MEMORANDUM

TO: **Horseshoe Crab Management Board**

FROM: **Horseshoe Crab Adaptive Resource Management (ARM) Subcommittee and Delaware Bay Ecosystem Technical Committee**

DATE: **October 21, 2022**

SUBJECT: **Horseshoe Crab Harvest Recommendations Based on the ARM Framework**

Background

Addendum VII (2012) established the Adaptive Resource Management (ARM) Framework, which incorporates both red knot and horseshoe crab abundance levels to set harvest levels for horseshoe crabs of Delaware Bay-origin. As part of the routine stock assessment schedule and because the original software used for the Framework is now obsolete and no longer supported, the ARM Framework was revised in 2021. The purpose of revising the ARM Framework was to address previous peer review critiques, include newly available data, and adopt advances in modeling software and optimization approaches. The ARM Revision (2021) was peer reviewed and accepted for management use by the Horseshoe Crab Management Board (Board). The Board initiated Draft Addendum VIII to consider formalizing the use of the ARM Revision for setting harvest specifications for horseshoe crabs of Delaware Bay-origin, and a public comment period occurred in August and September 2022. The Board will consider final action on Draft Addendum VIII at the November 2022 Board meeting.

Under the annual process of the ARM Framework, the ARM Subcommittee recommends harvest specifications for the upcoming year based on the ARM Framework results. The Delaware Bay Ecosystem Technical Committee (DBETC) then reviews the ARM results and recent horseshoe crab and red knot monitoring data to provide a recommendation for harvest specifications to the Board. This year, because the Draft Addendum VIII has not been finalized, the ARM considered harvest specifications generated using the original ARM Framework as well as the 2021 ARM Framework Revision. Two enclosed documents provide the details of the ARM Results and the discussions and recommendations of the ARM Subcommittee and DBETC:

1) 2023 Horseshoe Crab Harvest Recommendations Based on Adaptive Resource Management (ARM) Framework and Recent Monitoring Data: Report to the Delaware Bay Ecosystem Technical Committee by the ARM Subcommittee, October 2022
2) ARM Subcommittee and DBETC Meeting Summary from October 12, 2022

The key recommendations from the committees are highlighted below.

Committee Recommendations

The consensus recommendation from the DBETC and ARM Subcommittee members is to use the harvest recommendation from the 2021 ARM Revision. Because Draft Addendum VIII contains two options for rounding the harvest output from the ARM to protect confidential data, two possible harvest limits were generated using the revised ARM:

1) 475,000 male and 125,000 female horseshoe crabs; or
2) 450,000 male and 100,000 female horseshoe crabs

Consistent with the proposed allocation methodology in Draft Addendum VIII, the resulting state allocations of the Delaware Bay origin quota and total state quotas would be one of the two options presented in the table below, depending on the rounding option selected by the Board when final action is taken on Draft Addendum VIII. One committee member felt the quota caps for MD and VA that were established in Addendum VII should be removed.

Additionally, both committees recommend that the Board consider implementing the provision from Addendum VI that was omitted from Addendum VII that prohibits harvest and landings of all horseshoe crabs in New Jersey, Delaware, and Maryland from January 1 through June 7, and also prohibits the landing of horseshoe crabs in Virginia from federal waters from January 1 through June 7. This requirement would offer protection to spawning horseshoe crabs and reduce disturbance to migrating shorebirds foraging on the beaches.

Table 1. Delaware Bay-origin and total horseshoe crab quota for 2023 by state and rounding convention options included in Draft Addendum VIII. Virginia total quota only refers to the amount that can be harvested east of the COLREGS line.

State	Using sub-option B1 to round down to the nearest 25,000			
	Delaware Bay Origin Quota		Total Quota	
	Male	Female	Male	Female
Delaware	164,364	43,254	164,364	43,254
New Jersey	164,364	43,254	164,364	43,254
Maryland	126,220	33,215	135,100	35,553
Virginia	20,052	5,277	40,667	20,331
TOTAL	475,000	125,000	504,495	142,390

State	Using sub-option B2 to round down to the nearest 50,000			
	Delaware Bay Origin Quota		Total Quota	
	Male	Female	Male	Female
Delaware	155,713	34,603	155,713	34,603
New Jersey	155,713	34,603	155,713	34,603
Maryland	119,578	26,573	139,625	31,028
Virginia	18,996	4,221	40,667	20,331
TOTAL	450,000	100,000	491,718	120,564

Atlantic States Marine Fisheries Commission

Horseshoe Crab Adaptive Resource Management Subcommittee & Delaware Bay Ecosystem Technical Committee Conference Call

Call Summary

Wednesday, October 11, 2022
9:00 AM - 11:00 AM

Attendance:
Horseshoe Crab Adaptive Resource Management Subcommittee: John Sweka (Chair), Jim Lyons (Vice Chair), Henrietta Bellman, Linda Barry, Steve Doctor, Wendy Walsh, Margaret Conroy, Bryan Nuse
Delaware Bay Ecosystem Technical Committee: Wendy Walsh (Chair), Henrietta Bellman (Vice Chair), Adam Kenyon, Eric Hallerman, Yan Jiao, Jordy Zimmerman, Steve Doctor, Samantha MacQuesten
Horseshoe Crab Technical Committee Members*: Adam Kenyon, Catherine Fede, Claire Crowley, Jeffrey Dobbs, Jordy Zimmerman, Samantha MacQuesten, Steve Doctor, Chris Wright
ASMFC Staff: Caitlin Starks, Kristen Anstead, Toni Kerns
Additional Attendees: John Clark, Brett Hoffmeister, Bill Hyatt, Shanna Madsen, Jesse Hornstein, Clint Moore, Daniel Sasson, Kristoffer Whitney, Chad Wong, Sheila Eyler, Robert LaFrance

The Adaptive Resource Management (ARM) Subcommittee and the Delaware Bay Ecosystem Technical Committee (DBETC) met via webinar to review the most recent population estimates for horseshoe crabs and red knots, the harvest recommendations from the ARM for the 2023 fishing year, and supporting horseshoe crab and red knot data sets. Below are the agenda items and summary of the committee's discussion and decisions.

1. **Survey Results for 2021 Horseshoe Crab (Eric Hallerman)**

Eric Hallerman presented the Virginia Tech (VT) Trawl Survey results for 2021. Yan Jiao and Chad Wong provided analytical support for the report given to the ARM and DBETC. The lower Delaware Bay survey ended earlier than in most years due to a net being obstructed and destroyed. The average bottom temperature was the highest seen in the time series. Mean stratified catches-per-tow were at their highest point in the time-series for mature males, mature females, and newly mature males. Mean catch-per-tow of immature male and female horseshoe crabs in the coastal Delaware Bay area have remained variable since 2002 and have no apparent trend. Mean catch-per-tow of newly mature male horseshoe crabs in the coastal Delaware Bay area remained highly variable, with newly mature males showing a minor positive trend over the study period. Newly mature females have remained relatively low since 2019 and no newly mature females were observed in 2021. Mean catch-per-tow of mature male and

female horseshoe crabs in the coastal Delaware Bay area continue to be highly variable, with their highest points in 2021, showing a positive trend over the time-series. Correlation analyses showed that mean catch-per-tow of all demographic groups may be correlated with ordinal date, and mean catch-per-tow of immature and mature individuals may be correlated with temperature.

The committees discussed the finding of zero newly females being caught in the study areas. Hypotheses posed for the low numbers of newly mature crabs include a spatial distribution difference in recent years that has affected the trawl survey's ability to capture crabs at this state, a recruitment failure a decade ago, or misclassification of stage by the survey crew, which has changed in recent years. The ARM Subcommittee will need to discuss how this estimate will impact the ARM model when the VT Tech trawl data are used next year since the catch survey model relies on estimates of newly mature crabs to predict abundance in the following year.

The 2022 sampling season is currently underway, but has been slowed down due to hurricane activity. Eric noted that, anecdotally, numbers of crabs appear to be down, but they are seeing crabs in places where they are not usually seen. They are also seeing immature crabs getting soft and ready to molt although temperatures have not declined much.

2. Survey Results for 2022 Red Knots (Jim Lyons)

Jim Lyons presented the red knot stopover population estimate. The population estimate for red knots is 39,800 birds for 2022 (95% credible interval: 35,013 – 55,355). This estimation is a decrease from 2021, and was below 40,000 birds for the first time since 2011. The confidence intervals around the population estimates for 2020-2022 are wider than in previous years, which can be attributed to decreased survey effort due to COVID-19 restrictions. The 2022 red knot mark-resight data set included a total of 1,546 individual birds that were recorded at least once during mark-resight surveys at Delaware Bay in 2022, a similar number to the previous two years. This year few birds arrived before May 13th; about 20% arrived near May 15th and the proportion arriving peaked at 25% around May 27th. The stopover population increased steadily from the beginning of the season and peaked around May 18–21. The persistence pattern was fairly typical, with a peak early in the sampling season, and then declining toward the end of the season. The resight probability was low at the beginning of sampling but increased to around 50% at the end of the season.

It was noted by the ARM subcommittee that a decline in the accompanying aerial counts for 2022 may have been affected by an air show at the Air Force Base in Delaware on May 24th. Henrietta Bellman reported that Delaware resighting survey effort was comparable to pre-COVID levels.

3. Review of Supplementary Surveys for Horseshoe Crabs and Red Knots

a. NJ Ocean Trawl Survey (Lindy Barry)

Lindy Barry reminded the groups that the NJ Ocean Trawl did not run in 2020 or 2021 due to COVID restrictions. Since 2010, there has been an increasing trend through the terminal year of 2019.

In 2022, the survey was reinitiated starting in April. For the months used in the ARM model, preliminary numbers from the April are the highest in time series and the August numbers also seem relatively high. Lindy noted that due to budget issues fewer samples will be taken in the survey. For the 60ft and 90ft depth strata, there will be one less tow per cruise, resulting in a total of 60 instead of 78 samples. There is not a concern that this will significantly impact the quality of the data.

Wendy Walsh asked how the missing years of data from the NJ Ocean Trawl affect the results of the catch multiple survey analysis (CMSA). Kristen said that the CMSA can handle missing years of data because there are three surveys of relative abundance included in the model now.

b. DE Bay 30 ft. Trawl Survey and Spawning Survey (Jordy Zimmerman)

Jordy Zimmerman reviewed the DE Bay 30ft and 16ft Trawl Survey methods and sampling routine for horseshoe crabs. For the 30ft trawl, the 2021 catch per unit effort is above time series mean for April-July and all months. In the 16ft trawl the adult catch in 2021 is below the time series mean. Juvenile and young-of-year crab catch is also decreased in 2021, and have been below the time series mean since 2017. Staging of crabs caught in the surveys has occurred since 2017. The survey routinely catches more multiparous crabs than primiparous crabs, as expected, although most primiparous crabs caught were female and most multiparous crabs were male.

The spawning survey is used by the ARM for providing a sex ratio of males to females on the spawning beaches. Jordy noted that 36 sampling occasions (14%) were missed for 2021, which is a relatively low proportion for the time series. However, of the 36 samples missed, 22 occurred in the second lunar period in May, which is usually a time of high horseshoe crab abundance.

The index of female spawning availability for DE and NJ shows a slight but insignificant positive slope, with the 2021 values near the time series means. The 2021 index of male spawning availability for DE and NJ are above the time series mean, and show a significant increasing trend for both states. The Baywide female index shows no trend, while the Baywide male index shows an increasing trend. Peak spawning in 2021 occurred May 9 – 13 for DE (the first time the peak occurred in the 1st lunar period), and May 24 – 28 (2nd lunar period) for NJ.

c. Shorebird survey

Henrietta Bellman gave a summary of red knot sampling in Delaware. Henrietta said in Delaware it was a more typical year in terms of effort than the previous years which were impacted by COVID-19 restrictions. Team size and catch effort were similar to before COVID impacts. However, she noted that the capture success rate was low, amounting to about half of

the 2019 numbers of captures. The number of ratio scans were comparable to 2019, but the number of resights and unique flags were about half of the 2019 values. She also noted that this year they had a difficult time finding red knots outside the Mispillion site.

The committees discussed that ASMFC staff and committee chairs should work with Henrietta and Wendy to strategize on what red knot survey information should be presented to the ARM Subcommittee and DBETC on an annual basis. Staff will follow up to determine what summary information from the shorebird surveys would be most beneficial for the committees to consider when discussing ARM harvest recommendations.

4. Review Results of ARM Model

The sections below summarize the committees' discussion on the ARM results. Details on the methods applied and the results themselves are provided in the memo to the Board from the ARM Subcommittee and DBETC dated October 20, 2022.

a. Results from original ARM Framework

John Sweka reviewed the ARM model structure and annual process for the committees. Conor McGowan used the horseshoe crab population estimates from the Virginia Tech Trawl report and red knot population estimates in the optimization matrix of the original ARM model and determined the resulting harvest recommendation. Using the old ARM Framework, the recommended harvest package for the 2023 fishing year is package 5, or 420,000 male and 210,000 female horseshoe crabs. John noted that this is the first time since the ARM Framework was implemented that female horseshoe crab population estimates have exceeded their 11.2 million population utility threshold and that a harvest package other than package 3 has been recommended. Red knots remain below the population utility threshold established in the original ARM (81,900 birds).

b. Results from 2021 ARM Framework Revision

Kristen Anstead reviewed the annual process, results, and harvest recommendations for 2023 using the revised ARM Framework. The Virginia Tech Trawl Survey estimates are used in the CMSA along with the NJ Ocean Trawl and the DE Fish and Wildlife Adult Trawl (30') Surveys. All quantifiable sources of mortality (i.e., bait harvest, biomedical mortality, and commercial dead discards) were used in the CMSA to estimate male and female horseshoe crab population sizes. Public population estimates for horseshoe crabs were made using the coastwide biomedical data or no biomedical data, which provide upper and lower bounds. The exact harvest recommendation is based on the results using confidential biomedical data from the Delaware Bay region and cannot be publicly shared. The exact recommended male and female harvest levels are rounded down to protect confidential data.

In the Delaware Bay region in 2021, there were approximately 15.9-16.0 million mature male and 6.0-6.1 million mature female horseshoe crabs (the range represents the difference between using coastwide and no biomedical data). The 2021 red knot population estimate was

42,271. Harvest recommendations for the 2023 fishing year made using the ARM Revision are based on CMSA estimates of horseshoe crab abundance and the red knot mark-resight abundance estimate in 2021. The maximum possible harvest for both females and males are maintained from the previous ARM Framework at 210,000 and 500,000, respectively.

Two options were given in draft Addendum VIII which were to round down the optimal harvest to the nearest 25,000 or 50,000 crabs to uphold data confidentiality. Two harvest recommendations, one using each rounding option, have been provided below based on an optimal harvest level given horseshoe crab abundance and red knot abundance in 2021. If the Board chooses to use the 2021 ARM Revision to set Delaware Bay bait harvest specifications as proposed in Draft Addendum VIII, it may select one of the options provided below.

Using sub-option B1 to round down to the nearest 25,000	
Male harvest	Female harvest
475,000	125,000

Using sub-option B2 to round down to the nearest 50,000	
Male harvest	Female harvest
450,000	100,000

5. Board Recommendation

The ARM Subcommittee and DBETC recommend using the revised ARM to set the Delaware Bay bait harvest specifications for 2023. This would result in one of the two sets of harvest levels presented above, depending on the options selected by the Board when they consider approval of Draft Addendum VIII.

The allocation methodology that would be used to distribute the Delaware Bay-origin quota amongst the states of New Jersey, Delaware, Maryland, and Virginia is specified in Addendum VII, and maintained in Draft Addendum VIII. However, the committees discussed an issue regarding Maryland's total allocation, which includes non-Delaware Bay-origin crabs. Specifically, in order for Maryland to not exceed its Delaware Bay allocation of males and females, the state's total harvest quotas must maintain the same sex ratio as the ARM recommendation. This has not previously been discussed by the ARM Subcommittee and DBETC because until this year the ARM has recommended zero female harvest, restricting Maryland's total quota to male-only harvest. The state allocations recommended by the committees for 2023 are consistent with the proposed methodology in Addendum VIII and ensure the Delaware Bay-origin quota would not be exceeded (see Table 1 of the memo to the Board from the ARM Subcommittee and DBETC dated October 20, 2022.

One committee member felt the quota caps for MD and VA that were established in Addendum VII should be removed. They argued that the caps do not reflect the present abundance of horseshoe crabs, nor do they allow for the proper allocation of total quota among the four states.

The committees also recommended that for the Delaware Bay states, horseshoe crab harvest should not be allowed before June 7. Addendum III established a closed season for bait harvest of horseshoe crabs in and around the Delaware during peak horseshoe crab spawning that prohibited harvest and landings of horseshoe crabs in New Jersey, Delaware and Maryland from May 1 through June 7, inclusive. Addendum IV carried forward this requirement and also prohibited the landing of horseshoe crabs in Virginia from federal waters from January 1 through June 7. June 7 was chosen as the end of the closure as this is the date when most of the migrating shorebirds have left the Delaware bay region. However, Addendum VII did not include the seasonal closure for the Delaware Bay region. Re-establishment of this requirement would offer protection to spawning horseshoe crabs as well as reduce disturbance to migrating shorebirds foraging on the beaches. This requirement would be especially important if female harvest is going to be allowed. Current state regulations do prohibit harvest of Delaware Bay-origin horseshoe crab from January 1 through June 7.

6. Other Business

There was no additional discussion beyond the agenda items. No public comments were provided.

2023 Horseshoe Crab Harvest Recommendations Based on Adaptive Resource Management (ARM) Framework and Recent Monitoring Data

Report to the Delaware Bay Ecosystem Technical Committee
(DBETC) by the ARM Subcommittee

October 2022

This report describes the 2023 harvest recommendation for Delaware Bay horseshoe crabs using two methods: the Adaptive Resource Management (ARM) Framework adopted in 2013 (Section 1) and the Revised ARM Framework from 2021 (Section 2). The DBETC and ARM subcommittee met via conference call on October 12th to review the results and make recommendations to the Board (Section 3).

Established through Addendum VII (2012), the ARM Framework incorporates both shorebird and horseshoe crab abundance levels to set optimized harvest levels for horseshoe crabs of Delaware Bay-origin. The ARM Framework used a program called Adaptive Stochastic Dynamic Programming (ASDP) which produces a large look-up table that included the recommended harvest for all possible states of the horseshoe crabs and red knots populations and the recommended, or optimal, harvest for each combination of population estimates. The look-up table was created in 2012 and refreshed in 2016. In the interim years, the table provided the annual harvest recommendations.

As part of the routine stock assessment schedule and because the ASDP program is now obsolete and unmaintained, the ARM Framework was revised in 2021. The purpose of revising the ARM Framework was to address previous peer review critiques, include newly available data, and adopt advances in modeling software and optimization approaches. The ARM Revision (2021) was peer reviewed and accepted for management use by the Horseshoe Crab Management Board (Board), but Draft Addendum VIII, the management document that formalizes its implementation, has not been approved by the Board. The Board will consider final action on Draft Addendum VIII at the November 2022 Board meeting.

1. Harvest Recommendation Based on 2013 ARM Framework

This section summarizes the 2023 harvest recommendations using the ARM Framework adopted in 2013. Detailed background on the ARM Framework and data sources can be found in previous technical reports (ASMFC 2009; McGowan et al. 2009; ASMFC 2012).

1.1. 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.

1.2. Population Models

Underlying the original ARM model are population models for both red knots and horseshoe crabs. The ARM model uses an optimization routine which is a procedure for finding the best solution given the current state of the Delaware Bay system. Population dynamics models that link horseshoe crabs and red knots were used to predict the effect of harvest packages. In the ARM Framework, the model determines the best choice among five potential harvest packages (numbers of male and females that can be harvested) given the current abundance of red knots and horseshoe crabs. ASDP was used to create a decision matrix to identify the optimal harvest package given the most recent monitoring data.

1.3. Monitoring data

Red knot abundance estimates are taken from a mark-resight estimate (Figure 1). The spring estimate from 2022 was 39,800 red knots. These data and methods can be evaluated in Lyons 2022.

Sources of data for horseshoe crab abundance were a set of trawl surveys conducted by Virginia Tech university (Wong et al. 2022). For the ARM Framework, newly mature and mature horseshoe crabs from the Delaware Bay swept area population estimates calculated using the delta distribution model are added together (Table 1). Next, the total mature population estimates (newly mature plus mature) are decremented by half a year of natural mortality (M=0.274) to account for time between when the survey operates in the fall and the population lays eggs on the beach in the following spring. Therefore, 13.5 million females and 39.1 million males were used as an input to the Framework.
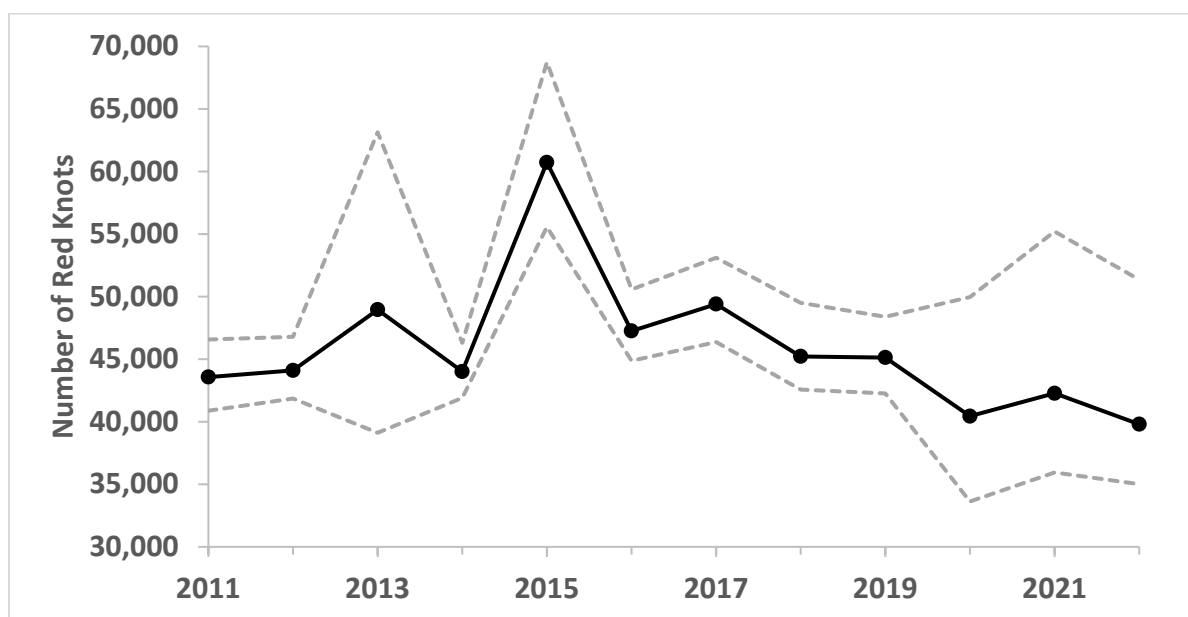

Figure 1. Mark-resight abundance estimates for the red knot stopover population with 95% confidence intervals, 2011-2022.

Table 1.   Horseshoe crab population estimates by sex and stage from the Virginia Tech Trawl Survey used in the ARM Framework.

Year	Females (in millions)			Males (in millions)		
	Newly Mature	Mature	Total	Newly Mature	Mature	Total
2002	1.5	5.0	6.5	0.5	11.6	12.1
2003	0.8	3.4	4.2	0.1	8.1	8.1
2004	0.4	2.7	3.1	0.8	5.2	5.9
2005	0.5	3.1	3.6	0.6	5.8	6.4
2006	2.1	6.6	8.7	3.1	15.8	18.9
2007	2.4	7.7	10.1	3.1	15.8	18.9
2008	2.6	6.3	8.9	0.8	14.6	15.4
2009	0.9	3.0	3.9	0.7	6.2	7.0
2010	1.3	5.2	6.5	1.4	14.0	15.4
2011	0.8	5.3	6.1	0.7	15.1	15.8
2012[1]	-	-		-	-	
2013	-	-		-	-	
2014	-	-		-	-	
2015	-	-		-	-	
2016	1.6	6.0	7.6	2.6	21.9	24.5
2017	1.5	7.2	8.7	1.5	20.7	22.2
2018	1.8	7.3	9.1	3.3	15.7	19.1
2019	0.2	5.1	5.4	1.3	8.9	10.2
2020	0.1	10.8	10.9	2.5	31.5	34.0
2021	0.0	15.5	15.5	6.3	38.5	44.9

[1] The Virginia Tech Trawl Survey was not conducted in 2012-2015.

1.4.   Harvest packages

The five harvest packages were compared to determine which will best meet the objective statement given the most recent monitoring data (Table 2). Harvest is of adult horseshoe crabs of Delaware Bay-origin.

Table 2.   The five possible harvest packages in the ARM Framework (2012).

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

## 1.5.	Harvest recommendation

The decision matrix was optimized incorporating recommendations on red knot stopover population estimates and associated calibration of a red knot utility threshold (81,900 red knots) as well as the horseshoe crab population estimates and a female horseshoe crab population utility threshold (11.2 million). The accepted procedure used in all past years was followed.

The recommended harvest package for the 2023 fishing year is package 5, or 420,000 male and 210,000 female horseshoe crabs. This is the first time since the ARM Framework was implemented that female horseshoe crab population estimates have exceeded their 11.2 million threshold and that a harvest package other than 3 has been recommended.

## 1.6.	Quota Allocation

Allocation of allowable harvest under ARM package 5 (420,000 males, 210,000 females) was conducted in accordance with management board approved methodology in Addendum VII (Table 3).

Table 3.	Delaware Bay-origin and total horseshoe crab quota for 2023 by state. Virginia total quota in the table only refers to the amount that can be harvested east of the COLREGS line. Virginia's overall state quota is 152,495 crabs, but only 40% of that may be harvested east of the COLREGS line.

	Delaware Bay Origin Quota		Total Quota		
State	Male	Female	Male	Female	Sexes Combined
Delaware	136,195	68,097	136,195	68,097	204,292
New Jersey	136,195	68,097	136,195	68,097	204,292
Maryland	118,533	59,268	113,769	56,884	170,654
Virginia	29,077	14,538	40,665	20,333	60,998
Total	420,000	210,000	398,382	241,854	640,236

2. Harvest Recommendation Based on 2021 ARM Revision

This section summarizes annual harvest recommendations using the ARM Framework Revision developed in 2021. Detailed background on the ARM Framework and data sources can be found in the ARM Revision report (ASMFC 2022).

2.1.   Objective Statement

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

2.2.   Population estimates

In the ARM Revision, all quantifiable sources of mortality (i.e., bait harvest, coastwide biomedical mortality, and commercial dead discards; Figure 2 - Figure 3) were used in the catch multiple survey analysis (CMSA) to estimate male and female horseshoe crab population estimates for 2003-2021 (Figure 4). Population estimates for horseshoe crabs were made using the coastwide biomedical data or no biomedical data which provide upper and lower bounds for the public. The harvest recommendation will be based on the results using confidential biomedical data from the region. The Virginia Tech Trawl Survey estimates are used in the CMSA along with the New Jersey Ocean Trawl and the Delaware Fish and Wildlife Adult Trawl Surveys (ASMFC 2022; Wong et al. 2022).

The 2021 CMSA population estimates for mature females is lower than those from the Virginia Tech Trawl Survey due to a few reasons. For one, the two estimates use different methods. Total abundance is estimated by extrapolating the mean catch-per-tow to the Delaware Bay sampling area for the Virginia Tech trawl versus a population model with the CMSA. Because the VA Tech Trawl Survey is conducted in the fall, the CMSA lags the Virginia Tech Trawl Survey forward to match the timing of the other two trawl surveys and most recent harvest data (i.e., the 2020 Virginia Tech trawl values are used in the model to estimate abundance in 2021; Figure 5). Thirdly, the CMSA population estimates are influenced by the staged abundance data from the Virginia Tech Trawl Survey, and the abundance of newly mature females was very low in 2019-2021 (Table 1). The CMSA is a simple, stage-based model that essentially sums the newly mature and mature crabs, subtracts harvest and accounts for natural mortality, and predicts the next year's population. Since the newly mature female estimates have been low, the model estimated lower population estimates than those of the Virginia Tech Trawl Survey in 2021.

Red knot abundance estimates used to make harvest recommendations under the ARM Revision are the same as those used in the original ARM Framework and based on mark-resight total stopover population estimates (Figure 1; Lyons 2022).

In summary, in the Delaware Bay region in 2021, there were approximately 15.9-16.0 million mature male and 6.0-6.1 million mature female horseshoe crabs (the range represents the difference between using coastwide and no biomedical data). The 2021 red knot population estimate was 42,271.
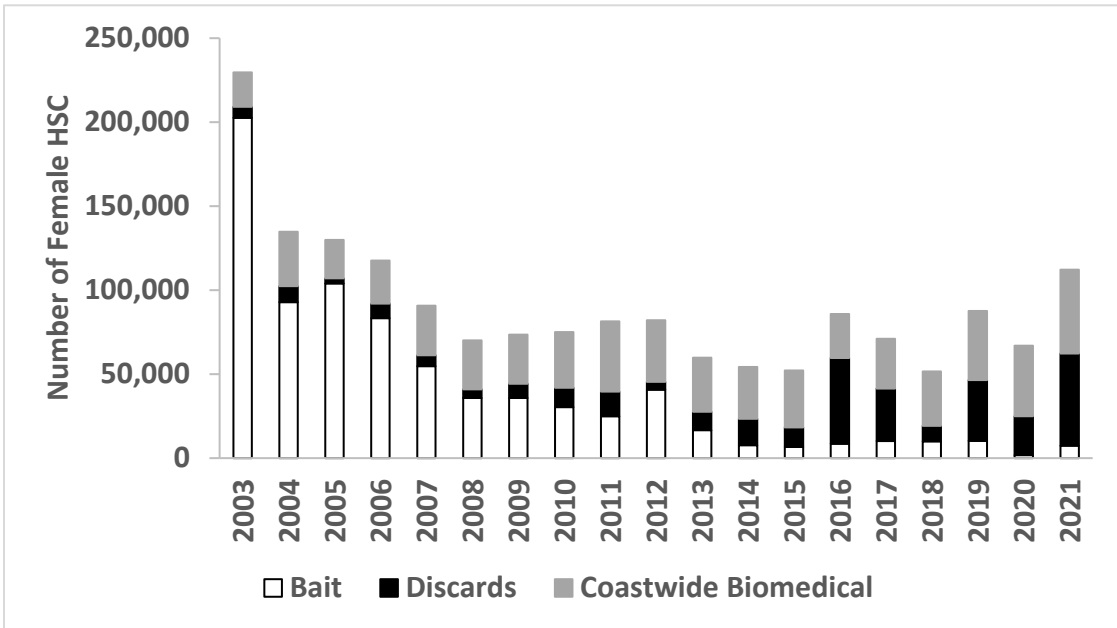

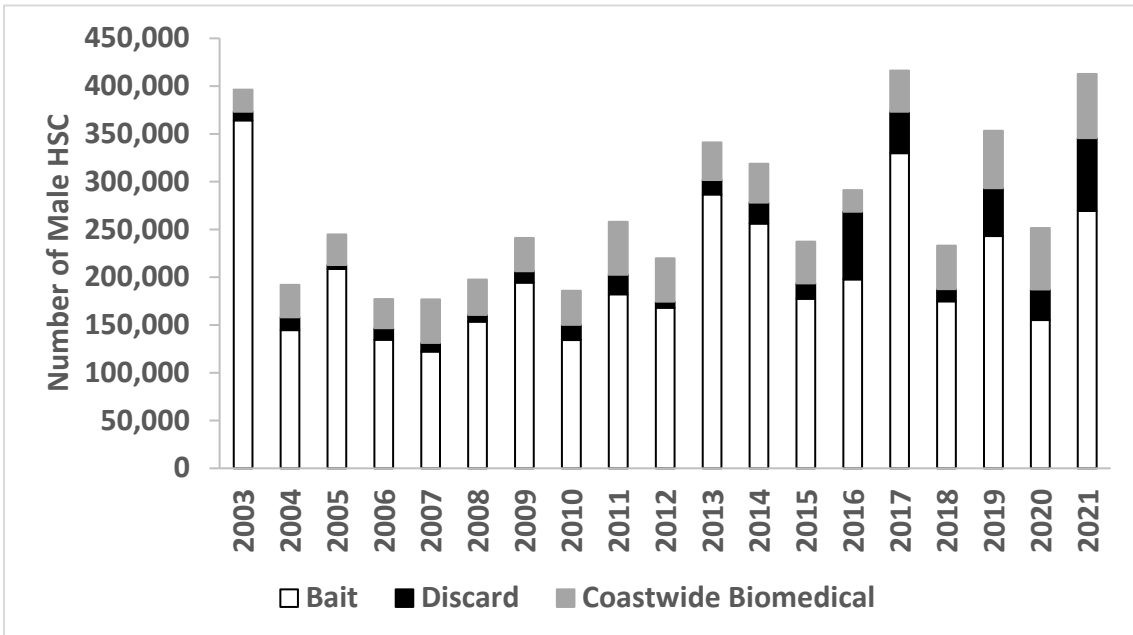Figure 2.   Total female horseshoe crab harvest by source in the Delaware Bay, 2003-2021.

Figure 3.   Total male horseshoe crab harvest by source in the Delaware Bay, 2003-2021.
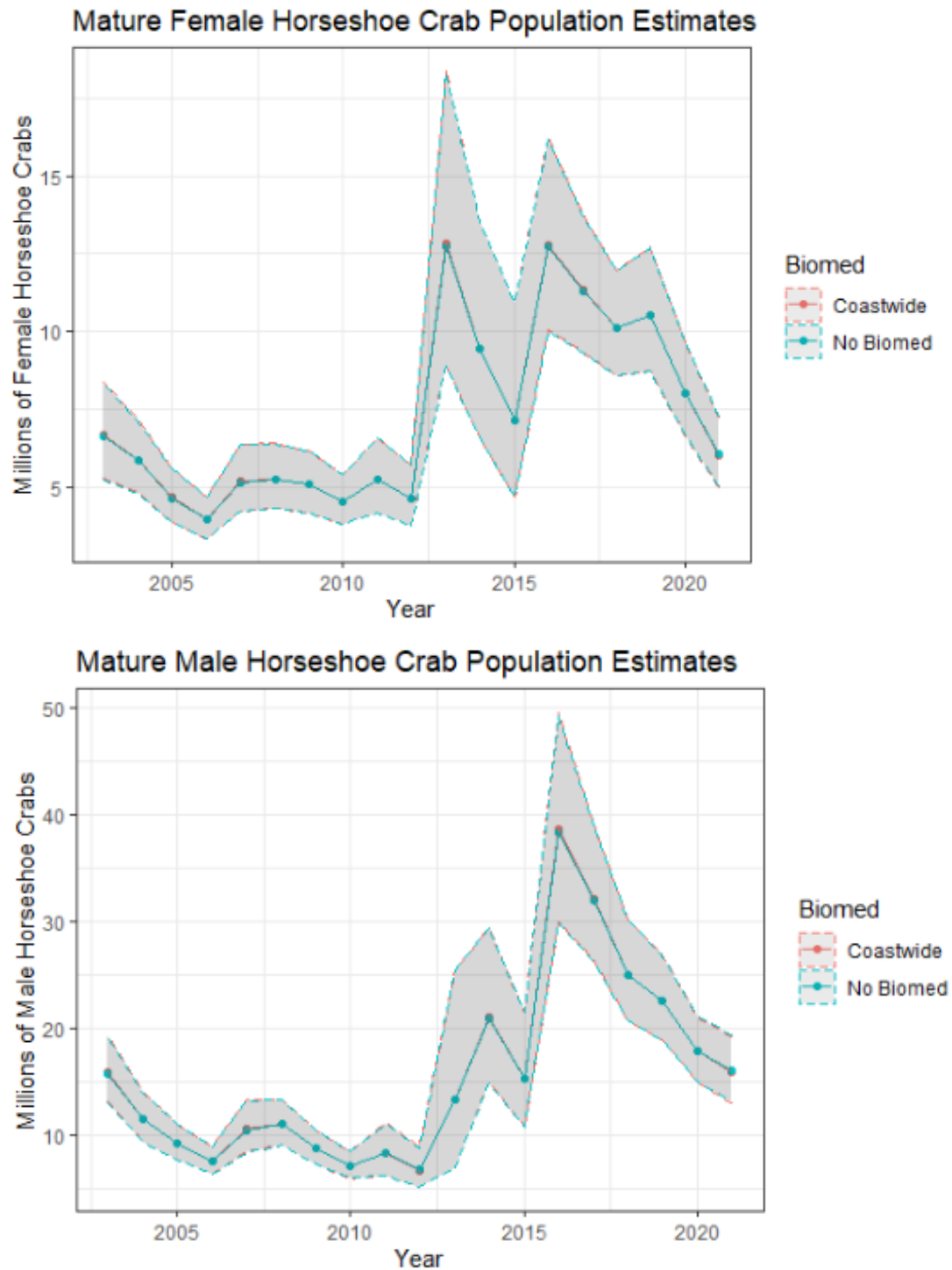
Figure 4. Population estimates from the CMSA for mature female (top) and male (bottom) horseshoe crabs with 95% confidence intervals. Delaware Bay biomedical data is confidential so population estimates using coastwide and zero biomedical data provide upper and lower bounds, although there is very little difference between the two and the time series overlap on the figures.
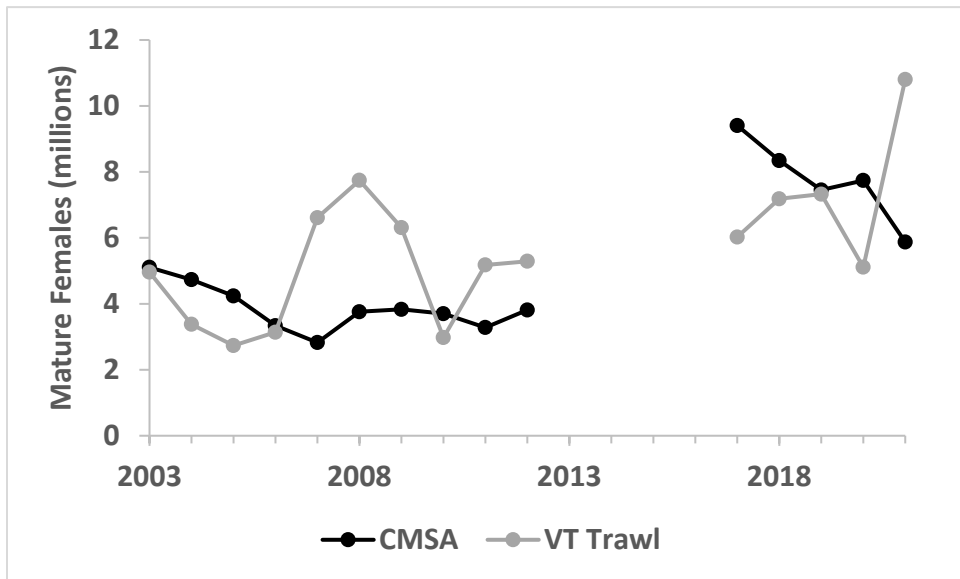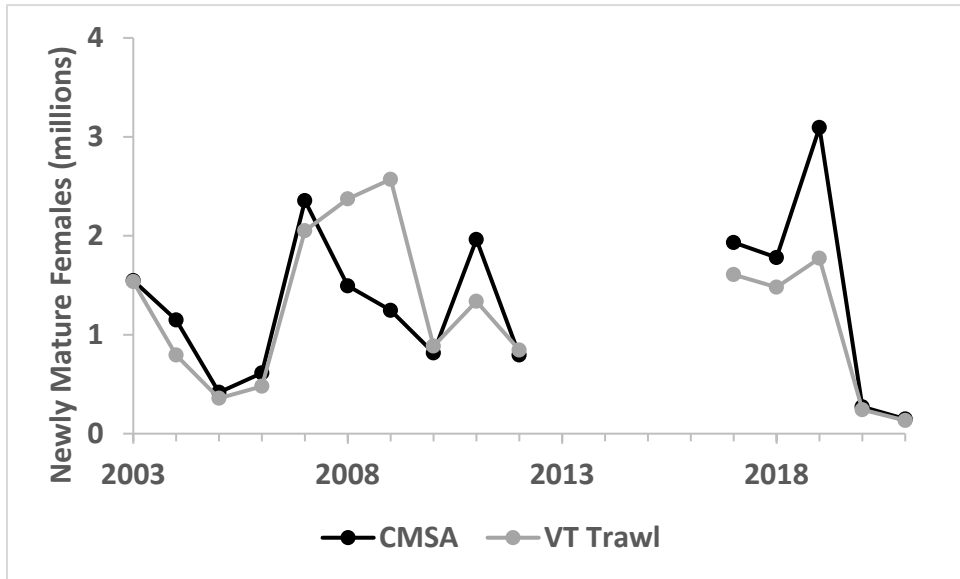
Figure 5. Comparison of newly mature and mature female horseshoe crab estimates between the catch multiple survey analysis (CMSA) using coastwide biomedical data and Virginia Tech Trawl Survey (VT Trawl) 2003-2021. VT Trawl data is lagged forward one year from the values reported in Table 1.

2.3.   Harvest Recommendation

Harvest recommendations for the 2023 fishing year made using the ARM Revision are based on CMSA estimates of horseshoe crab abundance and the red knot mark-resight abundance estimate in 2021. This is because the complete data series needed to run the CMSA in 2022 is not yet available since bait and biomedical removals are not finalized for 2022 when the model is run in the fall. The time lag between when CMSA estimates of crab abundance are available (e.g., a terminal year of 2021), the annual harvest decision is made (e.g., at the Board meeting in November 2022), and when harvest recommendations are actually implemented (e.g., the 2023 fishing year) was incorporated into the ARM Revision optimization.

ARM Revision harvest recommendations are based on a continuous scale rather than the discrete harvest packages in the previous Framework. Therefore, a harvest number up to the maximum allowable harvest could be recommended, not just the fixed harvest packages (Table 2). Harvest of females is decoupled from the harvest of males so that each are determined separately. The maximum possible harvest for both females and males are maintained from the previous ARM Framework at 210,000 and 500,000, respectively.

The annual decision of allowable Delaware Bay horseshoe crab harvest is based on current state of the system (abundances of both species in the previous calendar year) and the optimal harvest policy functions from the ARM Revision. Annual estimates of horseshoe crab and red knot abundances are used as input to the harvest policy functions, which then output the optimal horseshoe crab harvest to be implemented.

Two options were given in draft Addendum VIII which were to round down the optimal harvest to the nearest 25,000 or 50,000 crabs to uphold data confidentiality. Two harvest recommendations, one using each rounding option, have been provided here based on an optimal harvest level given horseshoe crab abundance and red knot abundance in 2021 (Table 4). The horseshoe crab abundance in 2021 was determined by using the confidential Delaware Bay biomedical data in the CMSA. If the Board chooses to use the 2021 ARM Revision to set Delaware Bay bait harvest specifications as proposed in Draft Addendum VIII, it may select one of the options provided below.

Table 4.   Harvest recommendations from the 2021 ARM Revision depending on the rounding convention options given in Draft Addendum VIII.

Using sub-option B1 to round down to the nearest 25,000	
Male harvest	**Female harvest**
475,000	125,000

Using sub-option B2 to round down to the nearest 50,000	
Male harvest	**Female harvest**
450,000	100,000

2.4. Quota Allocation

Quota of horseshoe crab harvest for Delaware Bay region states. Allocation of allowable harvest was conducted in accordance with the methodology proposed in Draft Addendum VIII (Table 5).

Table 5. Delaware Bay-origin and total horseshoe crab quota for 2023 by state and rounding convention options included in Draft Addendum VIII. Virginia total quota only refers to the amount that can be harvested east of the COLREGS line.

Using sub-option B1 to round down to the nearest 25,000				
State	Delaware Bay Origin Quota		Total Quota	
	Male	Female	Male	Female
Delaware	164,364	43,254	164,364	43,254
New Jersey	164,364	43,254	164,364	43,254
Maryland	126,220	33,215	135,100	35,553
Virginia	20,052	5,277	40,667	20,331
TOTAL	475,000	125,000	504,495	142,390

Using sub-option B2 to round down to the nearest 50,000				
State	Delaware Bay Origin Quota		Total Quota	
	Male	Female	Male	Female
Delaware	155,713	34,603	155,713	34,603
New Jersey	155,713	34,603	155,713	34,603
Maryland	119,578	26,573	139,625	31,028
Virginia	18,996	4,221	40,667	20,331
TOTAL	450,000	100,000	491,718	120,564

3. Committee Recommendation

There was consensus among the DBETC and ARM Subcommittee members that the harvest recommendation produced by application of the ARM Revision (Section 2) was preferred over that from the previous ARM Framework (Section 1). One committee member felt the quota caps for MD and VA that were established in Addendum VII should be removed. Additionally, both committees recommend the Board consider implementing the provision from Addendum VI that was omitted from Addendum VII that prohibits directed harvest and landings of all horseshoe crabs in New Jersey and Delaware from January 1 through June 7. The committees were in agreement that this

provision would provide additional protection for horseshoe crabs during beach spawning and red knot stopover.

4. References

ASMFC. 2009. A Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Constrained by Red Know Conservation, Stock Assessment Report No. 09- 02 (Supplement B) of the Atlantic States Marine Fisheries Commission. Washington D.C. 51pp.

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