Atlantic States Marine Fisheries Commission

Supplemental Report to the 2021 Revision to the Adaptive Resource Management Framework

Vision: Sustainably Managing Atlantic Coastal Fisheries

EXECUTIVE SUMMARY

The Peer Review Panel (Panel) for the 2021 Revision to the Framework for Adaptive Management (ARM) of Horseshoe Crab Harvest in the Delaware Bay Inclusive of Red Knot Conservation concluded that the ARM Modeling Wok Group completed the Terms of Reference, revised the ARM Framework successfully, and results are suitable for management advice. The Panel did request a few changes be made to some of the modeling, which resulted in a different base run of the model from what was included in the final version of the ARM Revision report. This report, a supplement to the full ARM Revision report, describes the changes requested by the Panel and the revised base run.

Population Models and Revised ARM Framework

The Delaware Adult Trawl Survey index was recalculated based on Peer Review Panel recommendations and therefore the catch multiple survey analysis (CMSA), the model used to estimate male and female horseshoe crab abundances, was rerun. With the new base run, in 2019, the CMSA estimated that there were 21.9 million male and 9.4 million female horseshoe crabs. Additional sensitivity runs were done to test various assumptions and inputs for the CMSA during the Peer Review Workshop and are included in this supplemental report.

Because the CMSA population estimates are included in the integrated population model (IPM) for red knots, this model was also rerun. Estimates of adult survival probability and recruitment were nearly identical to the previous model run, again indicating high adult survival (average 0.93) and low recruitment (average 0.06) for this population.

The projection model for horseshoe crabs was rerun to include the full time series of CMSA estimates (2003-2019) rather than the shorter period used previously (2013-2019), as recommended by the Peer Review Panel. This resulted in more variable and lower mean values of primiparous abundances which resulted in lower projected mean equilibrium values of male and female abundances.

Due to the revised population models and the changes made in the horseshoe crab projection model, the ARM Framework was rerun.

Stock Status

Based on the base run of the revised ARM model, the recommended harvest in 2019 would have been 500,000 male and 144,803 female horseshoe crabs. Conversely, the previous ARM model recommended 500,000 male-only harvest.

It should be noted that this ARM Revision was developed using coastwide biomedical data so as to avoid data confidentiality issues. The population estimates for horseshoe crabs from the CMSA therefore represent an overestimate. If this ARM Revision is accepted for management use, the Delaware Bay-specific biomedical data will be used to determine the harvest package and the model will be run by someone (e.g., ASMFC staff) with confidential data access. Therefore, the final harvest recommendations are likely to be marginally lower than those reported here. No other model inputs were affected by data confidentiality.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

1 OVERVIEW

This report serves as supplemental material to the 2021 Revision to the Framework for Adaptive Management (ARM) of Horseshoe Crab Harvest in the Delaware Bay Inclusive of Red Knot Conservation (ASMFC 2021). During the Peer Review Workshop in November, 2021, the Peer Review Panel (Panel) requested additional information and report for peer review. A description of the additional information, analysis, and conclusions follows, but refer to ASMFC 2021 for a more thorough discussion of the life history, available data sources, analysis background, and stock status discussions for the ARM Framework.

1.1 Modeling Changes

The Panel made many suggestions in the Peer Review Report for both long-term and short-term considerations. Some of the short-term recommendations were made to the base run of the revised ARM model and were completed at or following the Peer Review Workshop. Three changes were made to the data or base run of the models which resulted in different results from those brought to peer review and described in ASMFC 2021:

1. A model-based abundance index for the Delaware Fish and Wildlife Adult Trawl Survey was developed since the design-based index previously used was deemed inappropriate for a fixed-survey design. The catch multiple survey analysis (CMSA) then was rerun with the revised Delaware index in order to estimate female and male horseshoe crab abundances in the Delaware Bay Region for use in the Integrated Population Model (IPM) for red knots and the horseshoe crab projection model.
2. The recruitment function in the horseshoe crab projection model was updated using all years of available primiparous data (2003-2019) instead of the limited years (2013-2019) used in base run.
3. The Revised ARM Framework was rerun to reflect those changes and is now considered the new base run for the model. Associated optimal harvest recommendations was also revised.

Additionally, the Panel made several research recommendations that have now been incorporated into the research recommendations in ASMFC 2021. The revised and complete list of research recommendations is found in this supplemental report, Section 7.

2 DELAWARE FISH AND WILDLIFE ADULT TRAWL SURVEY

Refer to ASMFC 2021 for a description of the survey’s sampling design and biological sampling. In ASMFC 2021, the Delaware Adult Trawl Survey abundance index was developed using the delta distribution for the mean and variance for each year of the survey. During the Peer Review Workshop, this method was deemed inappropriate for a fixed-station survey design and the Panel requested that the survey be recalculated and standardized using generalized linear or additive models (GLMs or GAMs).

2.1 Evaluation of Survey Data

This survey catches mainly adult horseshoe crabs and spring (April through July) indices were developed from this survey for male and female horseshoe crabs separately. This survey was standardized using R code to consider a variety of statistical models, including GLMs, as well as zero-inflated models and nominal indices. A full model that predicted catch as a linear function of year, month, water temperature, salinity, depth, and station was compared with nested submodels using AIC. Based on several diagnostics (AIC, dispersion, percent deviance explained, and resulting CVs), the model chosen was a negative binomial that included year and station.

2.2 Abundance Index Trends

For all adult female horseshoe crabs in the spring (Figure 1), abundance began in 2003 with a mid-range value and then decreased in 2004-2005. There was a moderate increase in 2006 and 2007 before dropping to low abundance levels from 2008 through 2013. Since 2014 there has been a generally upward trend. A similar pattern was seen for the spring indices of adult males (Figure 2).

3 HORSESHOE CRAB POPULATION MODEL

3.1 Catch Multiple Survey Analysis (CMSA)

Refer to ASMFC 2021 for model background, description, configuration, and sensitivity runs. Since one of the inputs to the CMSA, the Delaware Bay Adult Trawl abundance index, was changed during the Peer Review Workshop, the CMSA base run had to re-run to calculate revised population estimates for male and female horseshoe crabs.

Revised input values for the CMSA can be found in Table 1 for female horseshoe crabs and Table 2 for male horseshoe crabs.

3.1.1 Results

Base model predictions fit indices well for both female and male horseshoe crabs, with excellent agreement with the primiparous index and well-behaved fits through observed multiparous indices (Figure 3-Figure 4).

Estimated female and male primiparous abundance was fairly stable through the time series with the exception of the missing years of the Virginia Tech trawl survey (2013-2016; Table 3-Table 4; Figure 5-Figure 6). Rising multiparous abundance was evident in both sexes and reflects some of the large increases seen in the multiparous trawl indices in later years (Table 3-Table 4; Figure 5-Figure 6).

3.1.2 Sensitivity Runs

In addition to the sensitivity runs provided in ASMFC 2021, several sensitivity runs were requested by the Panel during the Peer Review Workshop. The additional sensitivity runs requested included using the ASMFC 2019 survey weights, re-weighting the surveys based on area coverage, assuming all harvest is of Delaware Bay-origin, re-weighting the surveys based on area coverage and assuming all harvest is of Delaware Bay-origin, and the revised base run with the recalculated Delaware index. The results of previous sensitivity runs as well as the additional requested sensitivity runs can be found in Table 5-0.

3.2 Projection Model

The Peer Review Panel approved of the form of the horseshoe crab projection model as described in ASMFC 2021, but requested a change to the dataset used to inform the recruitment process used in the model (see Equations 6-7 of ASMFC 2021). The Panel concluded that the full time series of available CMSA estimates (2003-2019) of primiparous male and female horseshoe crabs should be used to determine the parameters of the recruitment process, rather than the shorter period used for ASMFC 2021 (i.e., 2013-2019). Primiparous abundances over the longer period are more variable and have lower mean values (Table 7), leading to lower projected median equilibrium values of male and female abundances (Figure 15) that are nevertheless bounded by wide confidence limits. Correlation between male and female primiparous abundances remains similar to that used in ASMFC 2021.

4 RED KNOT POPULATION MODEL

4.1 Integrated Population Model (IPM)

4.1.1 Model Description

No changes were made to the IPM model structure; refer to ASMFC 2021 for a detailed description of the model background, parameterization, and sensitivity runs. The model was rerun using the estimates of total female horseshoe crab abundance from the updated CMSA runs described above.

4.1.2 Results

4.1.2.1 Demographic rate estimates

Estimates of adult survival probability and recruitment were nearly identical to the previous model run (Table 8, Figure 7), again indicating high adult survival (average 0.93) and low recruitment (average 0.06) for this population.

4.1.2.2. Effects of environmental variables on red knot demographics

Regression coefficient estimates from this model run were very similar to the previous version (Table 9, Figure 8-Figure 9). The model indicated strong evidence for a positive association between female horseshoe crab abundance and apparent adult survival probability (β_1 = 0.37, 95% CRI: 0.12, 0.63) and no evidence of an effect or interaction with the timing of spawning. There was no clear evidence of a relationship between horseshoe crab abundance and red knot recruitment rate (β_5 = -0.14, 95% CRI: -0.53, 0.32).

5 REVISED ADAPTIVE RESOURCE MANAGEMENT FRAMEWORK

The Peer Review Panel concluded that the form of the decision model was appropriate and did not suggest any changes. However, changes to three inputs to the decision model had the potential to influence the optimal harvest policy for male and female horseshoe crabs. These were:

1) Revised CMSA estimates of primiparous and multiparous horseshoe crab abundances;

2) Revised red knot IPM parameter estimates that were influenced by the revision of CMSA estimates;

3) New parameters to the horseshoe crab recruitment process based on the full CMSA time series (2003-2019) instead of the shorter period used in ASMFC 2021 (2013-2019).

Time constraints precluded a full assessment of the sensitivity of the optimal harvest policy to each of the above changes independently. Rather, a new base run of the Approximate Dynamic Programming algorithm was conducted incorporating all three. The change to the recruitment process of the horseshoe crab projection model was expected to be quite influential since it represents a significant change to expected long-term equilibrium abundances and the annual variation around them. Broadly, it was expected that these lower projected horseshoe crab abundances would result in a more conservative harvest policy.

Results from the new base run (Figure 10-Figure 16; Table 10) differ from those in the previous base run (Figures 53-59 in ASMFC 2021) in several notable ways. First, as expected, projected equilibrium distributions for male and female horseshoe crab abundances are shifted lower (new median female abundance at projection year 100 is approximately 7.3 million, whereas it was 12.3 million in ASMFC 2021; year-100 median male abundance here is 14.9 million, it was 33.8 million in ASMFC 2021). For males in particular, however, uncertainty is still quite large.

The long-term distribution of red knot abundance has also shifted lower in the new base run (Figure 15), with a median of approximately 100,500 adults at year 100 (versus 128,400 in ASMFC 2021). Uncertainty around this expected value in the new base run is similarly large, compared with results in ASMFC 2021.

The combined influences of lower expected abundances of male and female horseshoe crabs and of adult red knots lead to differences in the optimal harvest strategies for male and female horseshoe crabs. For males, the policy is similar to that of ASMFC 2021, with maximum allowable harvest being the recommendation throughout most of the predicted range of male abundances (Figure 10). However, because those abundances are projected to be generally lower, the harvest curve rises toward maximum harvest at a lower absolute abundance than in ASMFC 2021.

The optimal female harvest surface in the new base run has a shallower slope than the one in ASMFC 2021, along both the female horseshoe crab and red knot axes (Figure 11-Figure 14; Table 10). In contrast to the ASMFC 2021 run, the new harvest policy is unlikely to recommend maximum allowable female harvest (210,000) within the projected range of female horseshoe crab and red knot abundances (green regions in Figure 11-Figure 14). However, its shallow slope results in recommendations of moderate female harvest even at low abundances of female horseshoe crabs and red knots.

6 STOCK STATUS AND CONCLUSIONS

Using the new base run with the recommended changes from the Peer Review Panel, the optimal harvest recommendations were also revised (Table 11; compare to Table 32 in ASMFC). In 2019, the harvest recommendation from the revised ARM Framework would have been 500,000 males and 144,803 females. Optimal harvest recommendations under the previous ARM Framework were for harvest package #3 (0 females, 500,000 males).

Again, it should be noted that this ARM Revision was developed using coastwide biomedical data so as to avoid data confidentiality issues. The population estimates for horseshoe crabs from the CMSA therefore represent an overestimate. If this Revision is accepted for management use, the Delaware Bay-specific biomedical data will be used to determine the harvest package and the model will be run by someone (e.g., ASMFC staff) with confidential data access. Therefore, the final harvest recommendations are likely to be marginally lower than those reported in Table 11 when the Delaware Bay-specific values are used.

7 RESEARCH RECOMMENDATIONS

The ARM subcommittee identified several recommendations that would benefit the adaptive management of horseshoe crabs and red knots in the Delaware Bay area. In section four of the Peer Review Panel's report, the Panel made several other recommendations that have been incorporated into the list. Below is the final and complete list of research recommendations.

The ARM subcommittee and the Peer Review Panel recommend that the ARM data be updated sooner than later (three years or less) as new data become available, notably when the Delaware and New Jersey trawl surveys collect new stage data to improve the estimation of HSC recruitment dynamics. Additionally, the ARM Framework should be revisited every five-ten years for possible revision to account for dynamic changes in the ecosystem.

7.1 Future Research

- Evaluate the effect of climate change on horseshoe crabs and red knots. This includes the effects of warming temperatures, sea level rise, and storm frequency and intensity on the timing and duration of spawning, movement of crabs into and out of Delaware Bay, and effects on spawning habitat. For red knots, this includes effects of climate change on breeding conditions in the arctic and resulting recruitment of red knots.
- Incorporate potential climate change effects into the optimization (e.g., predicted trends in arctic snow cover).
- Evaluate the relationship between horseshoe crab egg density on spawning beaches and abundance of horseshoe crabs in the bay-wide spawning survey and total population estimates derived from the catch multiple survey analysis.
- Improve the understanding of horseshoe crab recruitment for the purpose of updating the stock-recruitment relationship.
- Continue evaluation of catchability and factors influencing catchability of the Virginia Tech horseshoe crab trawl survey.

- Address the issue of gear saturation for spawning beach surveys and/or explore analyses that would be less sensitive to gear saturation. Explore the methodology and data collection of spawning beach surveys and the ability of these surveys to track spawning abundance.
- Quantify the amount of contemporary suitable horseshoe crab spawning habitat in the Delaware Bay.
- Further explore the multi-state mark-recapture analysis of red knot tagging data to estimate the probability of gaining weight and survival as a function of horseshoe crab abundance. Examine the effects of tagging biases, time periods of stopover, short- versus long-distance migrants, and selection of states (i.e., weight thresholds).
- Evaluate the proportion of New York bait landings that could be comprised of Delaware Bay-origin crabs and the movement between the two regions.
- If possible, include other sources of horseshoe crab removals (e.g., illegal take, poaching) in the CMSA. Other sources of removals are currently unknown, but can be added in the future if quantified.

7.2 Data Collection

- Continue funding and support for the annual Virginia Tech Trawl Survey. Consider increasing the sampling effort within the Delaware Bay region or expanding the survey along the Atlantic coast if future funding allows.
- Perform a simulation study to evaluate the performance of current Virginia Tech Survey design in capturing the Delaware Bay horseshoe crab stock dynamics. A simulation could also potentially identify a more cost-effective survey program to ensure the quality of the survey abundance indices.
- Better characterize horseshoe crab discards in other commercial fisheries and refine estimates of discard mortality.
- Continue to collect horseshoe crab sex and stage (primi- and multiparous stages) information from the Delaware Bay Adult Trawl Survey and the New Jersey Ocean Trawl Survey.
- Continue monitoring natural mortality from tagging data within the Delaware Bay region. It is possible that natural mortality is not constant across all age stages post-maturation and future revisions should consider recording post-maturation age group data based on carapace wear, epibionts, and mating scar criteria defined by Botton et al. (2021) in order to estimate age group-specific mortality estimates. Exploring differences in natural mortality among primiparous and multiparous crabs would be beneficial for obtaining age-group specific mortality estimates that could be incorporated into the CMSA model to obtain more accurate abundance estimates.
- Continue to evaluate biomedically bled crabs' mortality rates and effects on spawning behavior. Consider a tagging study of biomedically bled horseshoe crabs to obtain

relative survival and collaborations between researchers and biomedical facilities that would result in peer-reviewed mortality estimates.

- Maintain consistent data collection and survey designs for spawning beach surveys each year.
- Increase effort for tagging resights for horseshoe crabs and expand horseshoe crab tagging efforts throughout the US East Coast, particularly in North Carolina, to ameliorate movement and population exchange patterns adjacent to Delaware Bay. North Carolina has the lowest tagging effort (by tagged individuals and resighting effort) out of any state on the US East Coast. There is limited information regarding the migratory exchange between North Carolina and Delaware Bay that is also the boundary between stock units (ASMFC 2019).
- Improve estimates of counting error during red knot aerial surveys by recording and maintaining records of additional information such as observer ID, tide state, and weather conditions. The integration of simultaneous ground count data or a double-observer method could also be used to improve this component of the IPM.
- Evaluate phenology of horseshoe crab migration into Delaware Bay with more contemporary tools, such as satellite tags or acoustic telemetry. Understanding migration timing could improve understanding of temporal implications of trawl survey timing and horseshoe abundance index inference, as well as the timing of horseshoe crab spawning migrations relative to red knot arrival.
- Develop a survey targeting older juvenile horseshoe crabs within the subtidal zone to enhance the understanding of recruitment. The population dynamics and habitat use of juveniles (age 5-9) remains elusive within the literature, with the exception of the population in Pleasant Bay, Massachusetts.

7.3 Data analysis and modeling

- Update horseshoe crab stock-recruitment relationships as more data become available and refine methodologies to characterize uncertainty.
- Regularly updating the model runs with new information when it becomes available will continue to improve the estimates of recruitment dynamics for both horseshoe crabs and red knots. Although the recruitment dynamics are currently quantified with large uncertainty because of the short time period and missing years of data, the interannual variability in recruitment will be better understood when more data become available.
- Update parameters describing the influence of horseshoe cabs on red knot survival and recruitment though re-fitting the red knot integrated population model to new data.
- Integrate red knot “proportion marked” data into the IPM so that analyses conducted to determine the state of the system can be used to update model parameters with no additional effort.

- Conduct habitat suitability index modeling for primiparous and multiparous horseshoe crabs for both males and females to examine spatio-temporal variability in suitable habitat.
- Quantify and monitor the amount of suitable spawning habitat for horseshoe crabs throughout the Delaware Bay, including fringe marsh habitat which may affect horseshoe crab recruitment dynamics due to climate change.
- Conduct species distribution modeling to examine spatio-temporal changes in distributions of primiparous and multiparous female and male horseshoe crabs.
- Investigate alternative utility functions for red knots with additional stakeholder input.
- Continue to evaluate horseshoe crab tagging data by fitting capture-recapture models that include a short-term (1 year) bleeding effect, account for spatial distribution of harvest pressure, account for capture methodology, and account for disposition of recaptured tagged individuals. Potential methodological approaches include use of time-varying individual covariates to indicate which crabs are 1 year from bleeding and use of hierarchical models to estimate interannual variation in survival within time periods defined by major regulatory changes.
- Explore the possibility of modeling stopover persistence as a function of boreal-wintering area of marked birds using observations away from Delaware Bay.
- Continue to explore the apparent lack of relationship between horseshoe crab egg densities measured by beach surveys and red knot survival.
- Explore the use of expected value of perfect information (EVPI) to evaluate the effects of uncertainties in red knots and horseshoe crab dynamics on harvest decisions.

8 REFERENCES

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9 TABLES

Table 1. CMSA base model inputs for female horseshoe crabs. Biomedical numbers represent coastwide mortality, not Delaware Bay-specific. Values shown for the Virginia Tech (VT) survey's swept area estimations for primiparous (*R*) and multiparous (*N*) are in millions of horseshoe crabs.

Year	Removals				Indices				CVs			
	Bait	Discard	Biomedical	Total	VT, *R*	VT, *N*	DE Adult	NJ OT	VT, *R*	VT, *N*	DE	NJ
2003	202,614	6,567	20,456	229,637	1.537	4.959	0.644	2.246	0.26	0.30	0.47	0.19
2004	92,855	9,554	32,337	134,747	0.794	3.379	0.015	2.502	0.49	0.25	1.05	0.23
2005	103,972	3,031	22,885	129,888	0.358	2.735	0.015	2.770	0.29	0.23	1.05	0.24
2006	83,295	8,664	25,654	117,613	0.479	3.138	0.949	1.856	0.27	0.27	0.37	0.26
2007	54,773	6,500	29,469	90,742	2.051	6.611	0.877	1.474	0.31	0.42	0.37	0.25
2008	35,838	5,084	29,141	70,063	2.373	7.746	0.118	2.370	0.40	0.31	0.50	0.32
2009	35,793	8,475	29,287	73,555	2.571	6.311	0.199	1.368	0.43	0.29	0.45	0.29
2010	30,362	11,527	33,165	75,055	0.885	2.975	0.109	0.579	0.26	0.32	0.51	0.30
2011	24,906	14,742	41,754	81,403	1.338	5.178	0.156	2.215	0.59	0.23	0.47	0.26
2012	40,745	4,673	36,675	82,093	0.845	5.290	0.161	1.804	0.30	0.18	0.47	0.25
2013	16,635	10,933	32,222	59,790			0.014	7.996			1.08	0.35
2014	7,663	15,787	30,865	54,315			0.809	3.358			0.37	0.24
2015	6,680	11,593	33,897	52,169			0.396	3.145			0.40	0.25
2016	8,527	51,069	26,204	85,800			0.714	3.989			0.38	0.24
2017	10,136	31,295	29,635	71,066	1.608	6.024	1.159	5.613	0.23	0.21	0.36	0.25
2018	10,096	9,184	32,405	51,686	1.480	7.185	2.123	3.118	0.26	0.23	0.35	0.23
2019					1.773	7.326	1.349	6.966	0.31	0.21	0.36	0.40

	Starting Values				
M	*R*	*N*	*q_DE*	*q_NJ*	*s*
0.3	1.4E+06	5.3E+06	1.1E-07	5.9E-07	1

Table 2. CMSA base model inputs for male horseshoe crabs. Biomedical numbers represent coastwide mortality, not Delaware Bay-specific. Values shown for the Virginia Tech (VT) survey's swept area estimations for primiparous (R) and multiparous (N) are in millions of horseshoe crabs.

Year	Removals				Indices				CVs			
	Bait	Discard	Biomedical	Total	VT, *R*	VT, *N*	DE Adult	NJ OT	VT, *R*	VT, *N*	DE	NJ
2003	364,132	9,117	23,028	396,277	0.548	11.584	0.337	2.647	0.28	0.24	0.55	0.22
2004	144,729	13,265	34,115	192,109	0.078	8.069	0.000	2.077	0.84	0.29	1.00	0.25
2005	208,670	4,209	31,889	244,768	0.789	5.150	0.000	3.260	0.21	0.25	1.00	0.28
2006	134,617	12,028	30,536	177,181	0.597	5.844	0.328	1.783	0.33	0.22	0.44	0.27
2007	122,272	9,024	45,468	176,764	3.113	15.825	0.870	1.016	0.31	0.27	0.41	0.26
2008	153,516	7,059	37,007	197,581	3.129	15.795	0.105	2.319	0.28	0.28	0.52	0.34
2009	194,426	11,767	34,948	241,141	0.757	14.647	0.151	1.421	0.31	0.33	0.49	0.30
2010	134,223	16,004	35,581	185,809	0.725	6.240	0.240	0.684	0.34	0.30	0.46	0.31
2011	182,131	20,468	55,412	258,011	1.422	13.963	0.305	1.726	0.55	0.28	0.44	0.25
2012	168,034	6,488	45,389	219,911	0.749	15.060	0.112	2.069	0.36	0.40	0.51	0.30
2013	286,609	15,179	39,285	341,073			0.055	8.248			0.60	0.39
2014	256,155	21,919	40,712	318,786			0.874	3.610			0.41	0.27
2015	177,402	16,096	43,710	237,207			0.444	3.205			0.43	0.29
2016	197,734	70,904	22,579	291,218			0.527	5.041			0.42	0.31
2017	329,840	43,451	43,039	416,330	2.608	21.941	1.300	7.183	0.42	0.29	0.40	0.29
2018	175,031	12,752	45,420	233,203	1.523	20.664	3.071	4.564	0.28	0.25	0.39	0.28
2019					3.341	15.749	1.804	7.683	0.29	0.18	0.40	0.48

	Starting Values				
M	*R*	*N*	*q_DE*	*q_NJ*	*s*
0.3	1.5E+06	1.3E+07	4.7E-08	2.6E-07	1

Table 3. CMSA female horseshoe crab model outputs: *q*=catchability coefficients; *R*=primiparous abundance; *N*=multiparous abundance; and *F*=instantaneous fishing mortality rate.

Year	*R*	*N*	*R+N*	*F*
2003	1,544,190	5,061,010	6,605,200	0.041
2004	1,254,290	4,695,600	5,949,890	0.027
2005	415,565	4,291,810	4,707,375	0.032
2006	584,244	3,375,510	3,959,754	0.035
2007	2,337,530	2,832,230	5,169,760	0.021
2008	1,573,060	3,751,750	5,324,810	0.015
2009	1,292,980	3,884,420	5,177,400	0.017
2010	822,549	3,772,200	4,594,749	0.019
2011	2,074,450	3,339,270	5,413,720	0.018
2012	802,266	3,940,520	4,742,786	0.020
2013	9,569,380	3,442,890	13,012,270	0.005
2014	2	9,588,260	9,588,262	0.007
2015	299,411	7,056,410	7,355,821	0.008
2016	6,977,790	5,404,420	12,382,210	0.008
2017	1,867,980	9,099,120	10,967,100	0.008
2018	1,672,230	8,063,460	9,735,690	0.006
2019	2,189,510	7,167,890	9,357,400	

q_DE	7.41E-08
q_NJ	3.77E-07

Table 4. CMSA male horseshoe crab model outputs : *q*=catchability coefficients; *R*=primiparous abundance; *N*=multiparous abundance; and *F*=instantaneous fishing mortality rate.

Year	*R*	*N*	*R+N*	*F*
2003	555,967	15,597,600	16,153,567	0.029
2004	83,631	11,625,800	11,709,431	0.019
2005	880,457	8,509,190	9,389,647	0.031
2006	798,084	6,745,350	7,543,434	0.028
2007	4,929,030	5,435,810	10,364,840	0.020
2008	3,681,160	7,526,320	11,207,480	0.021
2009	788,876	8,132,640	8,921,516	0.032
2010	834,793	6,401,670	7,236,463	0.030
2011	3,822,740	5,200,980	9,023,720	0.034
2012	768,416	6,462,870	7,231,286	0.036
2013	11,581,300	5,167,790	16,749,090	0.024
2014	9,233,350	12,114,500	21,347,850	0.017
2015	436,065	15,540,500	15,976,565	0.017
2016	26,978,600	11,631,500	38,610,100	0.009
2017	3,312,030	28,352,400	31,664,430	0.015
2018	1,615,990	23,099,300	24,715,290	0.011
2019	3,789,120	18,108,800	21,897,920	

q_DE	3.17E-08
q_NJ	1.89E-07

Table 5. Sensitivity runs for the CMSA for female horseshoe crabs. All runs that included CONFIDENTIAL biomedical data have been removed. The "modeling base run" is the previous base run from ASMFC 2021, the "post-pr base run" is the post-peer review base run, and the "real (DB) base run" uses the confidential Delaware Bay biomedical data instead of the coastwide. The sensitivity to natural mortality (*M*), different discard mortality rates, leaving out the New Jersey Ocean Trawl (OT) or biomedical (biomed 0% mortality) data, using different survey weighting approaches, and assuming all harvest in the CMSA is Delaware Bay-origin was explored. Primiparous (*R*), multiparous (*N*) and fishing mortality (*F*) estimates are included.

Name	M	λ			Biomed	Discard Mortality			Starting Values				Terminal Output Values			
		VT	DE	NJ		Dredge	Trawl	Gill Nets	*R*	*N*	*q_de*	*q_nj*	*NegLL*	*R*	*N*	*F*
Modeling Base Run	0.3	1	1	1	Coastwide 15%	5%	5%	12%	14.1	15.5	-15.3	-14.3	87.9	2,247,290	7,533,500	0.006
M	0.274	1	1	1	Coastwide 15%	5%	5%	12%	14.1	15.5	-15.3	-14.3	86.5	2,204,475	7,834,127	0.006
Discard	0.3	1	1	1	Coastwide 15%	5%	5%	5%	14.1	15.5	-15.3	-14.3	87.9	2,247,210	7,533,130	0.006
Discard	0.3	1	1	1	Coastwide 15%	12%	12%	12%	14.1	15.5	-15.3	-14.3	88.1	2,251,259	7,511,908	0.007
Discard	0.3	1	1	1	Coastwide 15%	50%	50%	50%	14.1	15.5	-15.3	-14.3	89.3	2,278,436	7,385,285	0.015
No NJ OT	0.3	1	1	0	Coastwide 15%	5%	5%	12%	14.1	15.5	-15.3	-14.3	66.8	2,039,061	7,572,244	0.006
2019 Survey Weights	0.3	0.59	0.16	0.25	Coastwide 15%	5%	5%	12%	14.1	15.5	-15.3	-14.3	22.2	1,934,390	6,734,470	0.007
Area Survey Weights	0.3	0.45	0.15	0.40	Coastwide 15%	5%	5%	12%	14.1	15.5	-15.3	-14.3	22.1	2,045,187	6,955,199	0.006
Biomed	0.3	1	1	1	0% mortality	5%	5%	12%	14.1	15.5	-15.3	-14.3	87.6	2,242,272	7,564,675	0.002
All Harvest DB-origin	0.3	1	1	1	Coastwide 15%	5%	5%	12%	14.1	15.5	-15.3	-14.3	88.8	2,253,511	7,504,399	0.010
Area Wts All DB-origin	0.3	0.45	0.15	0.40	Coastwide 15%	5%	5%	12%	14.1	15.5	-15.3	-14.3	22.5	2,049,282	6,920,510	0.011
Post-PR Base Run	0.3	1	1	1	Coastwide 15%	5%	5%	12%	14.1	15.5	-16.0	-14.3	75.0	2,189,510	7,167,890	0.006
Real (DB) Base Run	0.3	1	1	1	Delaware Bay 15%	5%	5%	12%	14.1	15.5	-16	-14.3	Confidential			

Table 6. Sensitivity runs for the CMSA model for male horseshoe crabs. All runs that included CONFIDENTIAL biomedical data have been removed. The "modeling base run" is the previous base run from ASMFC 2021, the "post-pr base run" is the post-peer review base run, and the "real (DB) base run" uses the confidential Delaware Bay biomedical data instead of the coastwide. The sensitivity to natural mortality (M), different discard mortality rates, leaving out the New Jersey Ocean Trawl (OT) or biomedical (biomed 0% mortality) data, using different survey weighting approaches, and assuming all harvest in the CMSA is Delaware Bay-origin was explored. Primiparous (R), multiparous (N) and fishing mortality (F) estimates are included.

Name	M	λ			Biomed	Discard Mortality			Starting Values				Terminal Output Values			
		VT	DE	NJ		Dredge	Trawl	Gill Nets	*R*	*N*	*q_de*	*q_nj*	*NegLL*	*R*	*N*	*F*
Modeling Base Run	0.3	1	1	1	Coastwide 15%	5%	5%	12%	14.2	16.4	-15.8	-15.2	131.3	3,901,880	20,031,800	0.010
M	0.274	1	1	1	Coastwide 15%	5%	5%	12%	14.2	16.4	-15.8	-15.2	127.8	3,863,175	20,707,365	0.010
Discard	0.3	1	1	1	Coastwide 15%	5%	5%	5%	14.2	16.4	-15.8	-15.2	131.3	3,902,001	20,035,174	0.010
Discard	0.3	1	1	1	Coastwide 15%	12%	12%	12%	14.2	16.4	-15.8	-15.2	131.6	3,902,001	20,015,149	0.011
Discard	0.3	1	1	1	Coastwide 15%	50%	50%	50%	14.2	16.4	-15.8	-15.2	132.9	3,913,724	19,955,194	0.015
No NJ OT	0.3	1	1	0	Coastwide 15%	5%	5%	12%	14.2	16.4	-15.8	-15.2	105.7	3,741,511	20,957,350	0.009
2019 Survey Weights	0.3	0.59	0.16	0.25	Coastwide 15%	5%	5%	12%	14.2	16.4	-15.8	-15.2	35.0	3,532,410	17,504,300	0.011
Area Survey Weights	0.3	0.45	0.15	0.40	Coastwide 15%	5%	5%	12%	14.2	16.4	-15.8	-15.2	32.2	3,627,303	17,966,150	0.011
Biomed	0.3	1	1	1	0% mortality	5%	5%	12%	14.2	16.4	-15.8	-15.2	130.8	3,898,101	20,055,219	0.008
All Harvest DB-origin	0.3	1	1	1	Coastwide 15%	5%	5%	12%	14.2	16.4	-15.8	-15.2	133.3	3,909,813	20,015,149	0.015
Area Wts All DB-origin	0.3	0.45	0.15	0.40	Coastwide 15%	5%	5%	12%	14.2	16.4	-15.8	-15.2	33.0	3,630,932	17,912,332	0.016
Post-PR Base Run	0.3	1	1	1	Coastwide 15%	5%	5%	12%	14.2	16.4	-16.9	-15.2	102.19	3,789,120	18,108,800	0.011
Real (DB) Base Run	0.3	1	1	1	Delaware Bay 15%	5%	5%	12%	14.2	16.4	-15.8	-15.2	Confidential			

Table 7. Parameter values of the horseshoe crab recruitment process used in the projection model, for both the pre- and post-peer review versions of the model. See Equations 6-7 of ASMFC 2021 for a description of the bivariate lognormal distribution that generates male and female primiparous abundances annually.

Name	Symbol	Pre-peer review value (ASMFC 2021)	Post-peer review value
Primiparous female mean	μ^f	14.9493	14.3334
Primiparous female standard deviation	σ^f	0.4909	0.74505
Primiparous male mean	μ^m	15.7447	14.5869
Primiparous male standard deviation	σ^m	0.8837	1.4022
Correlation	ρ	0.6871	0.6712

Table 8. Estimates of average survival (φ) and recruitment (ρ) for red knot from 2005-2018. Average survival probability and recruitment rate were calculated using the average horseshoe crab abundance. 95% CRI (credible intervals) are the upper and lower bounds that contain 95% of the posterior distribution.

Parameter	Mean	95% CRI
Annual apparent survival probability (ϕ)	0.93	0.90, 0.95
Recruitment rate (ρ)	0.063	0.005, 0.149

Table 9. Estimated effects of horseshoe crab abundance, timing of spawning, and Arctic snow cover on red knot survival probability and recruitment rate , presented as the mean and 95% credible interval of the posterior distribution.

Demographic rate	Covariate	Mean	95% CRI
Survival probability	HSC	0.37	0.12, 0.63
	MaySpawnPct	-0.04	-3.31, 3.31
	HSC x MaySpawnPct	0	-0.61, 0.57
	Arctic snow	-1.02	-3.74, 1.83
Recruitment rate	HSC	-0.14	-0.53, 0.32

Table 10. Comparison of harvest policy parameters from the new base run of the decision model with those from ASMFC 2021 (Table 31).

Symbol	Description	New base run	ASMFC 2021
α^f	Slope of the female HSC harvest factor.	$3.573 / (2\times10^7)$	$5.017 / (2\times10^7)$
β^f	Inflection point of the female HSC harvest factor.	10.638×10^6	7.219×10^6
α^m	Slope of the male HSC harvest factor.	$25.422 / (3\times10^7)$	$16.908 / (3\times10^7)$
β^m	Inflection point of the male HSC harvest factor.	0.9121×10^6	7.953×10^6
α^k	Slope of the red knot harvest factor.	$2.162 / (1.8\times10^5)$	$15.783 / (1.8\times10^5)$
β^k	Inflection point of the red knot harvest factor.	6.433×10^4	9.929×10^4

Table 11. Comparison of harvest recommendations from the previous (top section) and revised (bottom section) ARM models when applied to recent abundance estimates of horseshoe crabs and red knots in the Delaware Bay. Coastwide biomedical mortality was used for model development, so actual Delaware-Bay specific values will result in slightly lower population estimates.

Year	VA Tech Swept Area Estimates		Red knots	Optimal HSC Harvest (previous ARM)	
	Female HSC	Male HSC		Female	Male
2017	6,654,877	21,405,997	49,405	0	500,000
2018	7,555,622	19,346,403	45,221	0	500,000
2019	7,934,057	16,645,912	45,133	0	500,000
Year	CMSA Estimates		Red knots	Optimal HSC Harvest (revised ARM)	
	Female HSC	Male HSC		Female	Male
2017	10,967,100	31,664,430	49,405	154,483	500,000
2018	9,735,690	24,715,290	45,221	146,792	500,000
2019	9,357,400	21,897,920	45,133	144,803	500,000

10 FIGURES

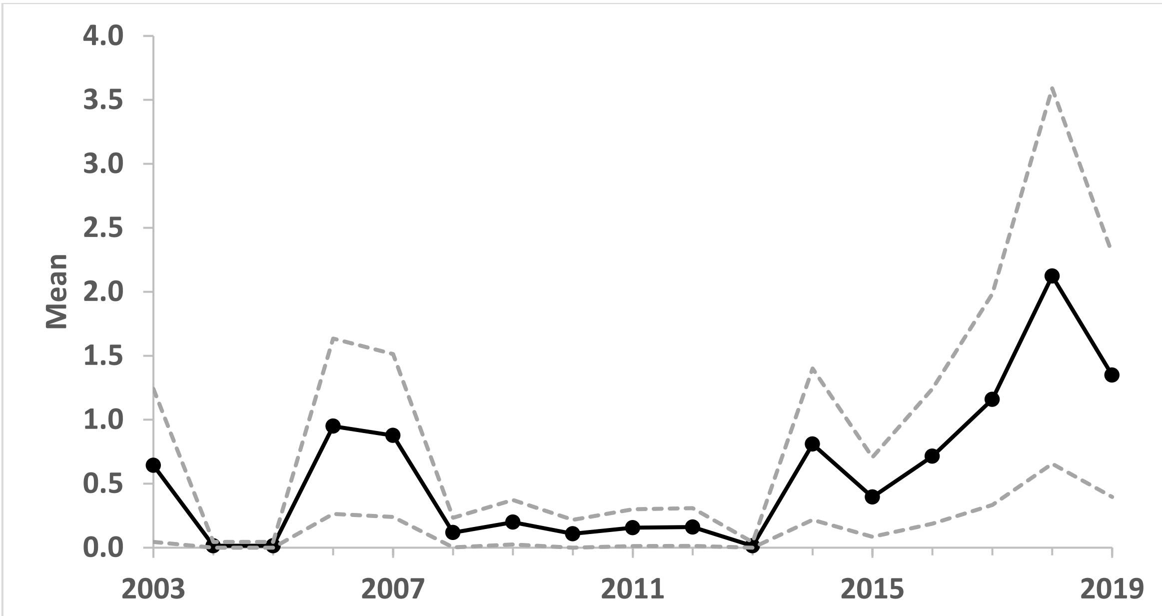

Figure 1. Delaware Fish and Wildlife Adult Trawl Survey abundance index for all adult female horseshoe crabs in the spring.

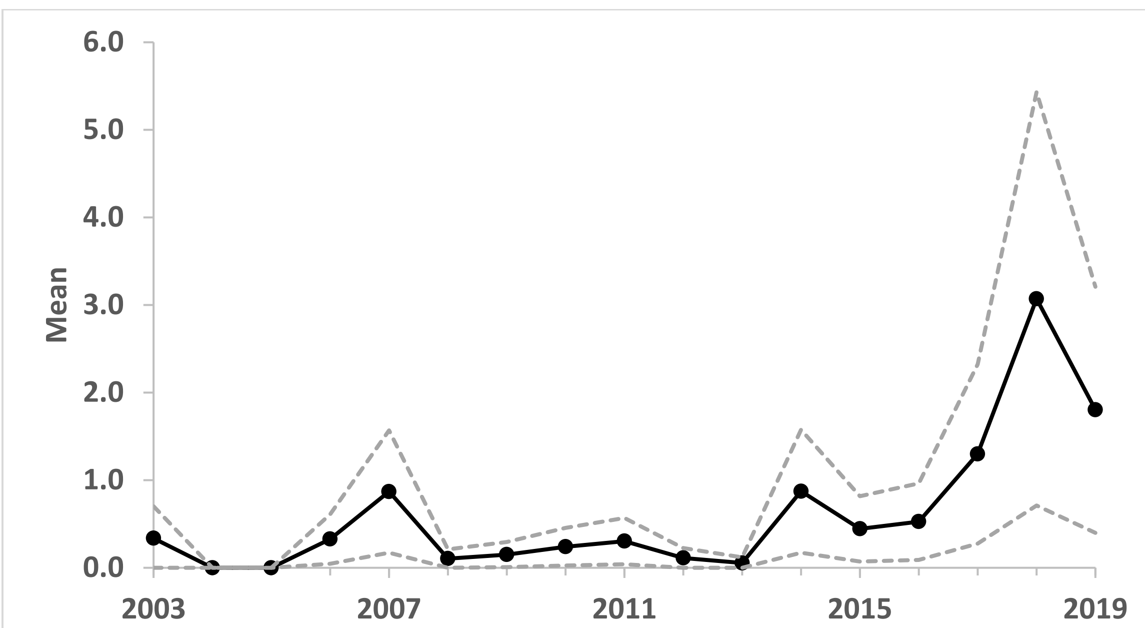

Figure 2. Delaware Fish and Wildlife Adult Trawl Survey abundance index for all adult male horseshoe crabs in the spring.

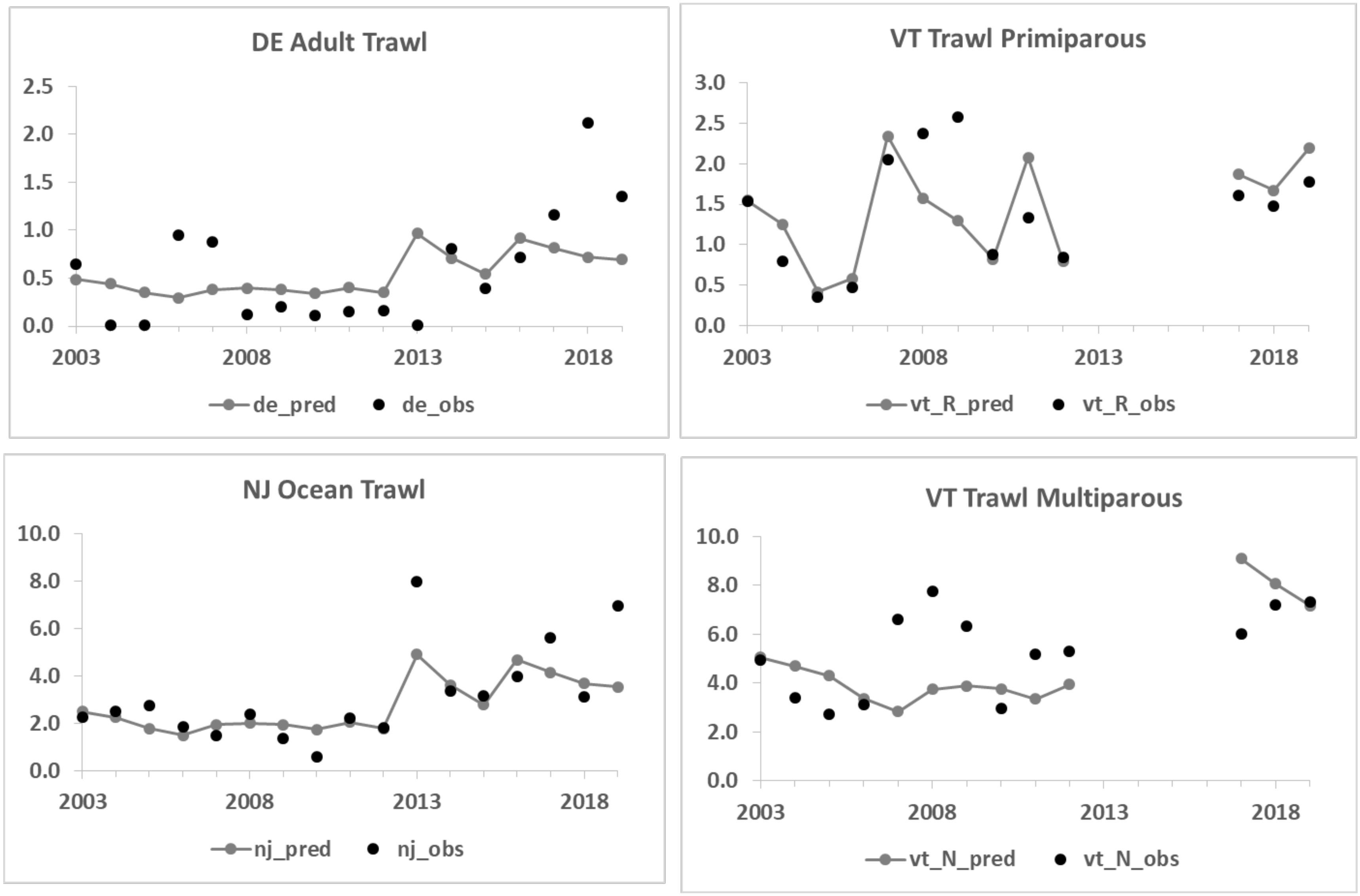

Figure 3. **CMSA model fits to the indices for the Delaware (DE) Adult Trawl, New Jersey (NJ) Ocean Trawl, and Virginia Tech (VT) Trawl Surveys for primiparous and multiparous female horseshoe crabs.**

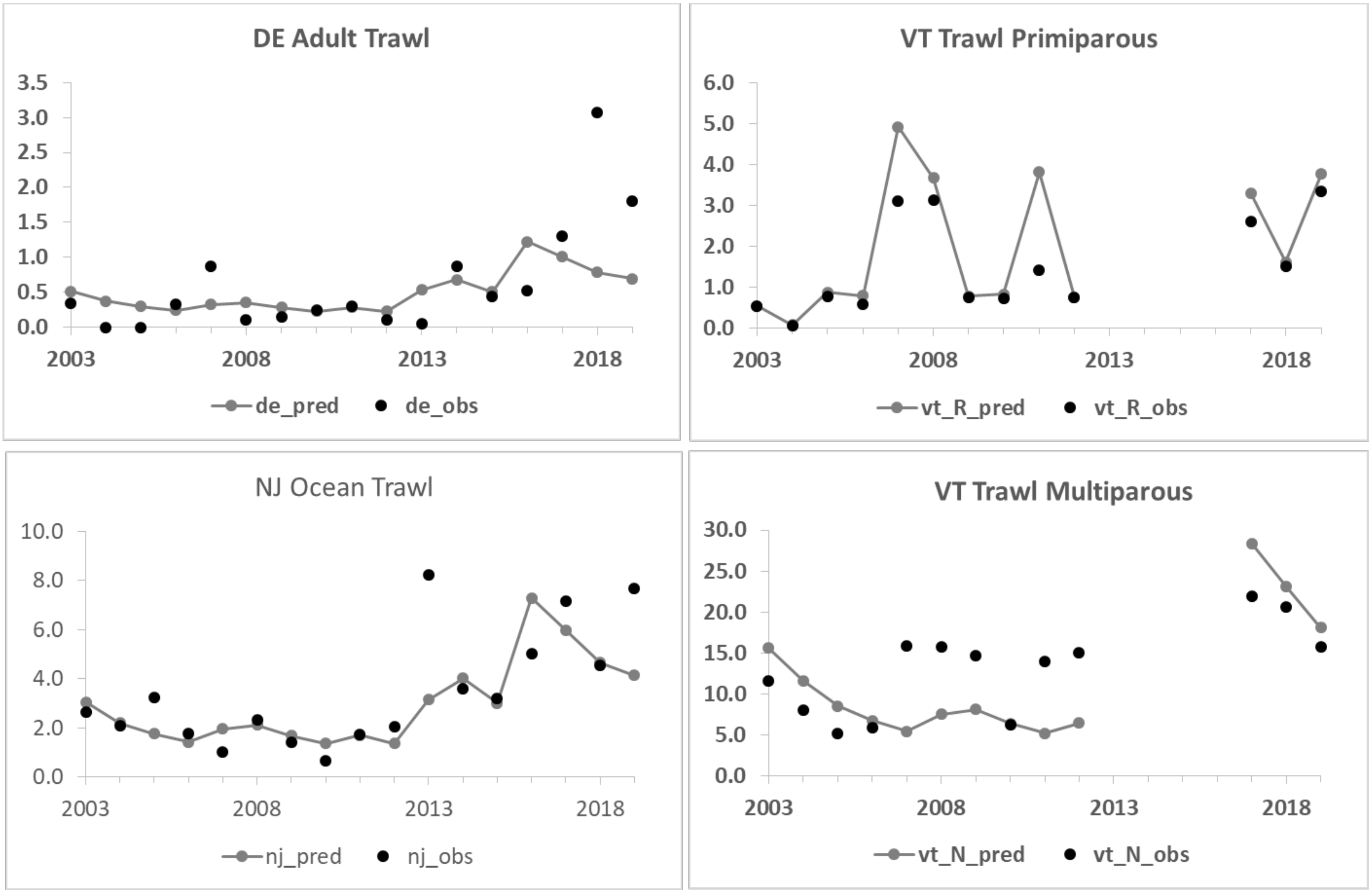

Figure 4. CMSA model fits to the indices for the Delaware (DE) Adult Trawl, New Jersey (NJ) Ocean Trawl, and Virginia Tech (VT) Trawl Surveys for primiparous and multiparous male horseshoe crabs.

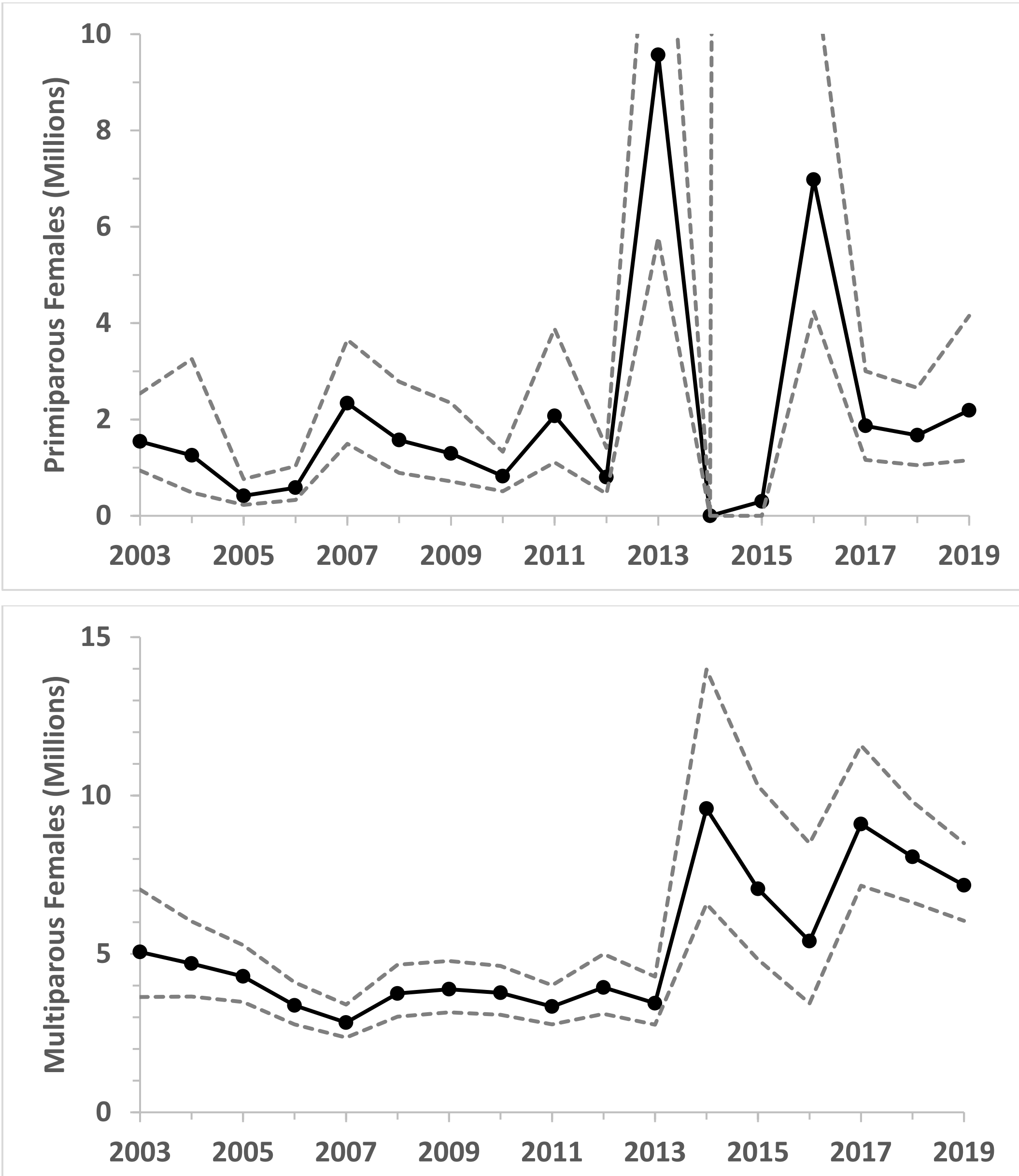

Figure 5. CMSA model estimated primiparous and multiparous female abundance with lower and upper 95% confidence limits. Upper confidence limits for 2013-2016 extend beyond y-axis for primiparous crabs due to missing years of data from the Virginia Tech Trawl Survey.

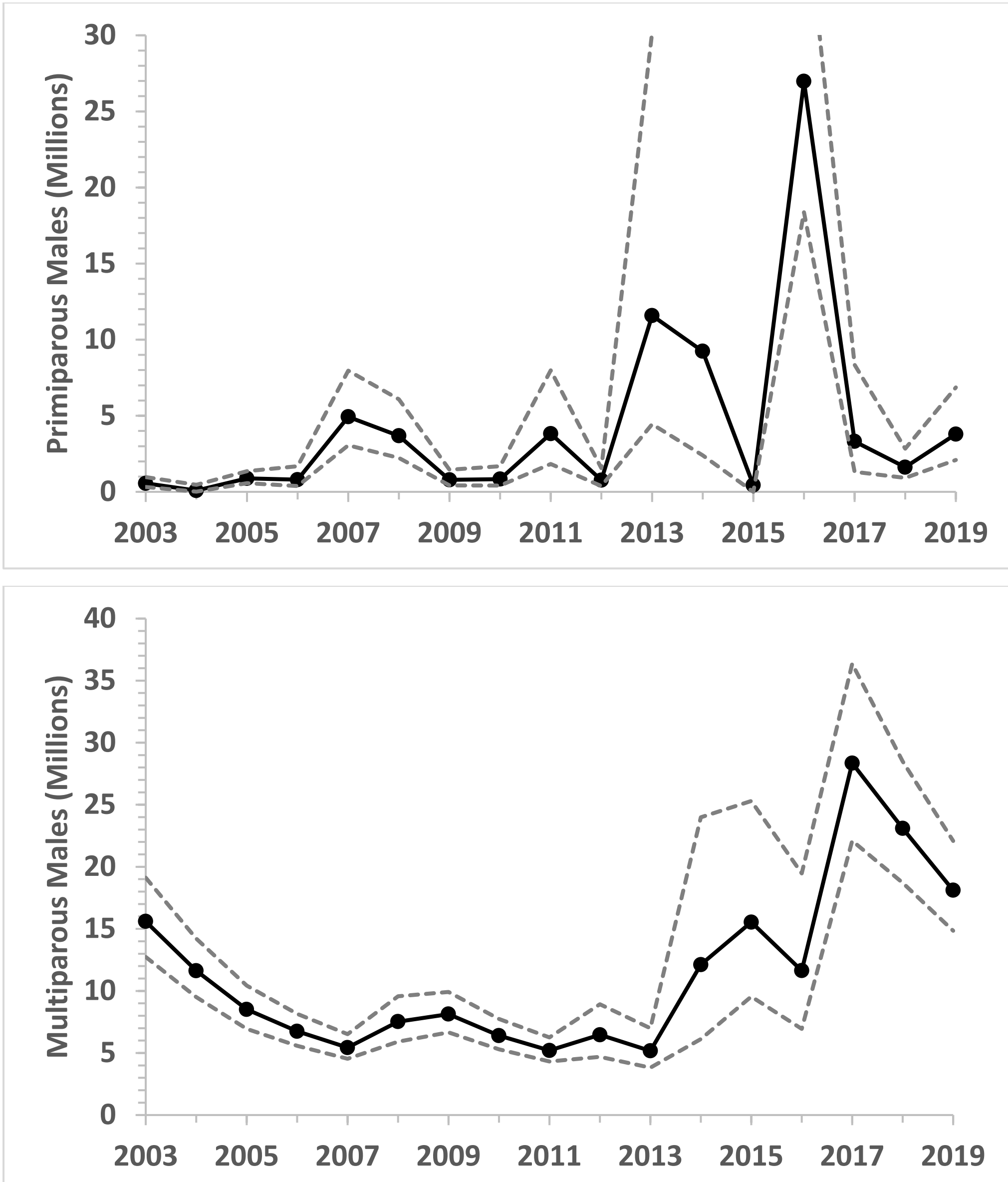

Figure 6. CMSA model estimated primiparous and multiparous male abundance with lower and upper 95% confidence limits. Upper confidence limits for 2013-2016 extend beyond y-axis for primiparous crabs due to missing years of data from the Virginia Tech Trawl Survey.

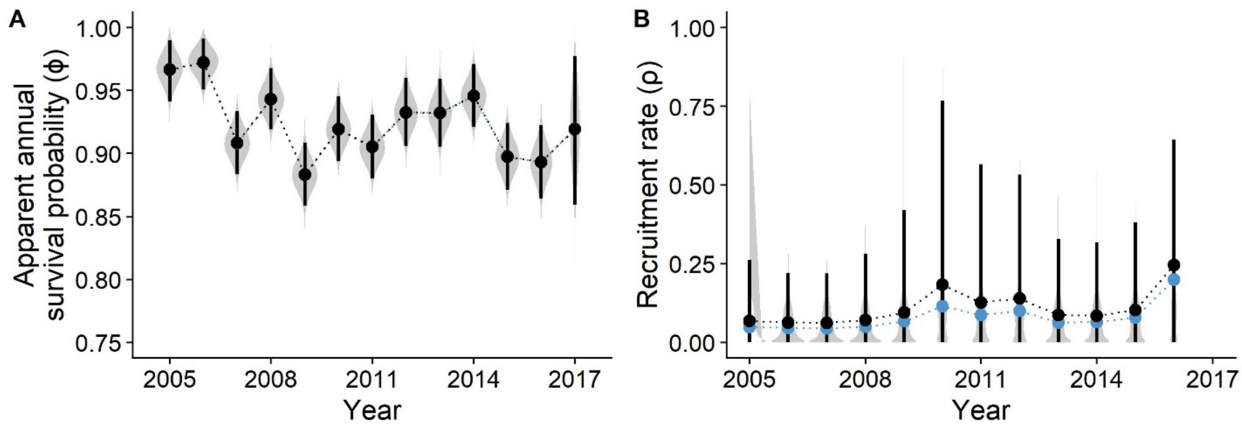

Figure 7. Estimates of survival (A) and recruitment (B) over time for red knot , 2005-2018. Gray shaded regions show the full posterior distributions. Black points and vertical lines represent posterior means and 95% credible intervals. Blue points represent the medians of the posterior distributions.

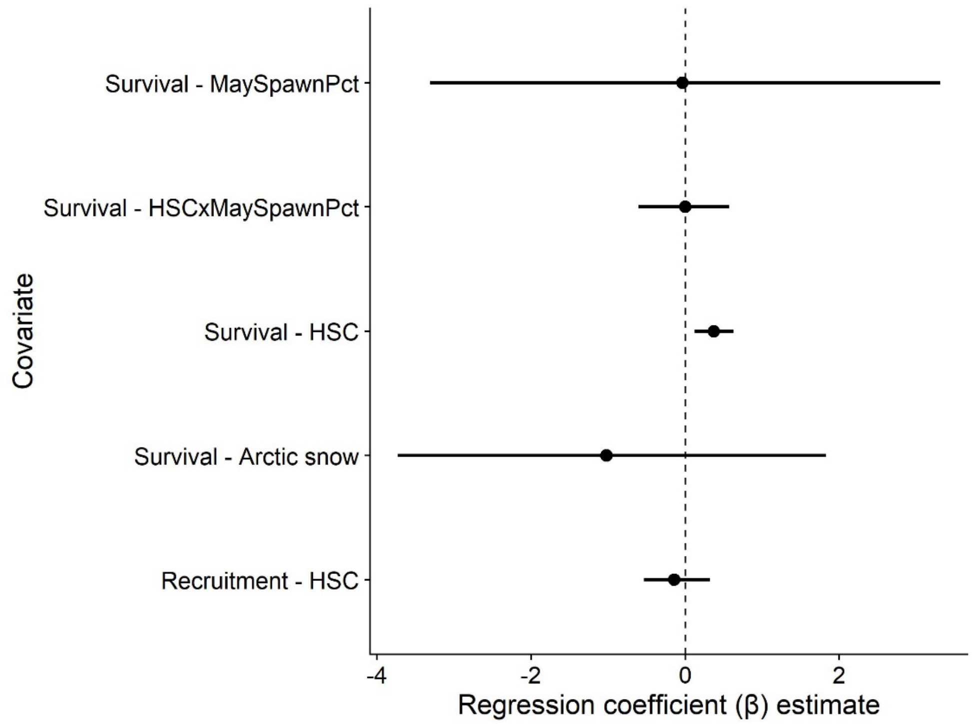

Figure 8. Estimated effects of horseshoe crab abundance, spawn timing, and Arctic snow on red knot survival probability and recruitment rate. Points represent posterior means of the standardized regression coefficients and vertical lines represent 95% credible intervals.

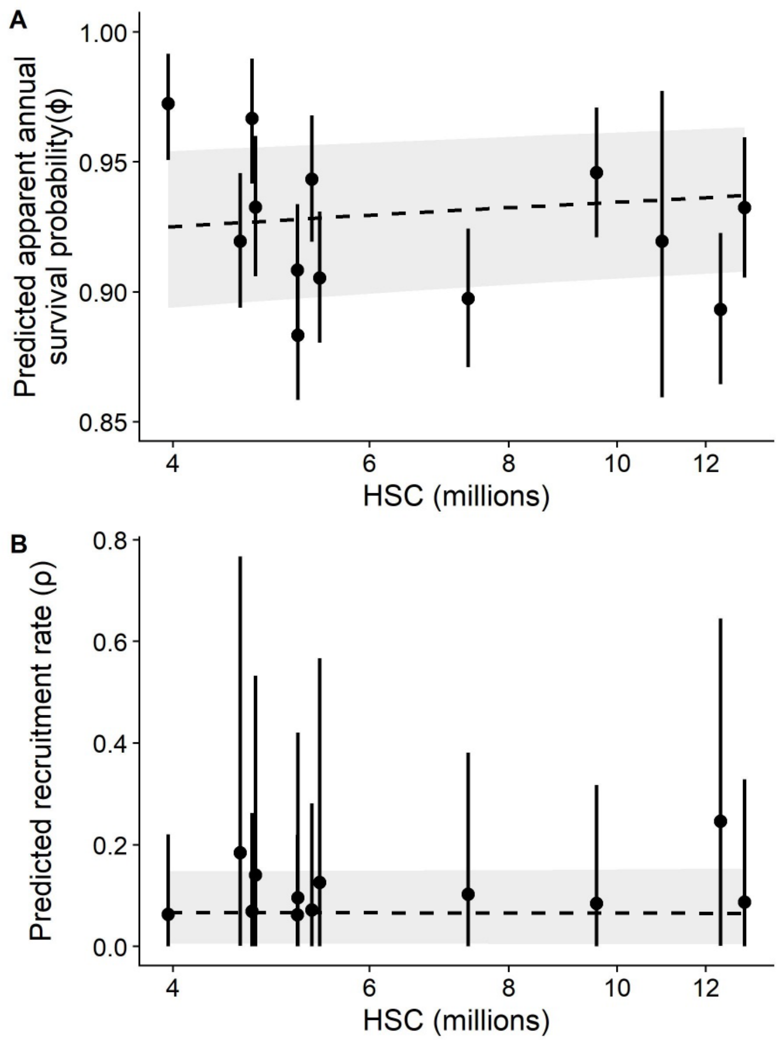

Figure 9. Estimated relationship between horseshoe crab abundance and red knot demographic rates. The black dashed line and gray shaded region show the mean and 95% credible interval of the predicted values. Points and vertical lines show the mean and 95% credible interval of model estimates.

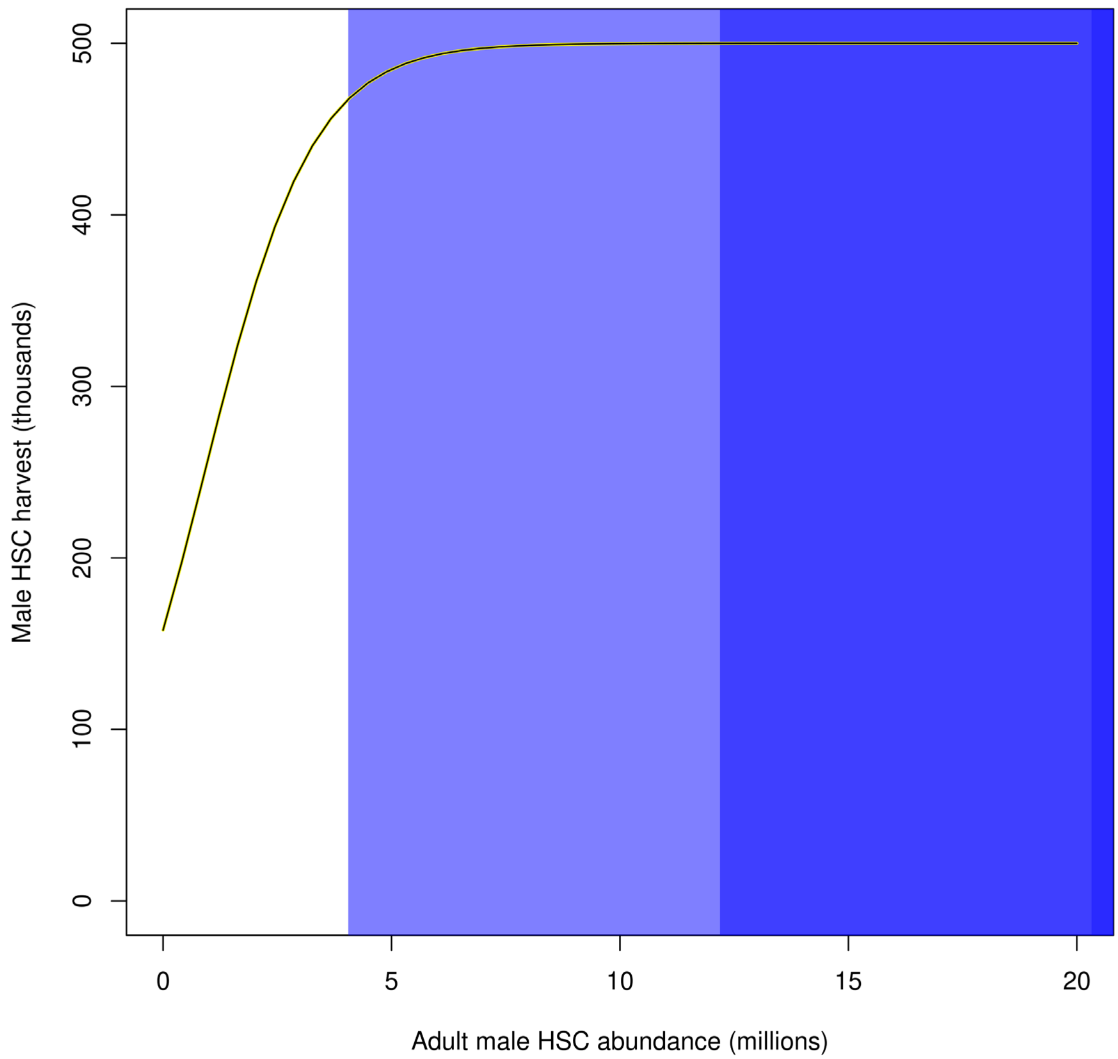

Figure 10. Optimal male bait harvest function for the canonical version of the revised ARM model , with $H^{f}_{\max}$ = 210,000 and $H^{m}_{\max}$= 500,000. Vertical blue lines indicate actual male abundance values in a particular year, in one of 10,000 simulated horseshoe crab populations; many of these values are larger than the upper limit of the x-axis used here and thus are not shown.

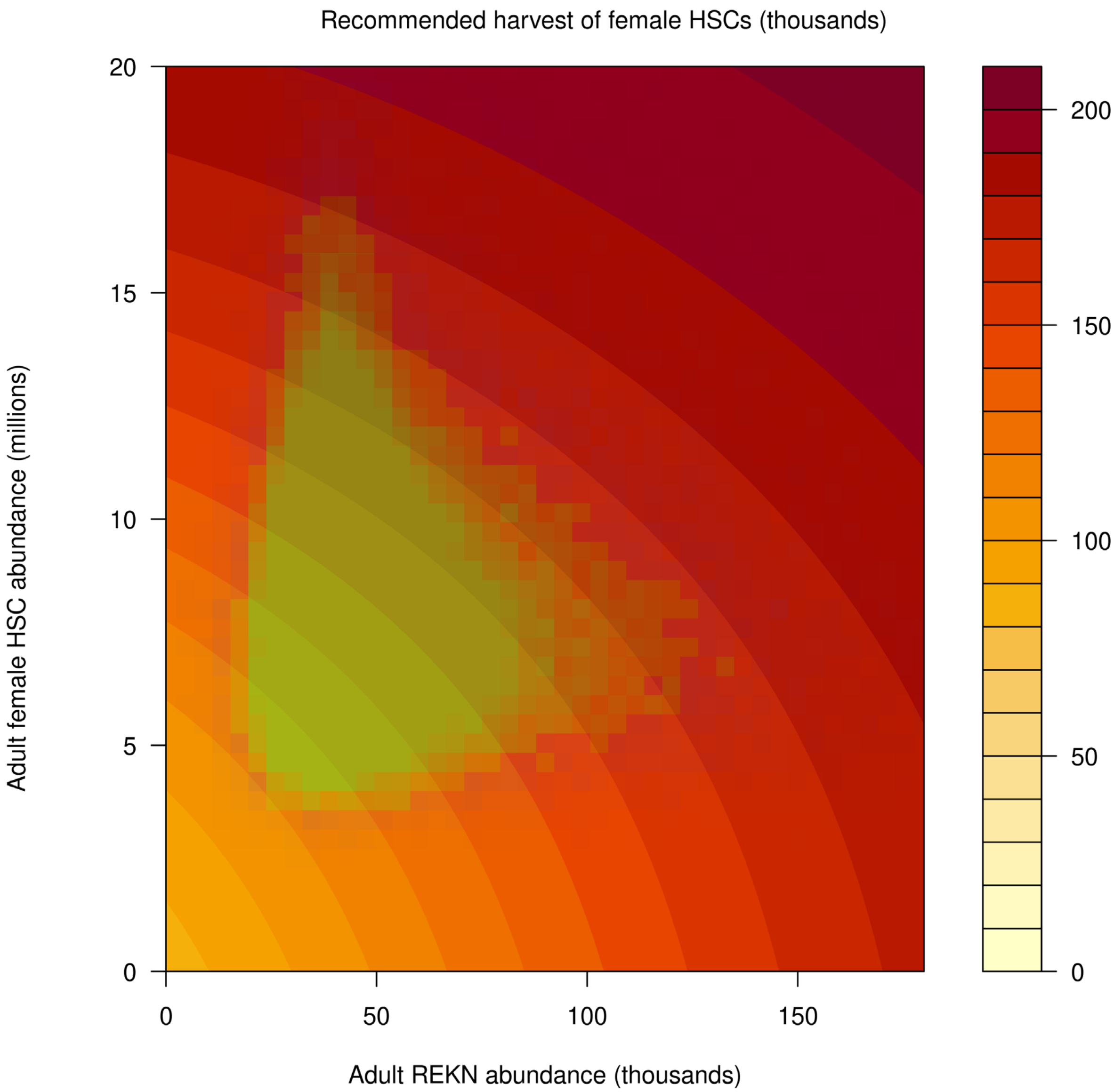

Figure 11. Optimal female bait harvest function for the canonical version of the revised ARM model , with $H^{f}_{\max} = 210,000$ and $H^{m}_{\max} = 500,000$. Recommended harvest depends on both female horseshoe crab (HSC) and adult red knot (REKN) abundances. Transparent green and blue overlay represents a non-parametric kernel, indicating where the bulk of the values of HSC and REKN abundances for the first 10 years of 10,000 simulations over 100 years: the green cells collectively contain 75% of the observations, the blue an additional 20%.

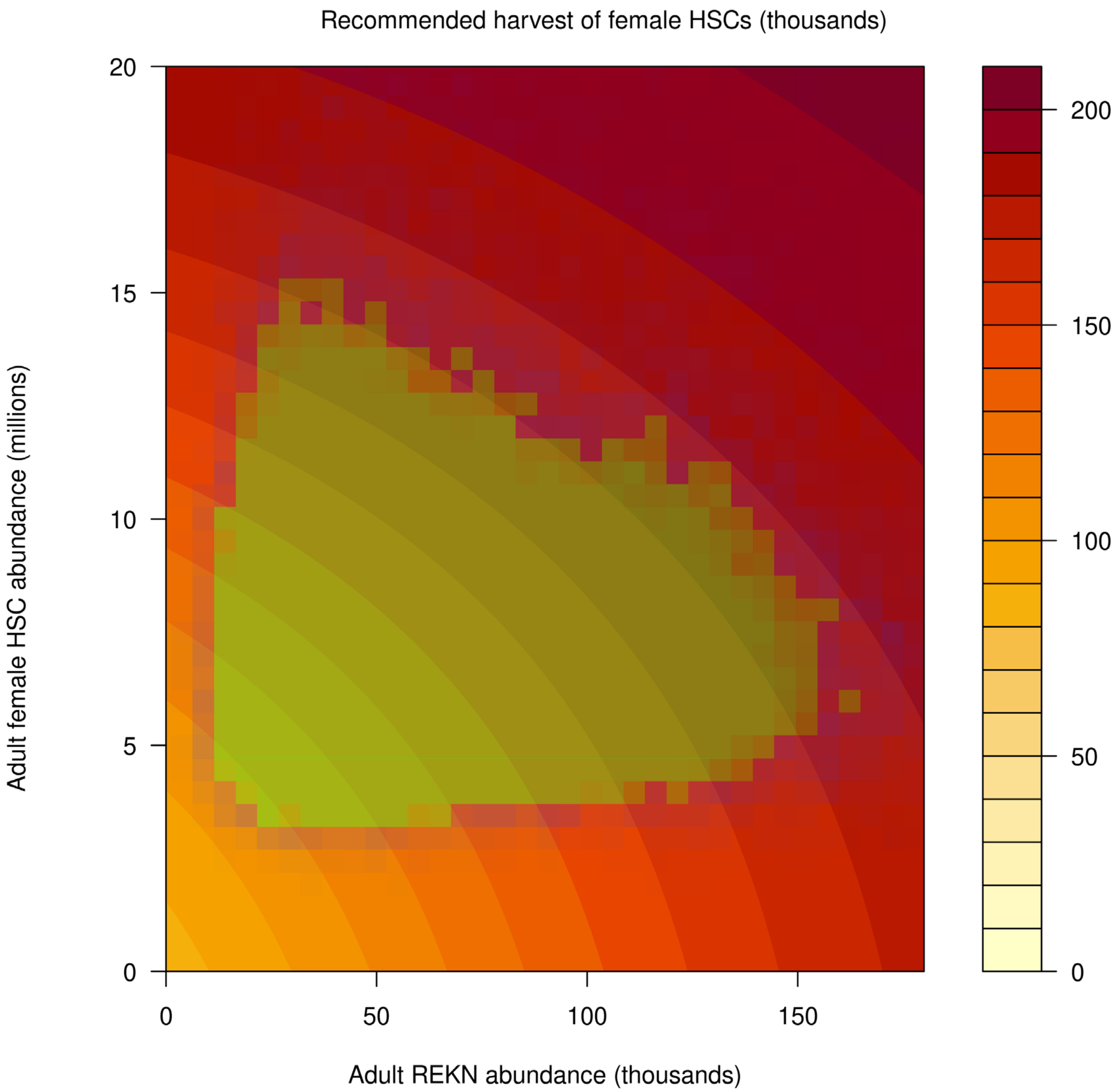

Figure 12. Optimal female bait harvest function for the canonical version of the revised ARM model , with $H^{f}_{\max} = 210{,}000$ and $H^{m}_{\max} = 500{,}000$. Recommended harvest depends on both female horseshoe crab (HSC) and adult red knot (REKN) abundances. Transparent green and blue overlay represents a non-parametric kernel, indicating where the bulk of the values of HSC and REKN abundances for years 11-20 of 10,000 simulations over 100 years: the green cells collectively contain 75% of the observations, the blue an additional 20%.

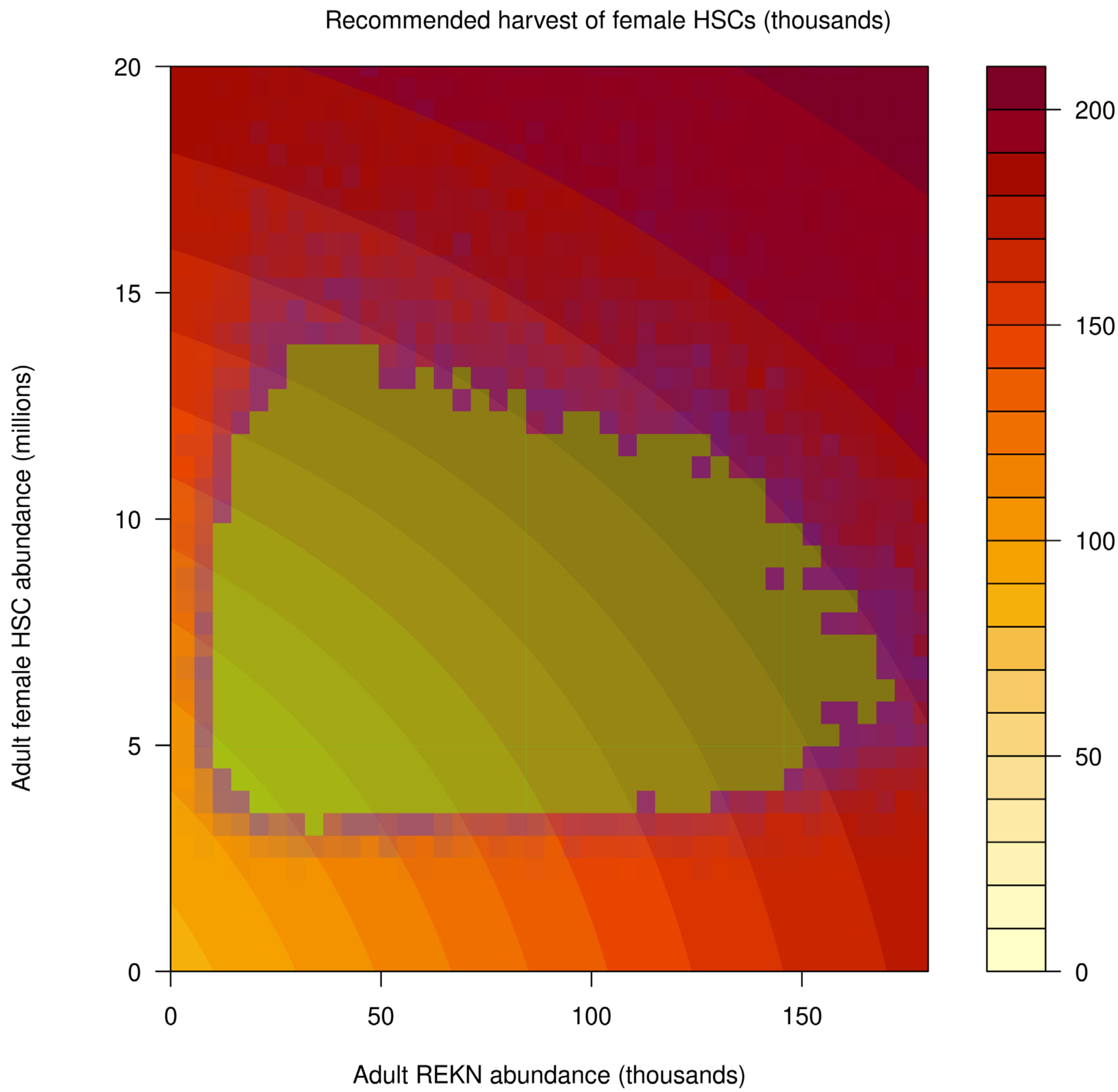

Figure 13. Optimal female bait harvest function for the canonical version of the revised ARM model , with $H^{f}_{\max} = 210,000$ and $H^{m}_{\max} = 500,000$. Recommended harvest depends on both female horseshoe crab (HSC) and adult red knot (REKN) abundances. Transparent green and blue overlay represents a non-parametric kernel, indicating where the bulk of the values of HSC and REKN abundances for years 21-30 of 10,000 simulations over 100 years: the green cells collectively contain 75% of the observations, the blue an additional 20%.

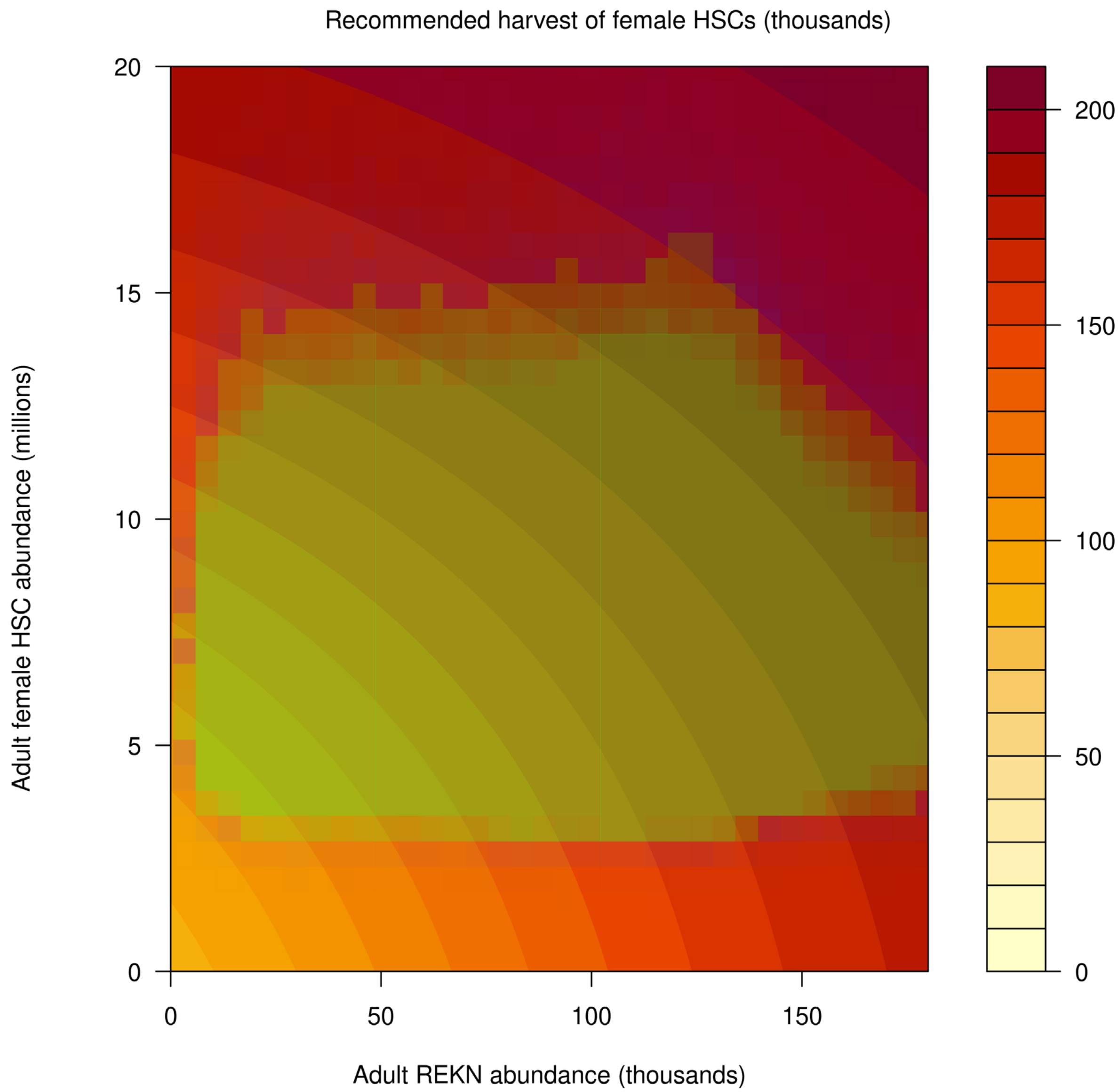

Figure 14. Optimal female bait harvest function for the canonical version of the revised ARM model, with $H^{f}_{\max} = 210,000$ and $H^{m}_{\max} = 500,000$. Recommended harvest depends on both female horseshoe crab (HSC) and adult red knot (REKN) abundances. Transparent green and blue overlay represents a non-parametric kernel, indicating where the bulk of the values of HSC and REKN abundances for years 31-100 of 10,000 simulations over 100 years: the green cells collectively contain 75% of the observations, the blue an additional 20%.

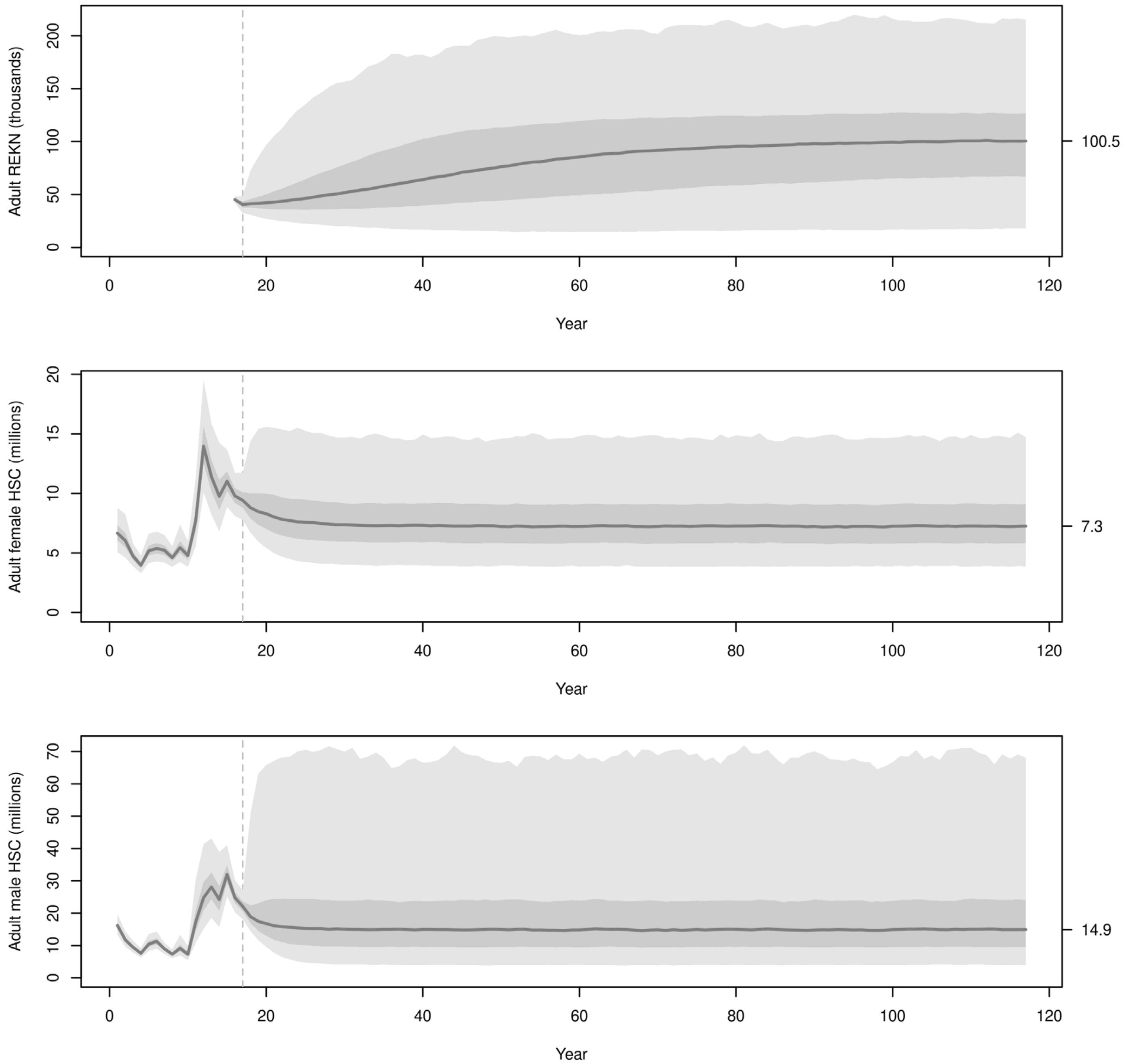

Figure 15. Summary of population trajectories for 10,000 simulated populations of horseshoe crabs and red knots under the optimal harvest policy for the canonical ARM model. Curves to the left of the vertical dashed gray line shows random draws from distributions based on actual estimates; simulated values begin to the right of the line. The dark gray line shows the median; dark gray region indicates the 25th and 75th percentile, or the 50% confidence interval; light gray region is bounded by the 2.5th and 97.5th percentiles, or the 95% confidence interval. Value in the right margin is the median at year 100 of the simulation (year 118 of the time series). Year 1 corresponds to 2003; dashed line is at 2019.

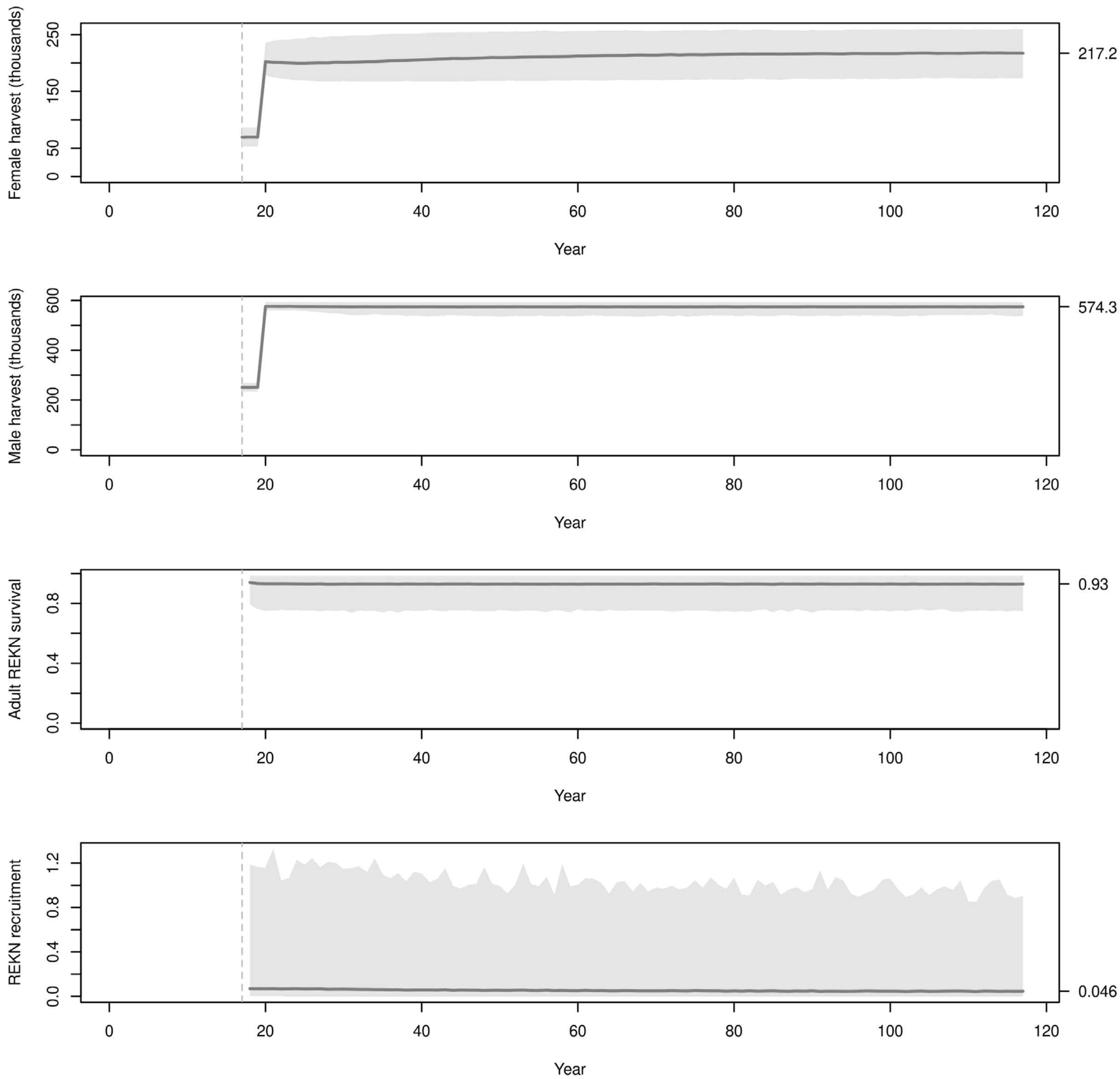

Figure 16. Summary of female and male horseshoe crab bait harvest and red knot (REKN) population parameters for 10,000 simulated populations under the optimal harvest policy for the canonical ARM model. The vertical dashed gray line lies at 2019; year 1 is 2003. The dark gray line shows the median; gray region is bounded by the 2.5th and 97.5th percentiles. Value in the right margin is the median at year 100 of the simulation (year 118 of the time series). Year 1 corresponds to 2003; dashed line is at 2019. Note that female and male harvest here include the 'background harvest' due to biomedical use and bycatch.

EARTHJUSTICE

January 18, 2022

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

VIA ELECTRONIC MAIL

Re: Proposed "Revision to the Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Inclusive of Red Knot Conservation"

Dear Commissioners:

I write on behalf of New Jersey Audubon and Defenders of Wildlife regarding the Atlantic States Marine Fisheries Commission's ("ASMFC" or "Commission") upcoming decision on a proposal to revise the Adaptive Resource Management ("ARM") Framework governing the bait harvest of horseshoe crabs. Specifically, as set forth in detail below, the parties to this letter strongly urge the Commission not to approve the proposed Framework Revision[1] that is scheduled for consideration at the Commission's meeting on January 26, 2022.[2] The proposed Framework Revision would dangerously jeopardize a critical food source for the *rufa* red knot, a shorebird listed as threatened under the Endangered Species Act ("ESA"). If the Commission were to approve the proposed revision, the resulting management changes would threaten to further imperil the red knot and would set ASMFC on a course to violate the ESA. Accordingly, the Commission should not approve the proposed Framework Revision.

I. Introduction

Each year, a population of red knots[3] completes one of the most epic migrations in the animal kingdom. Starting from Tierra del Fuego at the southern tip of South America, the red knots fly more than 9,000 miles to their breeding grounds in the Arctic Circle. For most red knots, the final staging area before the Arctic Circle is the Delaware Bayshore, where their stopover coincides with another ecological marvel: the spawning of millions of horseshoe crabs that emerge from the water and lay clusters of around 4,000 eggs, with the potential for an individual

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[1] ASMFC, Adaptive Resource Management Subcommittee, Draft "Revision to the Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Inclusive of Red Knot Conservation" (2021) ("Framework Revision") (beginning at page 28 of PDF), http://www.asmfc.org/files/Meetings/2022WinterMeeting/HorseshoeCrabBoard_Jan2022.pdf.
[2] ASFMC, ASMFC 2022 Winter Meeting Webinar, January 25-27: Preliminary Agenda, http://www.asmfc.org/home/2022-winter-meeting.
[3] In this document, "red knot" refers to the *rufa* subspecies.

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to lay more than 100,000 eggs over the course of several nights.[4] For red knots that have already flown thousands of miles at enormous physiological expense, the eggs provide essential replenishment, enabling a doubling of body mass in just 10 to 14 days, versus 21 to 28 days at comparable stopovers where clams and mussels are eaten.[5] This unique resource fuels the duration of their journey.

In recent decades, this migratory system has been severely strained. The harvest of horseshoe crabs for the bait and biomedical industries increased sharply in the late twentieth century, depleting the supply of eggs awaiting red knots. By the first decade of this century, the peak count of red knots stopping at Delaware Bay had dropped roughly 70 percent from two decades earlier. In 2015, the U.S. Fish and Wildlife Service ("FWS" or "Service") formally listed the *rufa* red knot as threatened under the Endangered Species Act.

ASMFC adopted a fishery management plan for the horseshoe crab harvest in 1998.[6] Since the 2013 fishing season, the Commission has set harvest quotas using an ARM Framework that links the allowable harvest to the red knot stopover population. The Commission has largely prohibited the bait harvesting of female horseshoe crabs in Delaware Bay since 2006, and the ARM process has selected for zero female harvesting every year since it was introduced.

Nevertheless, the red knot ESA listing and existing horseshoe crab harvest strategy have not proven sufficient to reverse population declines in either species. In 2021, the peak count of red knots at Delaware Bay reached a record low, while the estimated Delaware Bay horseshoe crab population has remained at historically low levels. All signs point to the need for additional measures to protect red knots and ensure an adequate food supply.

Unfortunately, instead of considering new measures to increase and restore Delaware Bay's horseshoe crab population, ASMFC is poised to consider adopting measures that would yield the opposite outcome. Indeed, ASMFC is considering the most dramatic weakening of protections in the history of its management of the horseshoe crab harvest. The proposed changes would result in lifting the prohibition on harvesting female horseshoe crabs, further imperiling the food supply for the remaining red knots. Were the Commission to approve these ill-advised changes, it would risk running afoul of the Endangered Species Act.

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[4] *See* U.S Fish & Wildlife Service, The Horseshoe Crab 1 (Aug. 2006), https://www.fws.gov/northeast/pdf/horseshoe.fs.pdf.

[5] *See* Lawrence Niles et al., *Effects of Horseshoe Crab Harvest in Delaware Bay on Red Knots: Are Harvest Restrictions Working?*, 59 BioScience 153, 154 (2009). Compared to other food sources, horseshoe crab eggs are superabundant, energy-rich, and easy to digest.

[6] *See generally* ASMFC, Interstate Fishery Management Plan for Horseshoe Crab (Fishery Management Report No. 32) (Dec. 1998) ("Horseshoe Crab FMP").

II. Since the 2015 ESA listing, the condition of the red knot has grown more dire.

At the outset, it is critical to recognize that 2022 marks the worst possible time since the listing of the red knot under the ESA for ASMFC to consider liberalizing rules for bait harvest of a species that provides a key red knot food source. When listing the *rufa* red knot as "threatened" under the ESA, FWS cited several studies indicating that red knot abundance had declined, "probably sharply," since the 1980s.[7] At Delaware Bay, peak spring population for 2005-2014 was, on average, 70 percent lower than when aerial surveys began in the early 1980s.[8] Over the past decade, the population had shown some signs of stabilizing at this low level. But aerial surveys in 2021 recorded a peak count of only 6,880 individuals—by far the lowest count since surveys began.[9] These figures are ominous for the entire subspecies, as "Delaware Bay provides the final Atlantic coast stopover for a significant majority (50 to 80 percent) of the red knot population making its way to the arctic breeding grounds each spring."[10] Despite eight years of ASMFC horseshoe crab harvest management under an adaptive framework that was supposed to ensure a sufficient food supply for migrating red knots, the most recent count reflects a new low for the affected red knot population and a dire warning about the subspecies' future viability.

Strong scientific evidence links red knot survival and demography to horseshoe crab egg availability at Delaware Bay. In its 2014 assessment for the ESA listing, FWS found that "[r]educed food availability in Delaware Bay due to commercial harvest of the horseshoe crab . . . is considered a primary causal factor in red knot population declines in the 2000s."[11] Reduced food availability is a particular threat for the Southern wintering population of red knots, which is disproportionately reliant on the Delaware Bay staging area.[12] Indeed, while the number of red knots at Delaware Bay indicates subspecies-wide declines over the past several decades, the declines have been especially profound at Southern wintering areas. The average red knot count at Tierra del Fuego for 2018-2020 declined more than 75 percent from average counts in the 1980s and 2000, and since 2011 has flattened at a relatively low level.[13] According to FWS, "[R]educed food availability at just one key migration stopover area (Delaware Bay) is considered the driving factor behind the sharp decline in the Southern wintering population in the

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[7] FWS, Rufa Red Knot Background Information and Threats Assessment (Supplement to Endangered and Threatened Wildlife and Plants; Final Threatened Status for the Rufa Red Knot) 85 (Nov. 2014) ("FWS Listing Supplement"). While FWS primarily analyzed red knot population trends within specific regions, it "note[d] a temporal correlation between declines at Tierra del Fuego and Delaware Bay." *Id.* at 84.
[8] *Id.* at 99. The Service explained that these figures reflected overall population declines, not merely a redistribution of red knots to alternate migration routes. *See id.* 99-100.
[9] Minority Opinion of Wendy Walsh, ARM Subcommittee Member and FWS Species Lead for the *rufa* red knot, *in* Framework Revision, at 115 ("FWS Species Lead Opinion").
[10] FWS Listing Supplement 12.
[11] FWS, Endangered and Threatened Wildlife and Plants; Final Threatened Status for the Rufa Red Knot, 79 Fed. Reg. 73,706, 73,707 (Dec. 11, 2014). The listing became effective on January 12, 2015. *See id.* at 73,706.
[12] *See* FWS, Species Status Assessment Report for the Rufa Red Knot (Version 1.1), at 9 (Sept. 2020) ("FWS 2020 Assessment").
[13] FWS, Draft Recovery Plan for the Rufa Red Knot 8 (May 2021) ("Draft Recovery Plan").

2000s."[14] FWS views the Southern wintering population as "a bellwether for the subspecies as a whole,"[15] which makes this population decline especially concerning.

As FWS has stated, "Studies have shown red knot survival rates are influenced by the condition (weight) of birds leaving the Delaware Bay staging area in spring."[16] In years when horseshoe crab spawning was delayed due to weather conditions, a very low percentage of red knots was able to reach a weight of 180 grams—a threshold that has frequently been used to assess whether red knots were able to achieve sufficient weight gain to complete their migratory journey and subsequent reproduction.[17] Research has also shown that, while red knots arriving relatively late to Delaware Bay were able to compensate by gaining weight at a higher rate, that was not the case in years with low horseshoe crab egg availability.[18] There is simply no question that horseshoe crab management in Delaware Bay impacts the fate of the red knot.

III. ASMFC has long prohibited the harvest of female horseshoe crabs in the Delaware Bay region.

For the past eight years, ASMFC has adopted an approach to horseshoe crab management that at least recognized the fundamental need to promote red knot recovery by restoring horseshoe crab numbers—and in particular female crab numbers—before any expansion of the horseshoe crab bait harvest could be considered. ASMFC issued its first fishery management plan ("FMP") for horseshoe crabs in December 1998, with the first mandatory restrictions implemented in 2000.[19] The plan was prompted by the Commission's October 1997 vote to create an FMP for horseshoe crabs and responded to "[c]oncern over increased exploitation of horseshoe crabs, particularly in the mid-Atlantic States . . . expressed by state and federal fishery resource agencies, conservation organizations, and fisheries interests."[20] The FMP described horseshoe crabs as "play[ing] an important ecological role in the food web" for several species, including red knots.[21]

In 2012, ASMFC approved Addendum VII to the Horseshoe Crab FMP, in which it acknowledged that "the red knot (*rufa* subspecies), one of many shorebird species that feed on horseshoe crab eggs, is at low population levels. Red knots have shown no sign of recovery . . . despite a nearly four-fold reduction in horseshoe crab landings since 1998."[22] Addendum VII implemented the ARM Framework, which was "designed to assist managers with future horseshoe crab harvest regulations by accounting for multiple species effects, focusing on red

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[14] *Id.* at 14.
[15] *Id.* at 13.
[16] FWS 2020 Assessment 25.
[17] *See* FWS Listing Supplement 254.
[18] *See id.* at 253.
[19] Horseshoe Crab FMP iv.
[20] *Id.* at 1.
[21] *Id.* at 12-13.
[22] ASMFC, Addendum VII to the Interstate Fishery Management Plan for Horseshoe Crabs for Public Comment (Adaptive Resource Management Framework) at 1 (Feb. 2012).

knot rebuilding in the Delaware Bay Region."[23] As such, Addendum VII applied only to states in the Delaware Bay region: New Jersey, Delaware, and applicable waters of Maryland and Virginia.[24]

Each year, the ARM model has utilized estimates of the abundance of horseshoe crabs and red knots in the Delaware Bay region to select one of five possible "harvest packages" for horseshoe crabs harvested for use in the bait industry. And each year, the ARM model has selected the same package: 500,000 males and 0 females.[25] These limits apply to the entire Delaware Bay region, and the Commission allocates the male harvest quota among the four states. The model was designed not to select for female harvest until either the female horseshoe crab or the red knot population recovered to a specified threshold, which neither species has done.[26]

Application of this ARM Framework has been deemed by federal wildlife officials to be central to ESA compliance for ASMFC's management of the horseshoe crab bait harvest. In listing the red knot, FWS stated, "We do not consider the [horseshoe crab] harvest a threat under the science-based management framework that has been developed and adopted to explicitly link harvest quotas to red knot population growth."[27] However, the Service has repeatedly qualified that statement to acknowledge the uncertainties about the adequacy of the red knot food supply. For example, at the time of the initial listing, the Service stated, "[B]ecause of the uncertain trajectory of horseshoe crab population growth, it is not yet known if the HSC egg resource will continue to adequately support red knot population growth over the next decade."[28] In 2020, the Service observed, "[T]he continued sufficiency of future crab egg supplies remains uncertain and the management of this fishery remains controversial."[29] And in its Draft Rufa Red Knot Recovery Plan of 2021, the Service noted that "the sufficiency of future crab egg resources is still uncertain."[30] Thus, the Service itself has repeatedly raised concerns about the adequacy of the existing ARM Framework—even before the changes to that framework that are now being considered. And more fundamentally, regardless of the Service's statements, the persistent inability of either red knots or horseshoe crabs to recover from population declines after eight years of the ARM Framework calls into question the adequacy of existing management to ensure that horseshoe crab harvest does not harm and further imperil the red knot population. The record in no way supports weakening protections at this time.

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[23] *Id.* at 2.
[24] *See id.* at 1.
[25] *See* Framework Revision 22.
[26] *See id.*
[27] 79 Fed. Reg. at 73,707.
[28] *Id.* at 73,708.
[29] FWS 2020 Assessment 20.
[30] Draft Recovery Plan 10.

IV. The proposed Framework Revision would imperil red knots by further reducing their food supply.

Despite the precarious condition of the red knots and the absence of progress toward recovery under existing management, ASMFC is now considering changes that would open the door for even more intensive bait harvest of horseshoe crabs in Delaware Bay. The proposed Framework Revision would make a number of significant changes to the ARM model. These include deeply problematic changes that would pave the way for allowing a female horseshoe crab harvest, despite the continued low population counts of both horseshoe crabs and red knots.

A key aspect of the proposed Framework Revision is the method for estimating the horseshoe crab population. Since the ARM model was first utilized, it has exclusively used horseshoe crab population figures from the Virginia Tech Horseshoe Crab Trawl Survey ("VT survey") whenever they are available. The VT survey is designed specifically to count horseshoe crabs in Delaware Bay, and FWS has called it "the best benthic trawl survey to support the ARM."[31] Citing a conclusion of the Commission's Horseshoe Crab Technical Committee, FWS further stated that "efforts have not identified a method by which . . . alternate data sets can be appropriately used for the full and proper functioning of the ARM models."[32]

The Framework Revision would drastically downgrade the model's reliance on the VT survey in favor of two other surveys that only incidentally count horseshoe crabs: the New Jersey Ocean Trawl Survey and the Delaware Fish and Wildlife Adult Trawl Survey.[33] Rather than specifically target the horseshoe crab population, these are general surveys of marine species, and horseshoe crabs are counted only to the extent that they are collected as part of these broader surveys.[34] Yet the Framework Revision would give all three models equal weight.[35]

In a review of the proposed Framework Revision that opposed this approach, FWS Species Lead on the *rufa* red knot and ASMFC ARM Subcommittee member Wendy Walsh described the foreseeable impact of the new approach. Namely, it will generate significantly higher horseshoe crab population estimates based predominantly on surveys that are not purpose-designed to count horseshoe crabs.[36] The review therefore urged the Subcommittee, at the very least, to accord greater weight to the VT survey based on its "technical rigor and deliberate design" and "the high level of confidence that stakeholders have expressed in" it, among other reasons.[37] As the review pointed out, even under the existing model, inflated population estimates from the three equally weighted surveys would have selected for the harvest of female horseshoe crabs in two

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[31] FWS Listing Supplement 247.
[32] *Id.* (citing ASMFC, News Release, "ASMFC Horseshoe Crab Board Sets 2015 Specifications for Horseshoe Crabs of Delaware Bay Origin" (Oct. 30, 2014)).
[33] Framework Revision 55.
[34] *See id.* at 43.
[35] *See id.* at 55.
[36] FWS Species Lead Opinion 111.
[37] *Id.*

of the four years for which data are available.[38] The New Jersey and Delaware surveys diverge from the purpose-designed VT survey in finding that the horseshoe crab population has modestly increased in recent years, which only heightens concerns about an abrupt and disproportionate reliance upon those surveys.[39]

Another troubling aspect of the proposed Framework Revision is the elimination of thresholds below which the ARM model will not select for female horseshoe crab harvest. The model's current utility function will not select for any female horseshoe crab harvest until the Delaware Bay region hosts at least 81,900 red knots or 11.2 million female horseshoe crabs.[40] The proposed revision abandons these constraints and would allow female horseshoe crab harvest even when neither species has reached its designated threshold.[41] The review by FWS's Species Lead for red knots explained that this revision "does not reflect the values and risk attitudes that were clearly expressed by the original group of stakeholders during initial setup of the existing ARM framework," and "[a] precautionary, risk-averse approach to female crab harvest is a central tenet of the existing framework as expressed by the stakeholders during the initial development and adoption of the ARM. Such a major reinterpretation of this tenet as is represented by the proposed new utility function should not be pursued under the mantle of technical updates."[42]

Fundamentally, it is deeply concerning that ASMFC would allow the "immediate resumption of female crab harvest" based on a new and untested model and despite the absence of any indication of red knot recovery under existing management.[43] The Framework Revision proposal suggested that the model will adapt based on new data, with the aim of reducing inaccuracies over time.[44] But the red knot is a threatened species that recently had a record-low population count and whose survival depends upon the annual availability of horseshoe crab eggs. It cannot afford a management tradeoff that allows for near-term harm based on optimistic data and an untested model in exchange for the mere possibility of fixing inaccuracies in the future.

When listing red knots as threatened, FWS stated, "As long as the ARM is in place and functioning as intended, ongoing horseshoe crab bait harvests should not be a threat to the red knot."[45] Now, however, in response to the proposed Framework Revision, the FWS Species Lead for red knots has warned that "[i]mmediate resumption of female harvest by the means described in the draft report may prompt the USFWS to reconsider if the ARM is functioning as

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[38] *See id.* at 111-12.
[39] *See* Framework Revision figs. 21 & 22.
[40] *See id.* at 21.
[41] *See id.* at 83-84.
[42] FWS Species Lead Opinion 113.
[43] *Id.* at 112.
[44] *See* Framework Revision 21.
[45] FWS Listing Supplement 247.

intended."[46] Yet, despite this admonition, ASMFC now appears poised to adopt the Framework Revision.

V. The proposed Framework Revision puts ASMFC on track to violate the Endangered Species Act.

ASMFC is scheduled to decide whether to adopt the proposed Framework Revision to govern the bait harvest of horseshoe crabs at its 2022 Winter Meeting. This decision is critical to the future of the horseshoe crab and red knot populations. Importantly, it also is critical to ASMFC's compliance with the mandates of the Endangered Species Act. Adopting the Revised Framework and reintroducing the harvest of female horseshoe crabs in Delaware Bay even as the red knot population reaches a new nadir would put ASMFC on track to violate the ESA.

The ESA prohibits any person from "tak[ing] any [endangered] species within the United States or the territorial sea of the United States."[47] Such prohibited "taking" includes actions that "harm" listed species, including "significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding or sheltering."[48] The ESA's "taking" prohibition extends to governmental authorization to take protected species that facilitates such harm by "solicit[ing]" or "caus[ing]" an offense.[49] By regulation, that prohibition extends to the taking of most threatened species, including the red knot.[50]

Like any other association or governmental entity, ASMFC is subject to this ESA taking prohibition.[51] Moreover, ASMFC's fishery management decisions have a direct causal connection to the ultimate bait-harvesting actions that impact horseshoe crabs and red knots.[52] Under the Atlantic Coast Fisheries Cooperative Management Act of 1993, ASMFC's fishery

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[46] FWS Species Lead Opinion 117.
[47] 16 U.S.C. § 1538(a)(1)(B).
[48] 50 C.F.R. § 17.3.
[49] *Strahan v. Coxe*, 127 F.3d 155, 163 (1st Cir. 1997); 16 U.S.C. § 1538(g).
[50] *See* 50 C.F.R. § 17.31(a) (applying the provisions of § 17.21 (addressing endangered species) to threatened species); *id.* § 17.21(a), (c) ("[I]t is unlawful . . . to solicit another to commit or to cause to be committed" the taking of an endangered species.").
[51] The ESA applies to any "person," which is broadly defined. *See* 16 U.S.C. § 1532(13) ("The term 'person' means an individual, corporation, partnership, trust, association, or any other private entity; or any officer, employee, agent, department, or instrumentality of the Federal Government, of any State, municipality, or political subdivision of a State, or of any foreign government; any State, municipality, or political subdivision of a State; or any other entity subject to the jurisdiction of the United States.").
[52] *See, e.g.*, *Sierra Club v. Yeutter*, 926 F.2d 429, 438-39 (5th Cir. 1991) (holding that government agency violated ESA taking prohibition by authorizing logging that destroyed habitat and thereby impaired essential behavioral patterns of listed woodpecker species); *Loggerhead Turtle v. County Council of Volusia County*, 896 F. Supp. 1170, 1181-82 (M.D. Fla. 1995) (holding that county that regulates vehicular access to beaches is liable under ESA for taking of sea turtles caused by nighttime beach driving).

management plans are legally binding upon affected states.[53] Once the Commission issues a plan, states "shall implement and enforce the measures of such plan within the timeframe established in the plan."[54] States are therefore prohibited from authorizing female horseshoe crab harvest in Delaware Bay under the existing framework.[55] The Revised Framework charts a course to lift that critical prohibition. As the FWS Species Lead has noted, lifting that prohibition and applying the Revised Framework would likely yield an immediate authorization for female horseshoe crab harvest in the range of 175,000 to 190,000 individuals per year.[56] Such harvesting of the critical component of the horseshoe crab population on which egg abundance depends threatens significant degradation and modification of red knot habitat at Delaware Bay that would kill or injure red knots by significantly impairing breeding and feeding activities that are essential to the continued existence of the species, as discussed above.[57]

In the Endangered Species Act, Congress adopted a precautionary approach. As the Supreme Court has stated, in the ESA, "Congress has spoken in the plainest of words, making it abundantly clear that the balance has been struck in favor of affording endangered species the highest of priorities, thereby adopting a policy which it described as 'institutionalized caution.'"[58] By setting ASMFC on a path to harm a threatened species whose population shows no sign of recovery, the proposed Framework Revision would fall far short of what the ESA requires.

VI. Conclusion

The Endangered Species Act provides strict protections for the *rufa* red knot, which is listed as threatened under the statute. The red knot's peak stopover population at Delaware Bay is at historically low numbers. Horseshoe crabs, whose eggs nourish the red knot at a critical point in its migration, have not recovered from decades of overharvest. Now is not the time for ASMFC to revise its horseshoe crab management framework in a manner that would allow even greater harvest, including resumption of harvest of the critical female component of the population. Doing so would compound the threats facing the red knot and further jeopardize its recovery, in violation of the ESA. For these reasons, the parties to this letter urge ASMFC not to approve the proposed Framework Revision.

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[53] *See* Atlantic Coastal Fisheries Cooperative Management Act of 1993, Pub. L. 103-206, 107 Stat. 2419, Tit. VIII (codified at 16 U.S.C. § 5101 *et seq.*).
[54] *Id.* § 5104(b)(1).
[55] *Cf. Defenders of Wildlife v. EPA*, 882 F.2d 1294, 1301 (8th Cir. 1989) (EPA's registration of pesticide effected a taking because the pesticide could not be used without such registration).
[56] FWS Species Lead Opinion 113.
[57] *See* 50 C.F.R. § 17.3.
[58] *Tenn. Valley Auth. v. Hill*, 437 U.S. 153, 194 (1978).

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