampling dates but not with water temperature (Table 7). In contrast, mean catches of mature crabs were correlated with mean water temperatures. Within the lower Delaware Bay, mean catches were not correlated with mean water temperatures or sampling dates.

Horseshoe crab tagging

We tagged a total of 509 adult horseshoe crabs in 2018, 224 females and 285 males. Of these, 235 were tagged in the coastal DBA area, and 274 were tagged within the LDB survey area. In addition, we captured one horseshoe crab in the DBA survey that was tagged within Delaware's Rehoboth Bay/Indian River Bay complex during the 2018 spawning season, but more precise information was not yet available.

Key findings

1. Mean catch-per-tow of immature male and female horseshoe crabs in the coastal Delaware Bay area have been variable since 2002 with no trend, and remain below the peak of 2009.
2. Mean catch-per-tow of newly mature crabs in the coastal Delaware Bay area have remained below peaks in 2007 (males) or 2008 (females) and show no long-term trend.
3. Mean catch-per-tow of mature males and females in the coastal Delaware Bay area have been variable throughout the time-series, but show increasing trends since 2002.
4. Mean catch-per-tow of immature horseshoe crabs in the coastal Delaware Bay area may be related to sampling date. Mean catch-per-tow of mature horseshoe crabs may be related to water temperature.
5. Annual mean prosomal widths of newly mature and mature horseshoe crabs in the coastal Delaware Bay area show decreasing trends.

Literature Cited

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.

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.

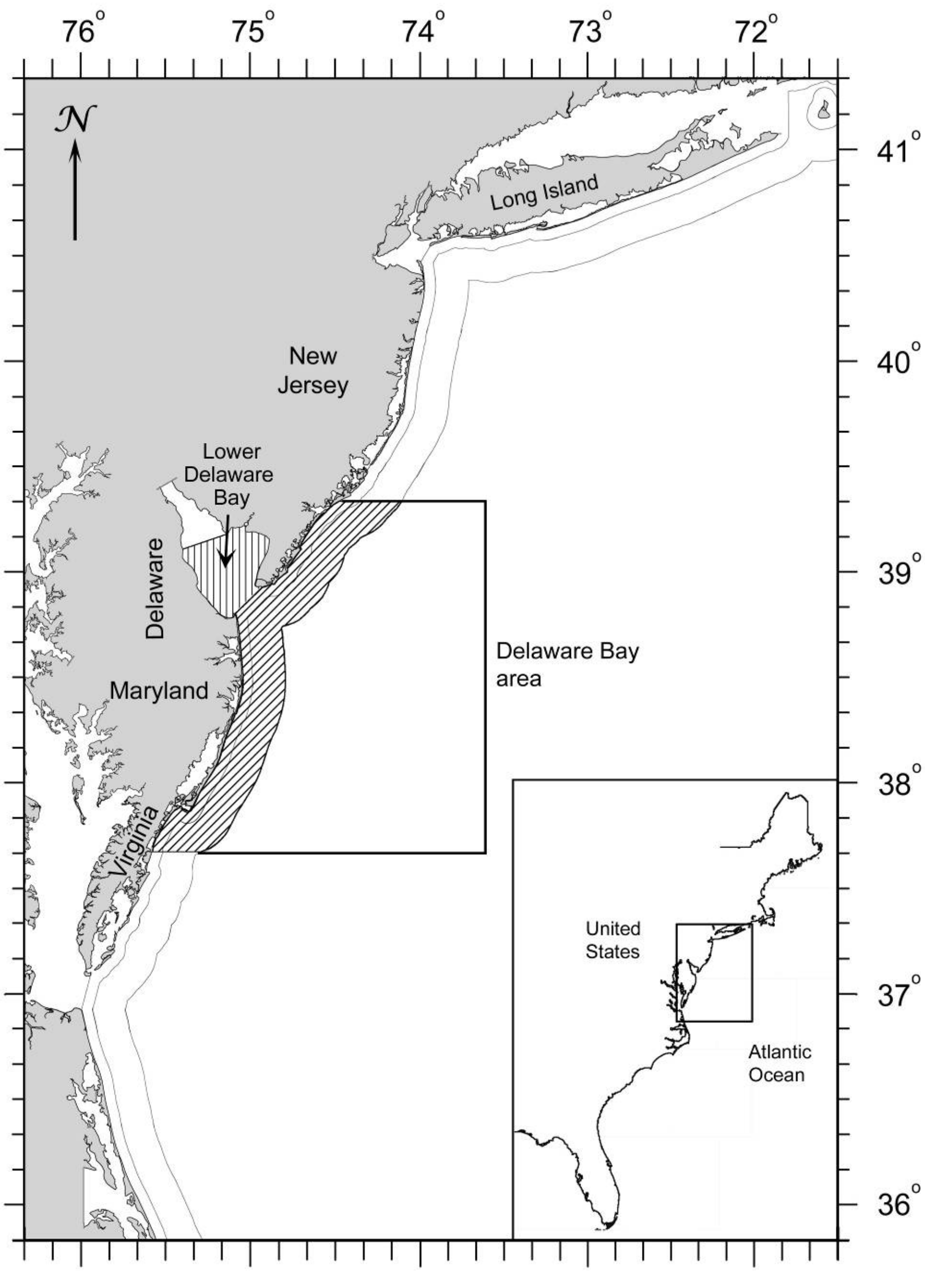

Figure 1. Fall 2018 horseshoe crab trawl survey sampling area. The coastal Delaware Bay area (DBA) and Lower Delaware Bay (LDB) survey areas are indicated. Mean catches among years were compared using stations within the shaded portions of the survey areas.

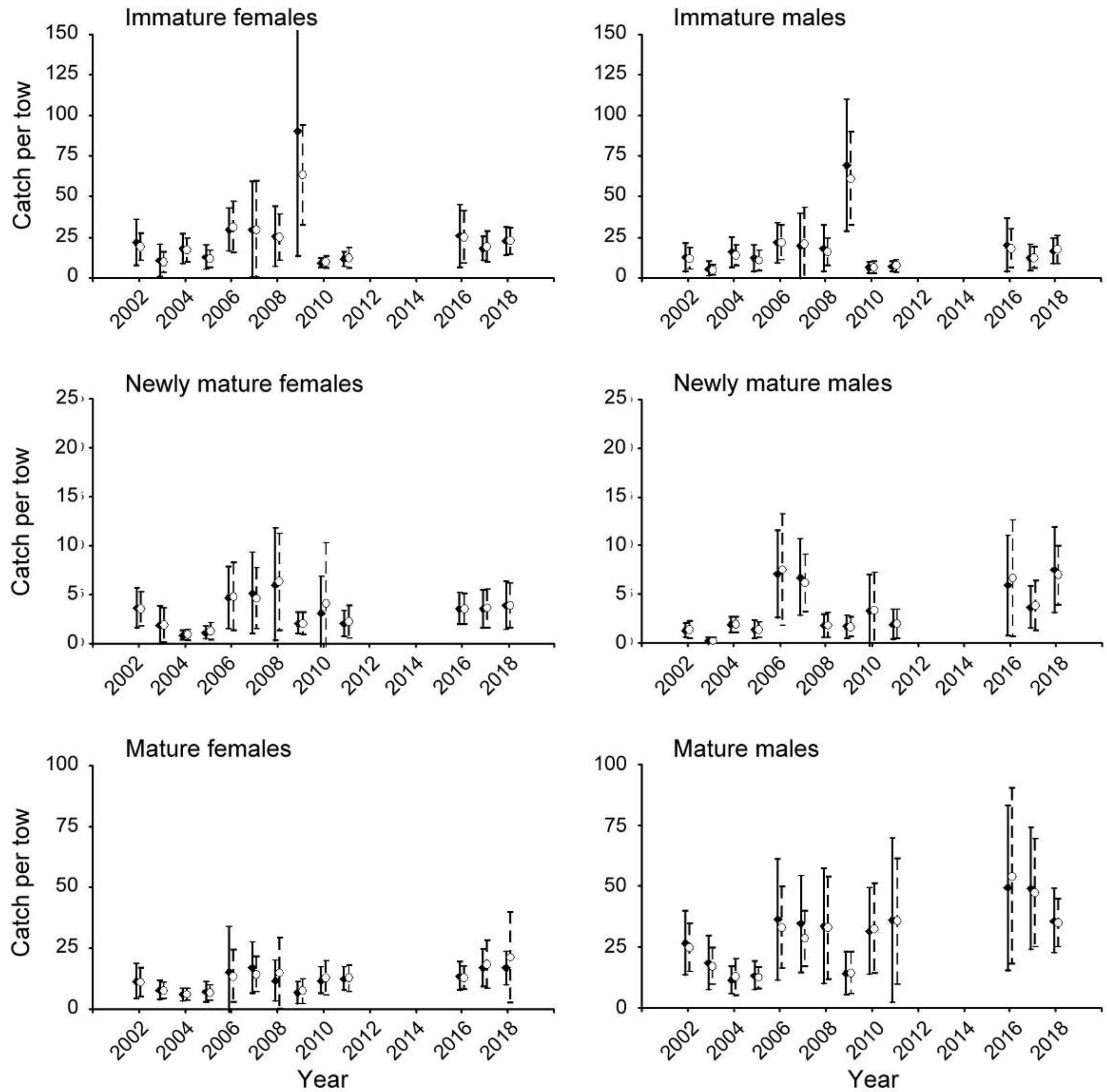

Figure 2. Plots of stratified mean catches per 15-minute tow of horseshoe crabs in the coastal **Delaware Bay area** survey by demographic group. Vertical lines indicate 95% confidence limits. Solid symbols and lines indicate the **delta distribution** model. Open symbols and dashed lines indicate the **normal distribution** model. Data are from Tables 1 and 2. Note differences in *y*-axis scales.

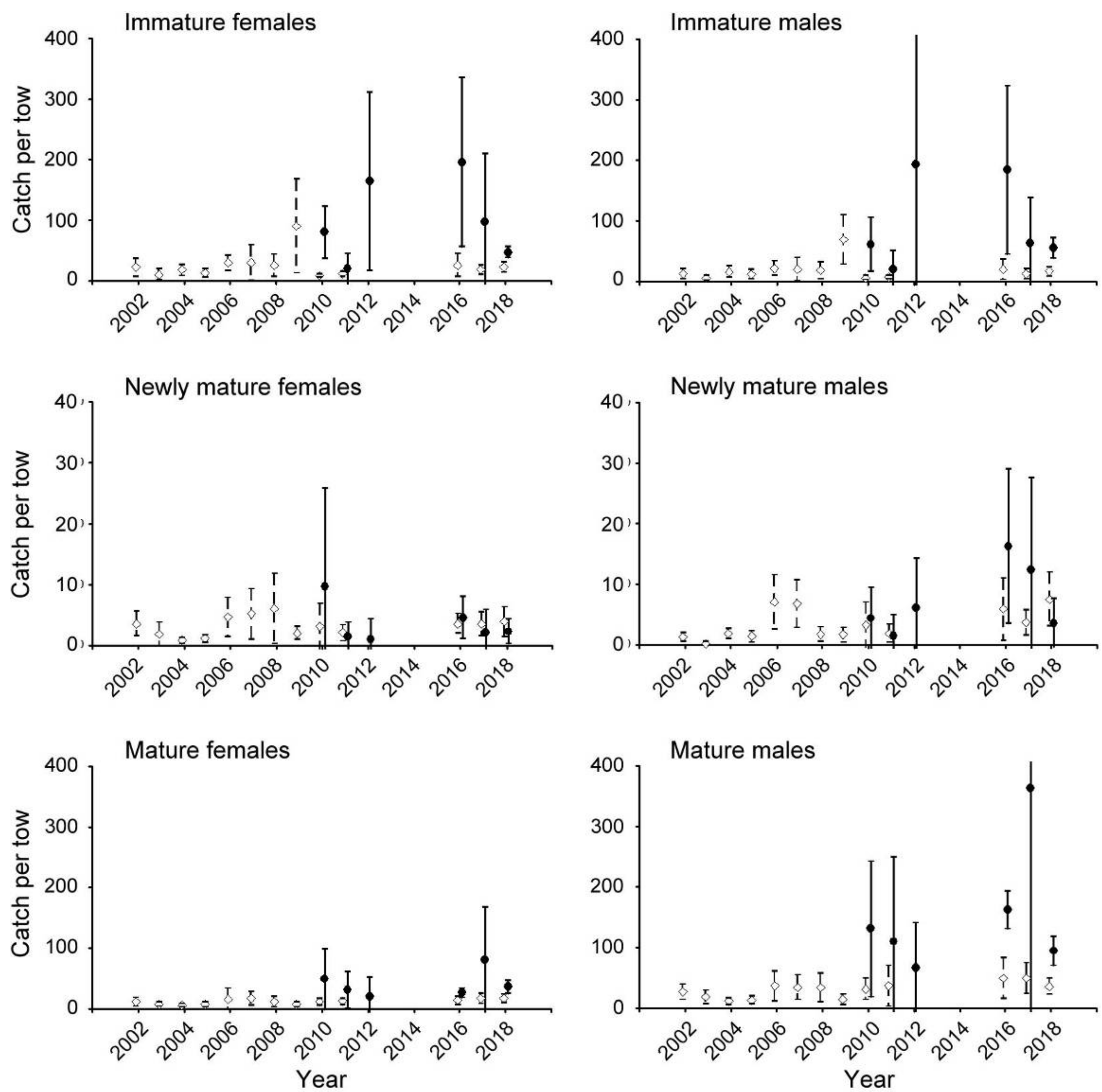

Figure 3. Stratified mean catches per tow of horseshoe crabs in the **lower Delaware Bay** survey by demographic group, with coastal **Delaware Bay area** survey means for comparison. Vertical lines indicate 95% confidence limits. Only the **delta distribution** model means are presented for clarity. 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.

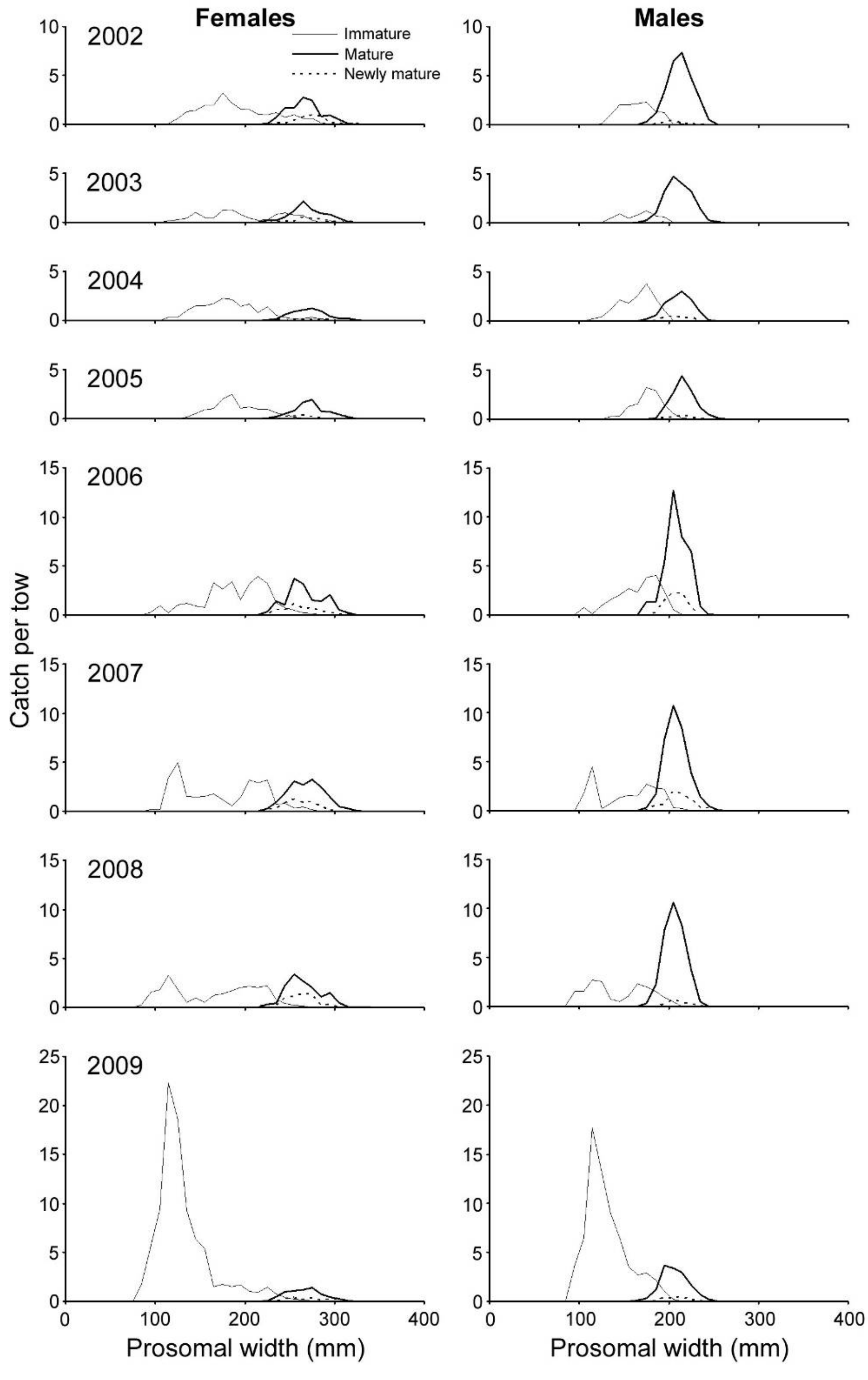

Figure 4. Relative size-frequency distributions of horseshoe crabs, by demographic group and year, in the coastal **Delaware Bay area** trawl survey. Relative frequencies are scaled to represent stratified mean catches in Table 1.

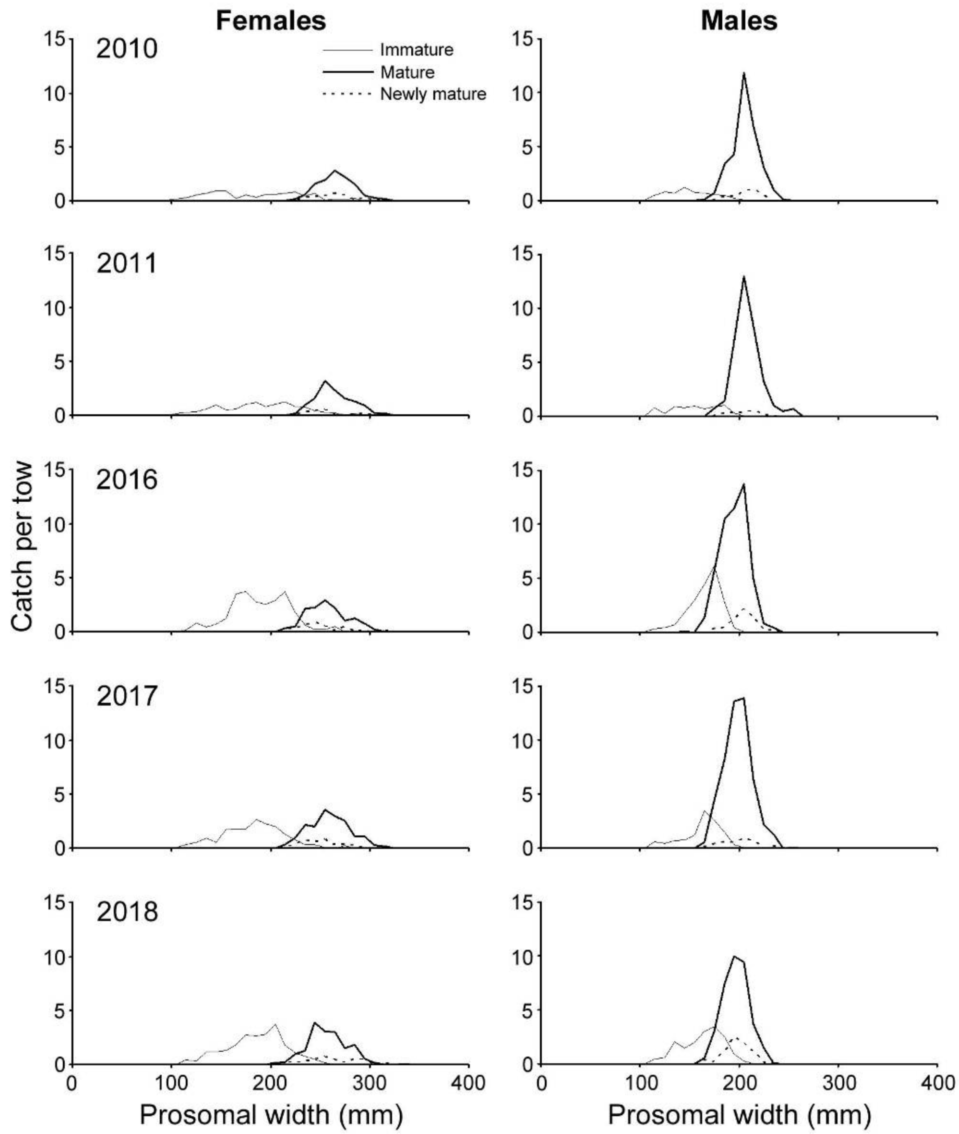

Figure 4 (continued).

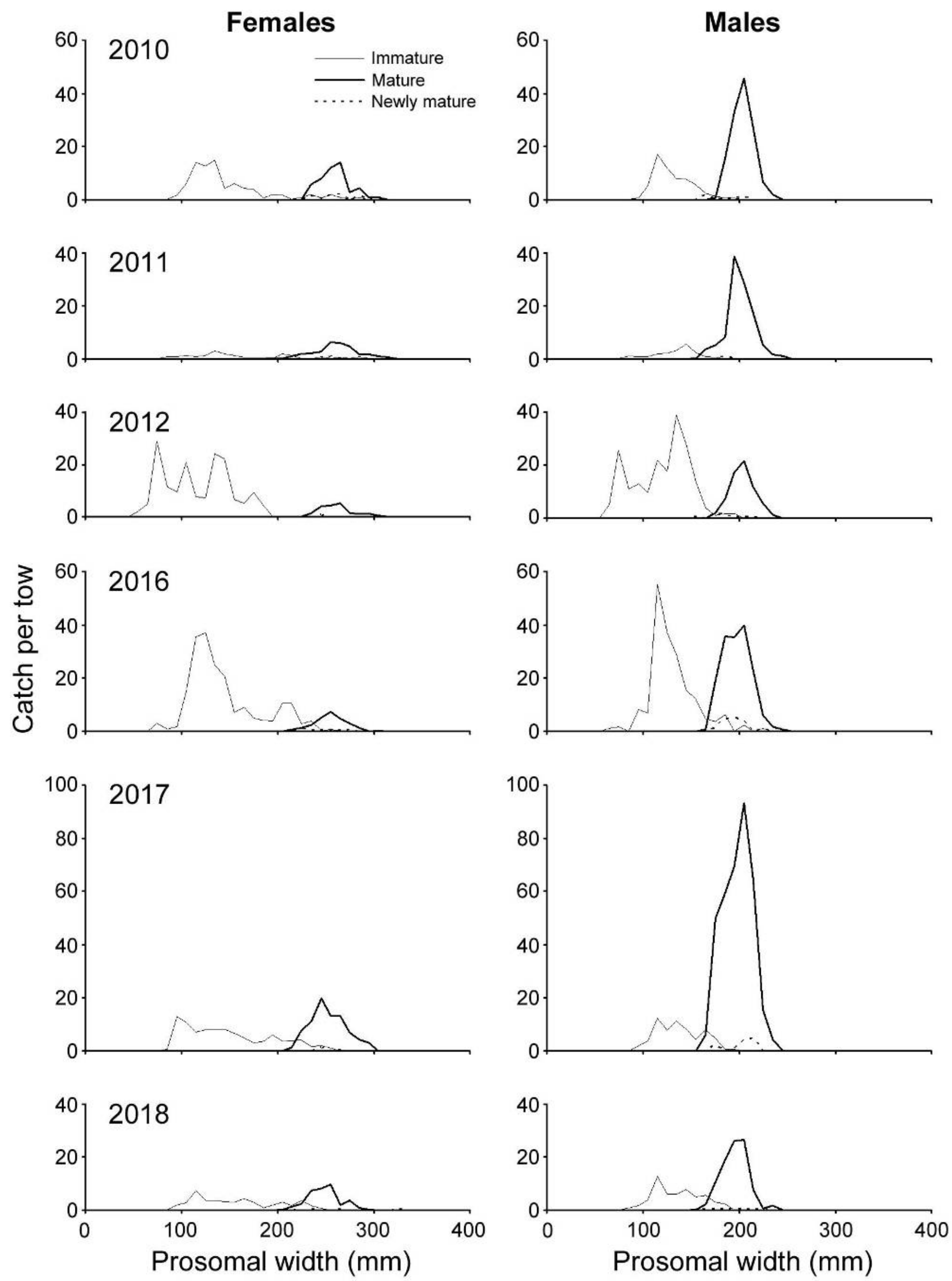

Figure 5. Relative size-frequency distributions of horseshoe crabs, by demographic group and year, in the **lower Delaware Bay** trawl survey. Relative frequencies are scaled to represent stratified mean catches in Table 3.

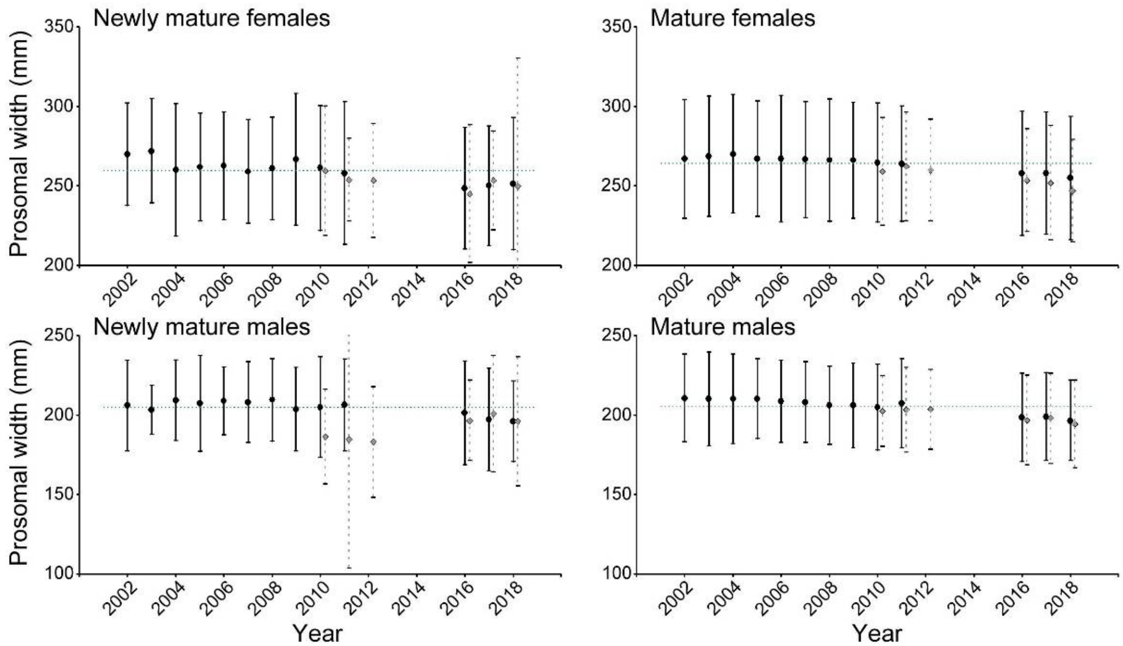

Figure 6. Mean prosomal widths (mm) (± 2 standard deviations) of mature and newly mature female and male horseshoe crabs in the Delaware Bay area (solid symbols and lines) and lower Delaware Bay (grey symbols and lines) surveys. Horizontal lines indicate overall means for all horseshoe crabs in the Delaware Bay area survey.

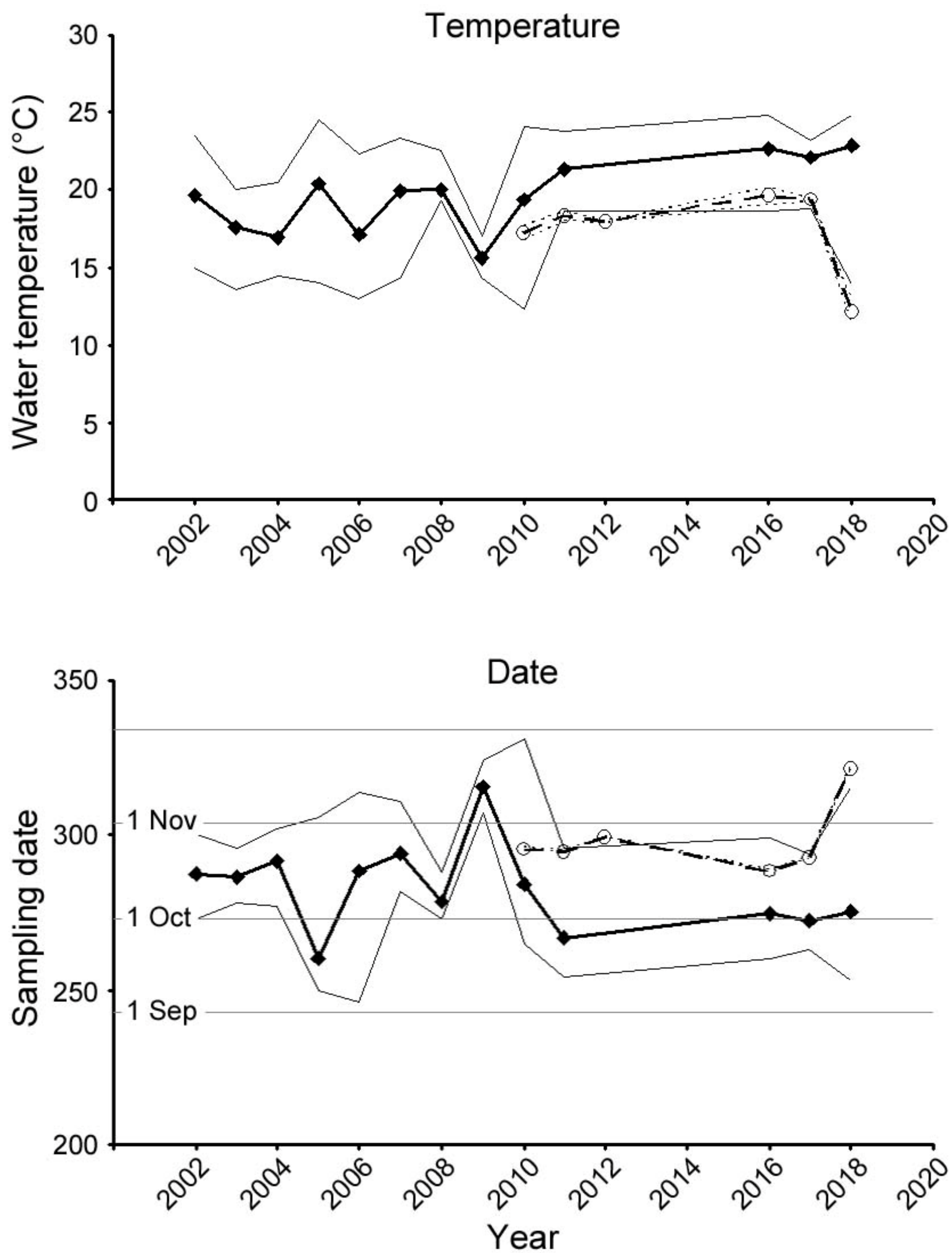

Figure 7. Plots of mean bottom water temperatures and ordinal sampling dates (days since 1 January) in the coastal Delaware Bay area and lower Delaware Bay trawl surveys. Solid symbols and lines indicate coastal Delaware Bay area. Open symbols and dashed lines indicate lower Delaware Bay. Approximate calendar dates are indicated by dashed 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, 2002-2018, with 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).

	mean	UCL	LCL	CV	sd		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	25.0	6.4	0.29	4.5
2005	12.7	19.9	5.5	0.28	3.5	2005	11.9	20.0	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	18.0	32.4	3.6	0.35	6.3
2009	90.2	167.4	12.9	0.39	35.5	2009	69.0	109.7	28.3	0.29	19.8
2010	9.0	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	20.0	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
Mature females						Mature males					
2002	11.4	18.5	4.2	0.30	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	0.27	2.0	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	0.30	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	0.30	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	36.0	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	0.23	3.9	2017	48.9	74.0	23.9	0.25	12.2
2018	16.8	23.7	9.9	0.20	3.3	2018	35.7	48.9	22.5	0.17	6.2
Newly mature females						Newly mature males					
2002	3.6	5.6	1.6	0.26	0.9	2002	1.3	2.0	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	0.30	0.2	2004	1.8	2.6	1.0	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	0.30	1.4	2006	7.1	11.6	2.6	0.36	2.7
2007	5.1	9.3	0.9	0.39	2.0	2007	6.7	10.6	2.8	0.28	1.9
2008	6.0	11.8	0.2	0.44	2.7	2008	1.8	2.9	0.6	0.32	0.6
2009	2.0	3.1	0.9	0.26	0.5	2009	1.7	2.8	0.5	0.34	0.6
2010	3.0	6.8	-0.7	0.59	1.8	2010	3.2	7.0	-0.5	0.55	1.8
2011	2.0	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	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	1.0
2018	3.9	6.3	1.4	0.30	1.2	2018	7.5	11.9	3.1	0.27	2.1

Table 2. Stratified mean catch-per-tow of horseshoe crabs in the coastal **Delaware Bay area** survey, 2002-2018, with 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).

	mean	UCL	LCL	CV	sd		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	0.27	3.2
2003	9.5	15.9	3.0	0.32	3.1	2003	4.9	8.1	1.8	0.30	1.5
2004	17.0	24.5	9.5	0.21	3.6	2004	14.0	20.3	7.6	0.22	3.1
2005	11.5	17.0	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	32.0	11.1	0.23	5.0
2007	29.8	59.6	0.0	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	61.0	89.8	32.1	0.23	14.0
2010	9.4	13.0	5.7	0.19	1.8	2010	6.4	10.1	2.6	0.29	1.8
2011	12.2	18.5	6.0	0.25	3.0	2011	7.3	11.2	3.3	0.26	1.9
2016	25.1	41.1	9.0	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
Mature females						Mature males					
2002	11.0	17.0	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	17.0	24.7	9.4	0.21	3.6
2004	6.0	8.3	3.7	0.19	1.1	2004	12.6	20.2	5.1	0.29	3.6
2005	6.8	10.0	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	0.20	5.6
2008	16.5	31.0	2.0	0.41	6.8	2008	32.7	53.7	11.7	0.31	10.0
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	0.20	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	90.0	17.8	0.30	16.2
2017	18.2	28.0	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
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	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	2.0	3.1	0.9	0.26	0.5	2009	1.6	2.6	0.6	0.30	0.5
2010	4.0	10.3	-2.3	0.74	3.0	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	1.0	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	10.0	3.9	0.21	1.5

Table 3. Stratified mean catch–per-tow of horseshoe crabs in the **lower Delaware Bay** survey area in 2010-2018, with 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).

	mean	UCL	LCL	CV	sd		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	0.30	18.1
2011	19.7	45.2	-5.9	0.47	9.2	2011	20.2	50.7	-10.4	0.55	11.0
2012	164.3	311.8	16.9	0.32	53.1	2012	192.6	548.4	-163.3	0.43	82.7
2016	196.0	335.5	56.6	0.29	57.0	2016	184.2	322.9	45.5	0.32	58.7
2017	96.7	210.0	-16.7	0.46	44.1	2017	62.9	137.6	-11.7	0.46	29.0
2018	47.2	56.2	38.1	0.08	3.8	2018	55.1	71.8	38.4	0.12	6.8
Mature females						Mature males					
2010	48.8	98.9	-1.2	0.40	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	249.0	-28.6	0.45	50.0
2012	19.1	51.6	-13.4	0.40	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	0.08	13.3
2017	80.6	167.1	-5.8	0.39	31.1	2017	362.7	868.5	-143.2	0.50	182.2
2018	36.2	46.6	25.8	0.12	4.3	2018	94.3	117.9	70.7	0.11	10.0
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	2.0
2011	1.4	3.8	-0.9	0.58	0.8	2011	1.4	4.9	-2.2	0.94	1.3
2012	1.0	4.4	-2.3	0.76	0.8	2012	6.1	14.2	-2.0	0.48	2.9
2016	4.6	8.0	1.1	0.31	1.4	2016	16.2	29.0	3.5	0.30	5.0
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

Table 4. Stratified mean catch-per-tow of horseshoe crabs in the **lower Delaware Bay** survey area in 2010-2018, with 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).

	mean	UCL	LCL	CV	sd		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	0.60	12.9
2012	165.5	287.6	43.4	0.30	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	0.21	34.6
2017	90.8	176.0	5.6	0.37	33.2	2017	58.2	109.0	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
Mature females						Mature males					
2010	49.1	99.8	-1.7	0.40	19.7	2010	128.0	227.9	28.2	0.30	38.9
2011	28.6	49.9	7.4	0.27	7.7	2011	100.3	187.7	13.0	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	0.11	3.0	2016	161.8	192.4	131.1	0.08	13.3
2017	80.5	165.0	-4.0	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	0.11	10.8
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	1.0	4.4	-2.3	0.76	0.8	2012	6.1	14.1	-1.9	0.47	2.9
2016	4.5	8.0	1.1	0.30	1.3	2016	16.0	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	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

Table 5. Results of correlation analyses of mean prosomal width (mm) and survey year for newly mature and 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				
2002-2018				
Mature females	13	-10.00	<0.001	-0.949
Newly mature females	13	-5.89	<0.001	-0.872
Mature males	13	-12.36	<0.001	-0.966
Newly mature males	13	-4.03	0.002	-0.772
Lower Delaware Bay				
2010-2018				
Mature females	6	-5.21	0.006	-0.934
Newly mature females	6	-2.00	0.116	-0.707
Mature males	6	-5.34	0.006	-0.936
Newly mature males	6	4.12	0.015	0.900

Table 6. 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	19.7	23.5	15.0	287	300	273
2003	17.5	20.0	13.5	287	296	278
2004	16.9	20.5	14.5	292	302	277
2005	20.4	24.5	14.0	260	306	250
2006	17.1	22.3	13.0	288	314	246
2007	20.0	23.3	14.3	294	311	282
2008	20.1	22.6	19.3	279	288	273
2009	15.6	17.0	14.3	316	324	307
2010	19.4	24.1	12.3	284	331	265
2011	21.3	23.8	18.6	267	296	254
2016	22.7	24.8	18.6	275	299	260
2017	22.1	23.2	18.8	272	294	263
2018	22.8	24.8	13.9	275	315	253
Lower Delaware Bay						
2010	17.2	17.7	16.7	295	296	295
2011	18.3	18.6	18.0	294	295	294
2012	18.0	18.0	17.9	299	299	299
2016	19.6	20.1	19.0	288	289	288
2017	19.3	19.5	19.2	292	293	292
2018	12.2	12.8	11.3	321	322	321

Table 7. 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 12 years, and the lower Delaware Bay surveys included five years. Statistics presented include correlation coefficient, *r*; *T*-score; and probability, *p*. Data are from Tables 1, 3, and 5.

	Water temperature			Ordinal date		
	r	*T*	*p*	*r*	*T*	*p*
Delaware Bay area						
Immature females	-0.478	-1.81	0.098	0.755	3.82	0.003
Immature males	-0.481	-1.82	0.096	0.723	3.48	0.005
Mature females	0.624	2.65	0.023	-0.261	-0.90	0.389
Mature males	0.708	3.32	0.007	-0.371	-1.32	0.212
Newly mature females	0.295	1.02	0.327	0.039	0.13	0.900
Newly mature males	0.374	1.34	0.209	-0.023	-0.08	0.940
Lower Delaware Bay						
Immature females	0.486	1.11	0.328	-0.435	-0.97	0.388
Immature males	0.338	0.72	0.513	-0.269	-0.56	0.606
Mature females	0.153	0.31	0.772	-0.150	-0.30	0.777
Mature males	0.445	0.99	0.376	-0.398	-0.87	0.434
Newly mature females	0.032	0.06	0.952	-0.216	-0.44	0.682
Newly mature males	0.558	1.34	0.250	-0.514	-1.20	0.296

Table 7. Estimated population (in thousands) of horseshoe crabs in the coastal **Delaware Bay area** survey, 2002-2018, with 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).

	mean	UCL	LCL	CV	sd		mean	UCL	LCL	CV	sd
Immature females						Immature males					
2002	9,470	15,665	3,275	0.31	581	2002	5,483	9,284	1,683	0.33	357
2003	4,585	8,848	321	0.43	388	2003	2,303	4,217	390	0.39	174
2004	7,774	11,770	3,778	0.25	379	2004	6,810	10,895	2,725	0.29	387
2005	5,630	8,856	2,404	0.28	306	2005	5,260	8,839	1,681	0.33	337
2006	12,928	18,691	7,164	0.21	533	2006	9,327	14,554	4,100	0.24	442
2007	13,684	27,486	-118	0.41	1,100	2007	8,966	18,246	-314	0.42	740
2008	10,933	18,650	3,216	0.32	684	2008	7,841	13,917	1,766	0.35	532
2009	39,032	72,868	5,197	0.39	2,998	2009	29,864	47,269	12,460	0.28	1,654
2010	3,954	5,220	2,688	0.16	120	2010	2,686	4,144	1,229	0.26	139
2011	4,965	6,945	2,985	0.20	189	2011	3,092	4,547	1,637	0.23	139
2016	11,699	20,462	2,935	0.36	817	2016	9,102	16,649	1,555	0.39	701
2017	7,505	10,708	4,302	0.19	276	2017	5,091	8,465	1,717	0.27	269
2018	10,173	14,285	6,061	0.19	378	2018	7,507	11,173	3,842	0.23	333
Mature females						Mature males					
2002	4,959	8,084	1,834	0.30	289	2002	11,584	17,335	5,834	0.24	539
2003	3,379	5,160	1,599	0.25	167	2003	8,069	13,029	3,110	0.29	454
2004	2,735	4,043	1,426	0.23	122	2004	5,150	7,788	2,511	0.25	251
2005	3,138	4,942	1,333	0.27	164	2005	5,844	8,461	3,228	0.22	245
2006	6,611	14,330	-1108	0.42	542	2006	15,825	26,060	5,589	0.27	844
2007	7,746	12,704	2,789	0.31	462	2007	15,795	25,104	6,487	0.28	873
2008	6,311	10,202	2,419	0.29	360	2008	14,647	24,995	4,299	0.33	952
2009	2,975	4,971	979	0.32	186	2009	6,240	10,197	2,283	0.30	369
2010	5,178	7,616	2,740	0.23	228	2010	13,963	21,910	6,015	0.28	749
2011	5,290	7,282	3,297	0.18	182	2011	15,060	29,000	1,120	0.40	1,179
2016	6,024	8,635	3,413	0.21	245	2016	21,941	37,216	6,665	0.29	1,260
2017	7,185	10,525	3,844	0.23	319	2017	20,664	31,208	10,119	0.25	1,001
2018	7,326	10,520	4,131	0.21	298	2018	15,749	21,880	9,619	0.18	564
Newly mature females						Newly mature males					
2002	1,537	2,400	675	0.26	79	2002	548	869	227	0.28	30
2003	794	1,633	-45	0.49	76	2003	78	221	-65	0.84	13
2004	358	575	141	0.29	20	2004	789	1,127	451	0.21	32
2005	479	753	206	0.27	25	2005	597	1,002	191	0.33	39
2006	2,051	3,509	594	0.31	123	2006	3,113	5,113	1,113	0.31	188
2007	2,373	4,339	408	0.40	183	2007	3,129	4,972	1,287	0.28	171
2008	2,571	4,984	158	0.43	218	2008	757	1,254	261	0.31	46
2009	885	1,361	410	0.26	45	2009	725	1,240	210	0.34	48
2010	1,338	2,990	-314	0.59	153	2010	1,422	3,070	-226	0.55	153
2011	845	1,360	331	0.30	49	2011	749	1,335	164	0.36	53
2016	1,608	2,357	860	0.23	71	2016	2,608	4,884	331	0.42	212
2017	1,480	2,274	687	0.26	76	2017	1,523	2,392	654	0.28	83
2018	1,773	2,923	622	0.31	108	2018	3,341	5,367	1,316	0.29	186

Table 8. Estimated population (in thousands) of horseshoe crabs in the coastal **Delaware Bay area** survey, 2002-2018, with 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).

	mean	UCL	LCL	CV	sd		mean	UCL	LCL	CV	sd
Immature females						Immature males					
2002	8,222	11,875	4,568	0.21	344	2002	5,076	7,998	2,155	0.28	273
2003	4,089	6,860	1,317	0.32	255	2003	2,114	3,462	766	0.30	123
2004	7,376	10,616	4,135	0.21	305	2004	6,033	8,786	3,281	0.22	260
2005	5,104	7,521	2,687	0.23	227	2005	4,673	7,414	1,932	0.28	255
2006	13,714	20,988	6,439	0.25	672	2006	9,378	13,971	4,786	0.23	428
2007	13,692	27,335	48	0.41	1,088	2007	9,350	19,735	-1,035	0.45	828
2008	10,595	16,578	4,612	0.26	544	2008	6,897	10,443	3,350	0.23	314
2009	27,375	40,519	14,232	0.23	1,242	2009	26,435	38,730	14,140	0.23	1,162
2010	4,102	5,706	2,497	0.19	152	2010	2,781	4,423	1,139	0.29	156
2011	5,426	8,433	2,420	0.27	284	2011	3,301	5,219	1,382	0.28	182
2016	11,292	18,441	4,144	0.30	668	2016	8,185	13,512	2,858	0.31	498
2017	7,948	11,818	4,077	0.23	364	2017	5,082	7,829	2,335	0.26	257
2018	10,115	13,839	6,391	0.18	346	2018	7,768	11,653	3,882	0.24	358
Mature females						Mature males					
2002	4,779	7,431	2,128	0.26	243	2002	10,711	14,972	6,450	0.19	400
2003	3,308	4,851	1,764	0.22	144	2003	7,454	10,827	4,082	0.21	312
2004	2,767	3,919	1,615	0.20	109	2004	5,586	8,875	2,297	0.28	308
2005	2,957	4,323	1,592	0.22	124	2005	5,408	7,322	3,494	0.17	181
2006	5,867	10,517	1,218	0.31	353	2006	14,461	21,734	7,188	0.23	637
2007	6,553	9,864	3,243	0.25	313	2007	13,100	18,506	7,694	0.20	514
2008	7,172	13,336	1,008	0.40	561	2008	14,244	23,240	5,247	0.30	838
2009	3,230	5,523	936	0.33	211	2009	6,319	10,255	2,383	0.29	360
2010	5,588	8,698	2,478	0.26	289	2010	14,396	22,600	6,192	0.27	765
2011	5,388	7,629	3,147	0.20	205	2011	14,858	25,890	3,825	0.33	951
2016	5,735	7,770	3,700	0.17	193	2016	24,017	40,197	7,837	0.30	1,416
2017	7,785	12,033	3,537	0.27	403	2017	19,985	29,245	10,724	0.23	884
2018	9,463	18,463	464	0.44	818	2018	15,264	19,849	10,680	0.15	433
Newly mature females						Newly mature males					
2002	1,509	2,278	741	0.24	72	2002	561	925	196	0.31	33
2003	787	1,547	26	0.45	69	2003	78	222	-66	0.84	13
2004	367	613	120	0.32	23	2004	786	1,120	452	0.20	31
2005	531	908	154	0.34	36	2005	580	927	233	0.29	33
2006	2,122	3,705	540	0.33	139	2006	3,377	6,076	678	0.38	251
2007	2,129	3,584	674	0.33	135	2007	2,841	4,214	1,468	0.23	129
2008	2,697	4,780	613	0.36	192	2008	776	1,315	237	0.33	50
2009	883	1,366	399	0.26	45	2009	708	1,157	259	0.31	43
2010	1,770	4,532	-992	0.74	255	2010	1,464	3,180	-252	0.56	159
2011	882	1,495	269	0.34	58	2011	766	1,343	190	0.36	54
2016	1,583	2,304	863	0.22	68	2016	2,939	5,588	290	0.43	248
2017	1,502	2,323	680	0.27	79	2017	1,590	2,623	557	0.32	98
2018	1,780	2,866	695	0.29	101	2018	3,064	4,466	1,663	0.22	131

Table 9. Estimated population (in thousands) of horseshoe crabs in the **lower Delaware Bay** survey area in 2010-2018, with 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).

	mean	UCL	LCL	CV	sd		mean	UCL	LCL	CV	sd
Immature females						Immature males					
2010	3,510	5,199	1,822	0.20	1,306	2010	2,632	4,476	788	0.29	1,426
2011	870	1,931	-191	0.44	723	2011	881	2,160	-397	0.52	871
2012	8,021	15,084	958	0.32	4,814	2012	9,381	21,965	-3,204	0.42	7,484
2016	9,046	15,558	2,534	0.29	5,037	2016	8,429	14,813	2,044	0.32	5,110
2017	4,536	10,029	-956	0.47	4,044	2017	2,920	6,458	-618	0.47	2,605
2018	2,211	2,803	1,619	0.10	436	2018	2,597	3,516	1,678	0.15	735
Mature females						Mature males					
2010	2,117	4,260	-25	0.39	1,578	2010	5,657	10,247	1,067	0.32	3,379
2011	1,348	2,599	96	0.33	853	2011	4,829	10,570	-912	0.43	3,913
2012	938	2,522	-646	0.39	697	2012	3,263	6,864	-338	0.35	2,142
2016	1,274	1,710	837	0.15	358	2016	7,735	9,709	5,761	0.10	1,527
2017	3,674	7,501	-153	0.38	2,609	2017	16,794	40,517	-6,929	0.51	16,170
2018	1,771	2,588	953	0.18	602	2018	4,616	6,600	2,631	0.18	1,535
Newly mature females						Newly mature males					
2010	414	1,087	-260	0.63	496	2010	187	409	-35	0.46	163
2011	65	170	-40	0.58	72	2011	58	208	-93	0.94	103
2012	50	214	-114	0.76	72	2012	301	710	-109	0.49	279
2016	206	357	55	0.30	117	2016	727	1,268	186	0.29	398
2017	88	249	-73	0.66	110	2017	542	1,100	-16	0.40	411
2018	115	220	9	0.36	78	2018	148	290	7	0.40	113

Table 10 Estimated population (in thousands) of horseshoe crabs in the **lower Delaware Bay** survey area in 2010-2018, with 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).

	mean	UCL	LCL	CV	sd		mean	UCL	LCL	CV	sd
Immature females						Immature males					
2010	3,503	5,155	1,851	0.18	1,216	2010	2,588	4,056	1,120	0.24	1,175
2011	938	2,311	-435	0.53	936	2011	935	2,437	-567	0.58	1,024
2012	8,125	14,222	2,027	0.31	4,716	2012	9,023	17,690	356	0.35	5,907
2016	8,618	13,190	4,046	0.22	3,536	2016	7,725	11,638	3,812	0.21	3,027
2017	4,325	8,829	-178	0.41	3,316	2017	2,731	5,408	53	0.38	1,971
2018	2,209	2,780	1,638	0.10	420	2018	2,595	3,529	1,661	0.15	722
Mature females						Mature males					
2010	2,124	4,340	-91	0.41	1,631	2010	5,600	9,916	1,285	0.30	3,177
2011	1,290	2,239	340	0.27	647	2011	4,479	8,332	625	0.31	2,627
2012	915	2,242	-412	0.34	584	2012	3,188	5,456	921	0.28	1,669
2016	1,264	1,647	880	0.13	315	2016	7,727	9,570	5,883	0.10	1,475
2017	3,654	7,307	2	0.36	2,490	2017	13,805	23,702	3,908	0.26	6,746
2018	1,782	2,666	898	0.19	651	2018	4,647	6,901	2,393	0.19	1,659
Newly mature females						Newly mature males					
2010	418	1,097	-260	0.63	500	2010	185	391	-22	0.43	152
2011	65	170	-40	0.58	72	2011	58	208	-93	0.94	103
2012	50	214	-114	0.76	72	2012	302	719	-114	0.50	284
2016	205	355	55	0.28	110	2016	716	1,176	256	0.25	339
2017	88	249	-73	0.66	110	2017	541	1,090	-9	0.40	405
2018	114	226	3	0.35	76	2018	149	296	1	0.41	114