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.

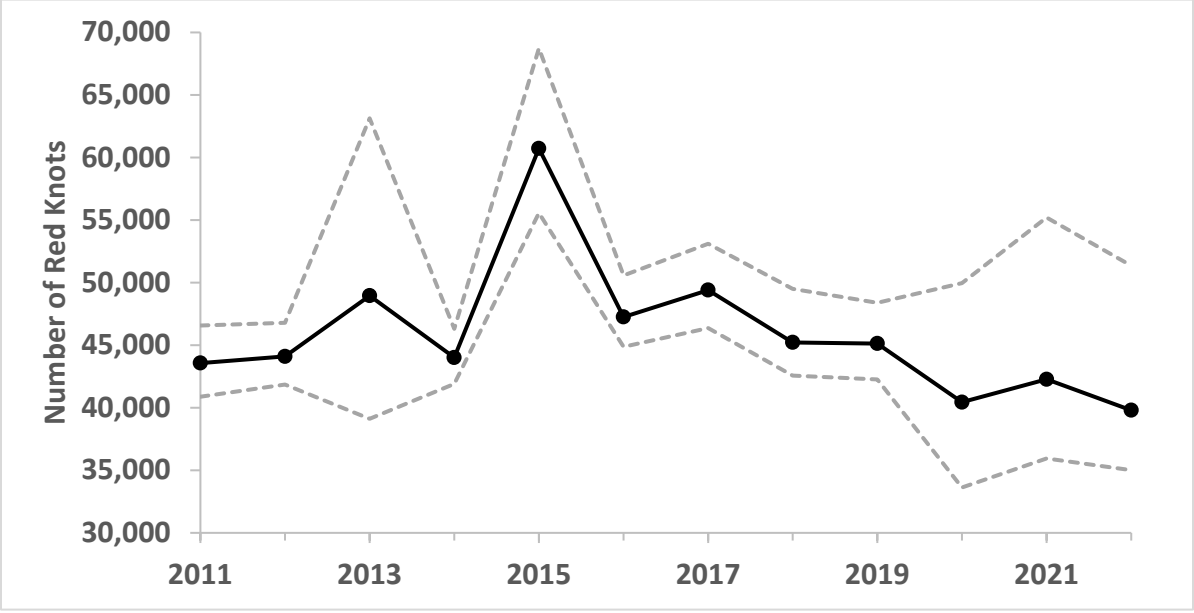


Figure 1. Mark-resight abundance estimates for the red knot stopover population with 95% confidence intervals, 2011-2022.

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.

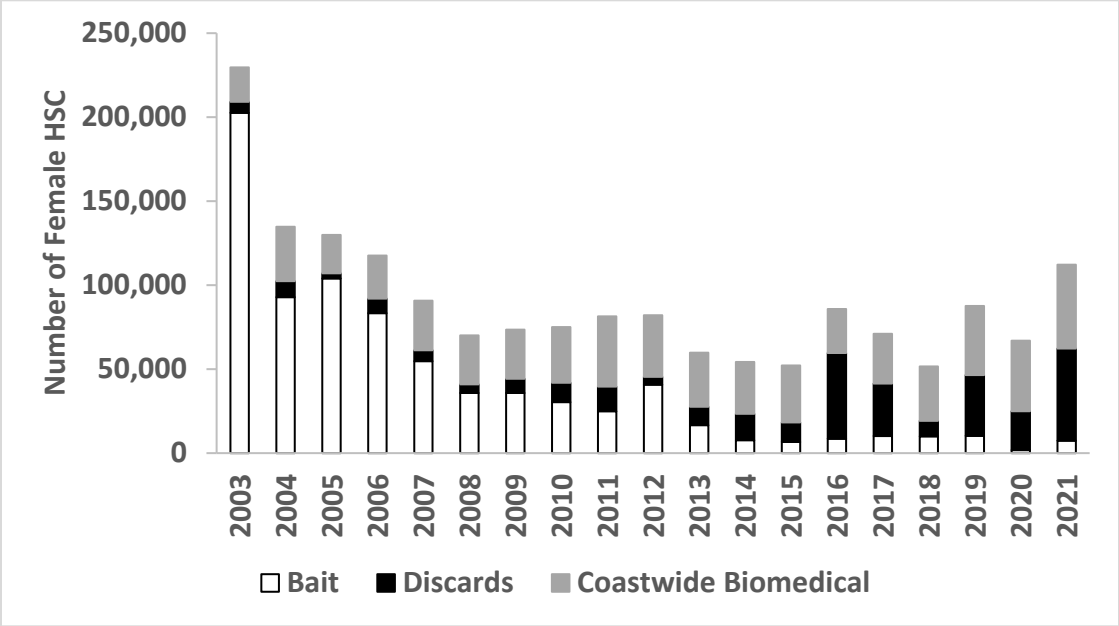


Figure 2. Total female horseshoe crab harvest by source in the Delaware Bay, 2003-2021.

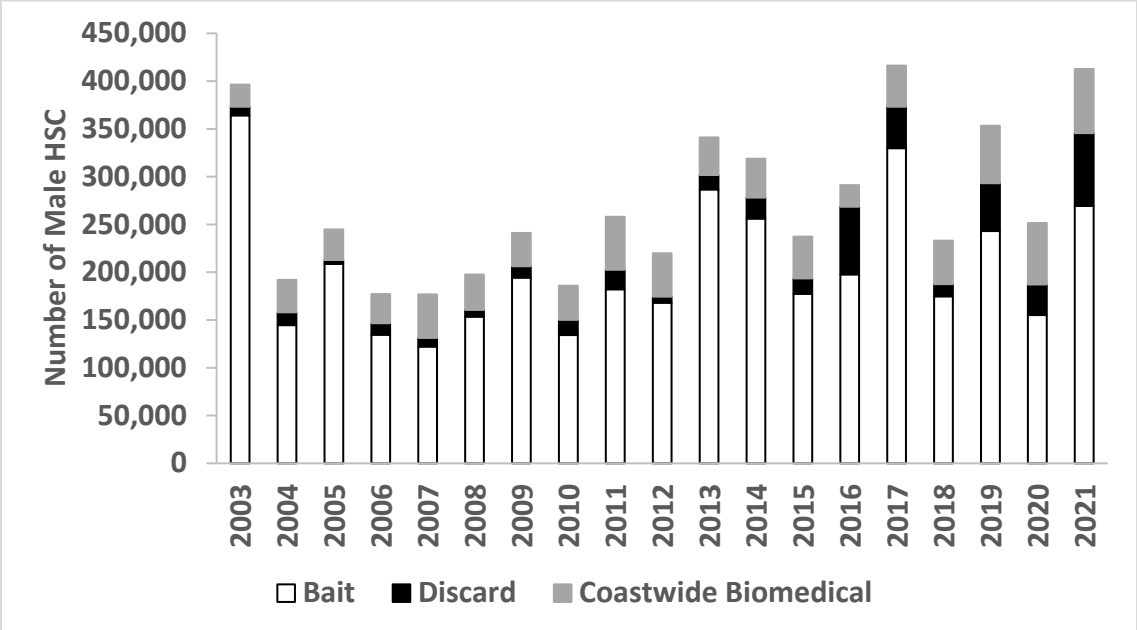


Figure 3. Total male horseshoe crab harvest by source in the Delaware Bay, 2003-2021.

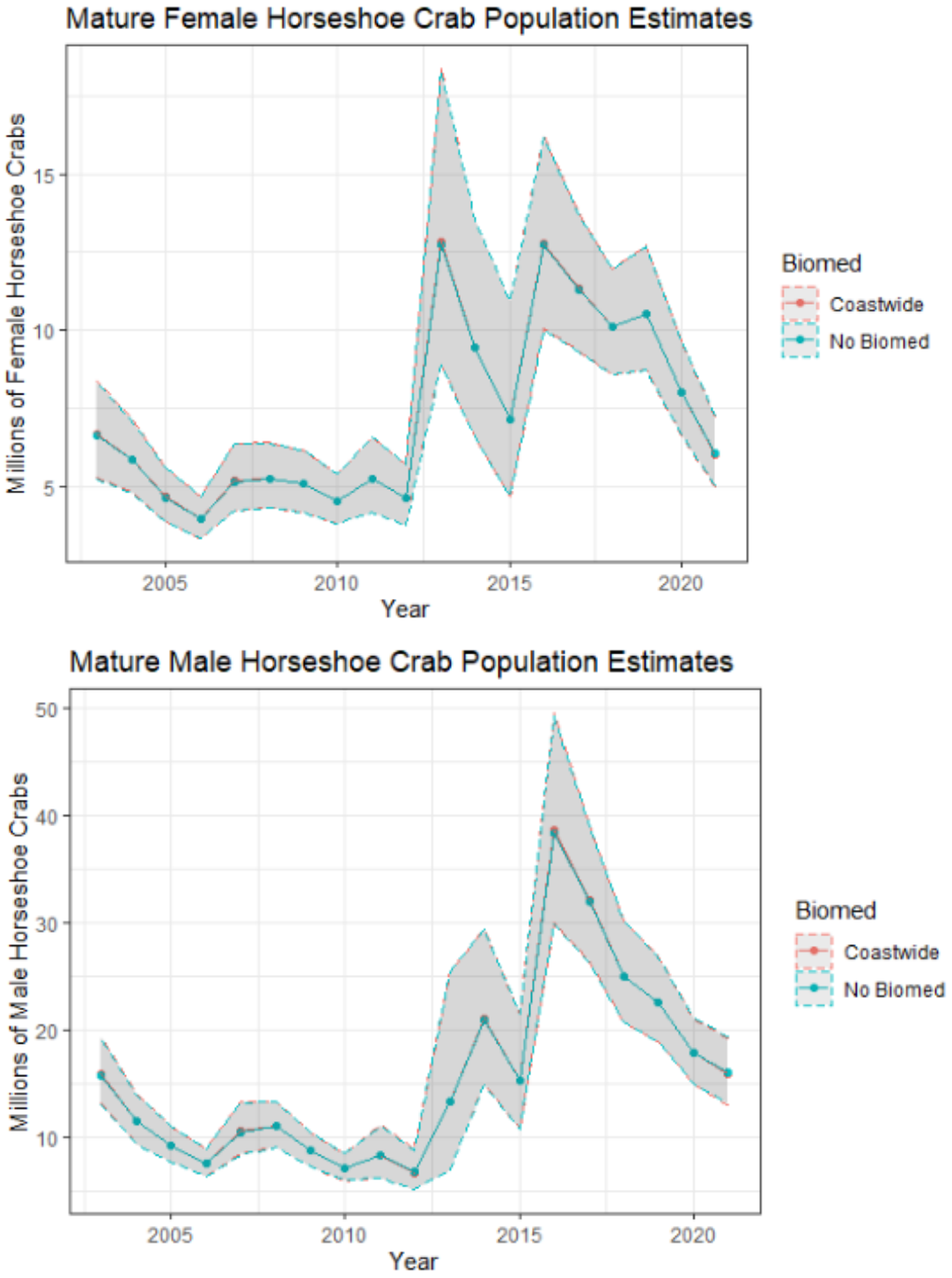
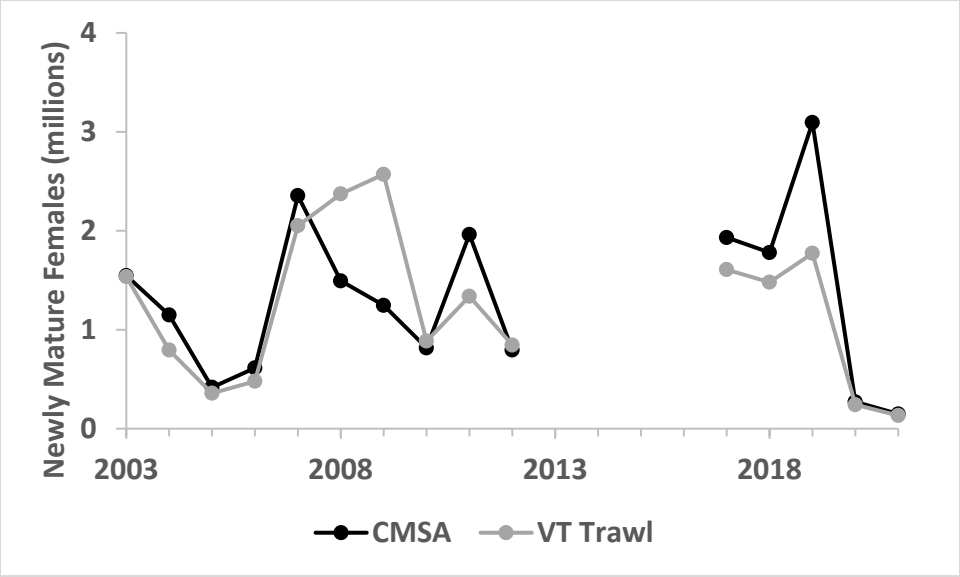


Figure 4. Population estimates from the CMSA for mature female (top) and male (bottom) horseshoe crabs with 95% confidence intervals. Delaware Bay biomedical data is confidential so population estimates using coastwide and zero biomedical data provide upper and lower bounds, although there is very little difference between the two and the time series overlap on the figures.



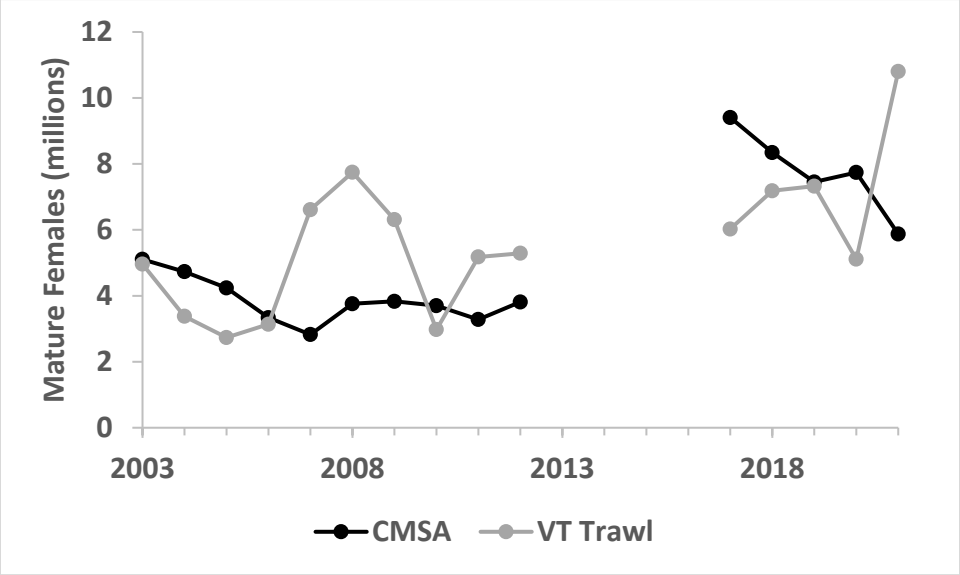


Figure 5. Comparison of newly mature and mature female horseshoe crab estimates between the catch multiple survey analysis (CMSA) using coastwide biomedical data and Virginia Tech Trawl Survey (VT Trawl) 2003-2021. VT Trawl data is lagged forward one year from the values reported in Table 1.

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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ASMFC. 2022. Revision to the Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Inclusive of Red Knot Conservation and Peer Review Report. Arlington, VA. 302 pp.

Lyons, J.E. 2022. Red Knot Stopover Population Estimate for 2021. Memorandum to the Delaware Bay ARM Working Group. U.S. Geological Survey Patuxent Wildlife Research Center, Laurel, Maryland. 13 pp.

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.

Wong, C. Y. Jiao, and E. Hallerman. 2022. Results of the 2021 Horseshoe Crab Trawl Survey: Report to the Atlantic States Marine Fisheries Commission Horseshoe Crab and Delaware Bay Ecology Technical Committees. 27 pp.