Stock Assessment Overview: Horseshoe Crab


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Introduction

This document provides an overview of the 2021 Revision of the Adaptive Resource Management (ARM) Framework. The ARM Revision was evaluated and endorsed by an independent panel of scientific experts through the Atlantic States Marine Fisheries Commission's (ASMFC) external peer review process. The objectives of the ARM Revision were to address previous peer review critiques, include many new sources of data and horseshoe crab mortality, and adopt new modeling software since the old software is obsolete. The report represents the best and most recent information for managing horseshoe crabs of Delaware Bay-origin with consideration of the needs of migrating shorebirds.

Management Overview

Horseshoe crabs provide the backdrop for one of the most interesting marine resource management issues along the Atlantic coast. In addition to the role their eggs play as a food source for birds, horseshoe crabs provide bait for commercial American eel and conch fisheries along the coast. Their unique blood is also used by the biomedical industry to produce Limulus Amoebocyte Lysate (LAL). Horseshoe crabs are managed from Maine to Florida by ASMFC through the 1998 Interstate Fishery Management Plan (FMP) for Horseshoe Crab. In 2012, the Commission adopted the use of the ARM Framework for setting harvest levels for horseshoe crabs of Delaware Bay-origin given the important ecological role horseshoe crab eggs play in the food web for migrating shorebirds in that region. The Framework considers the abundance levels of horseshoe crabs and red knots in determining the optimal harvest level in the Delaware Bay Region. For this ARM Revision, the proportion of horseshoe crabs of Delaware Bay-origin from each state was based on genetics and tagging studies. In New Jersey and Delaware, 100% of the horseshoe crabs are of Delaware Bay-origin, while 45% of horseshoe crabs in Maryland and 20% in Virginia are of Delaware Bay-origin.

Red Knot Status

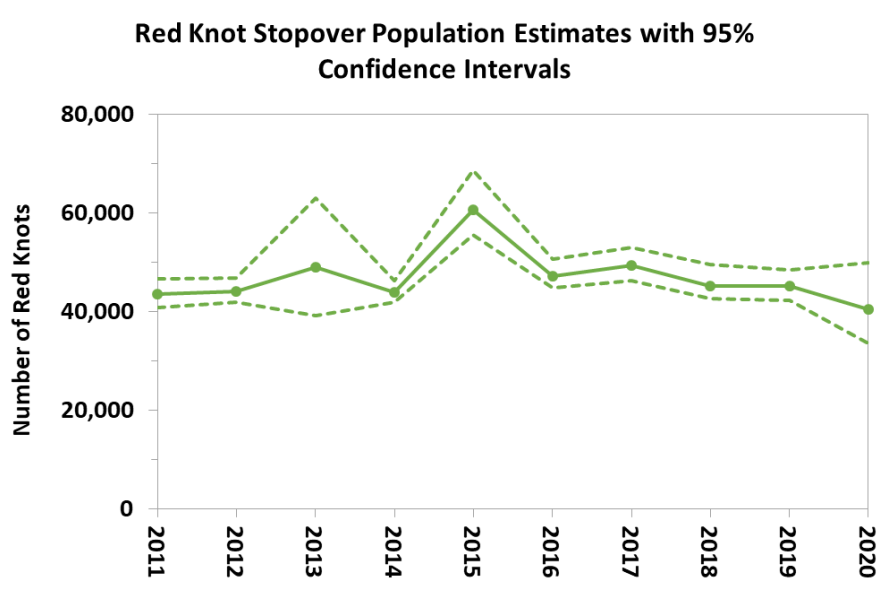
The red knot is one of the many shorebird species that feed on horseshoe crab eggs in the Delaware Bay Region during their annual migration from South America to the Arctic. The red knot was listed as "threatened" under the U.S. Endangered Species Act in January 2014, due to loss of habitat, climate change, timing mismatches between the birds' migration and food availability, and other threats. In May 2021, the U.S. Fish and Wildlife Service (USFWS) released a draft recovery plan for red knots to ensure the species' recovery and resiliency with a goal of delisting by 2080. In July 2021, the USFWS published a proposed rule to designate critical habitat for the red knot. Both the final recovery plan and final critical habitat rule are expected to be released in 2022.

What Data Were Used?

Abundance surveys were used for both red knots and horseshoe crabs to estimate population sizes. The ARM Revision used fishery-dependent data for horseshoe crabs from the commercial bait fishery, dead discard estimates from other fisheries, and mortality estimates from the biomedical industry.

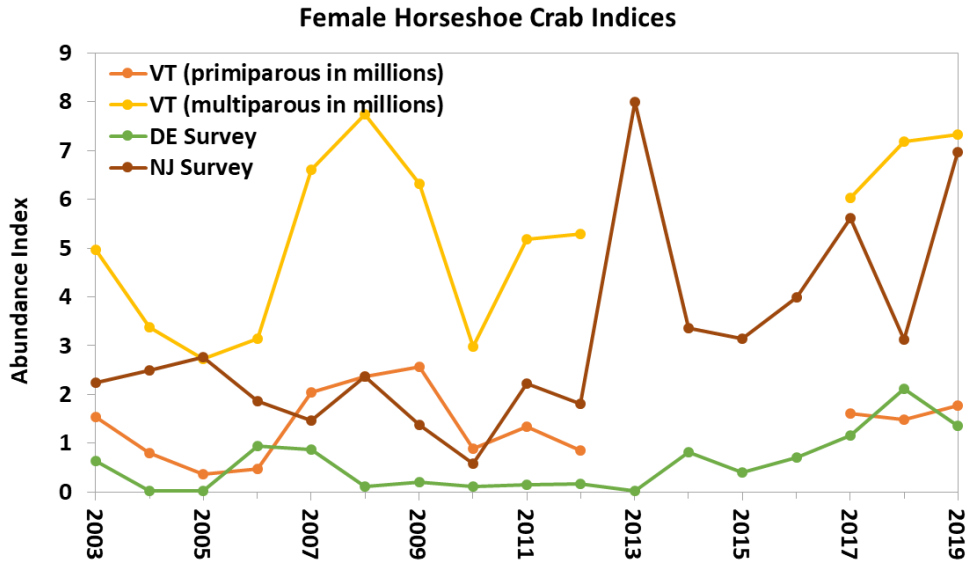
Red Knot Surveys

Mark-resight and count data from New Jersey and Delaware were used to estimate the population of red knots passing through the Delaware Bay. The passage population estimates were fairly stable between 2011 and 2020 at approximately 45,000 birds.



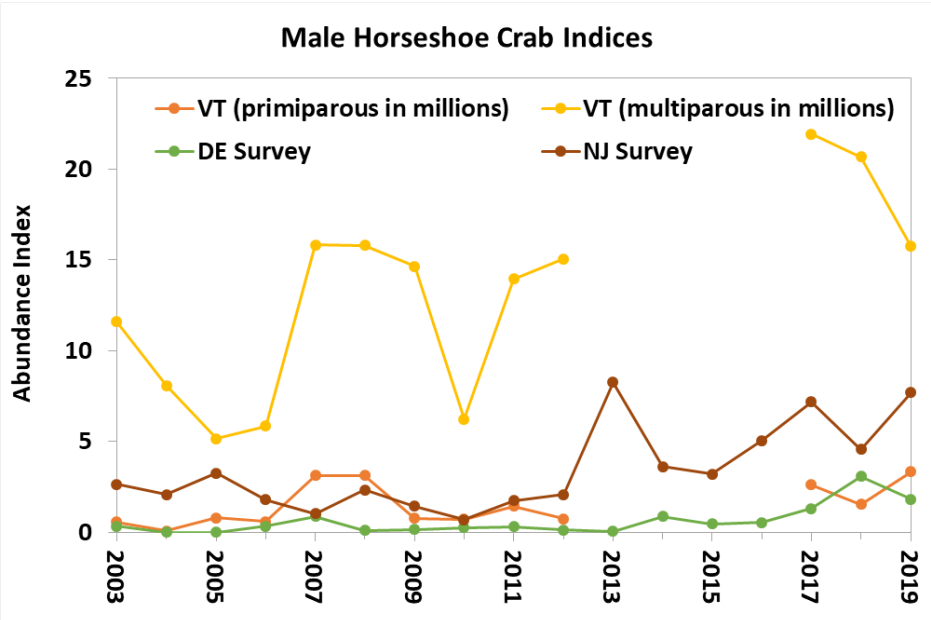
Horseshoe Crabs Surveys

Three fishery-independent surveys were used for the ARM Revision to estimate horseshoe crab abundance: New Jersey Ocean Trawl, Delaware Fish and Wildlife Adult Trawl Survey, and Virginia Tech Horseshoe Crab Trawl Survey. All three surveys indicate stable horseshoe crab abundance from 2003 through the early 2010s, then variable but increasing abundance through 2019. Additionally, the Delaware Bay Horseshoe Crab Spawning Survey was used to estimate spawning beach sex ratios, which have varied annually from three to five males for every female.



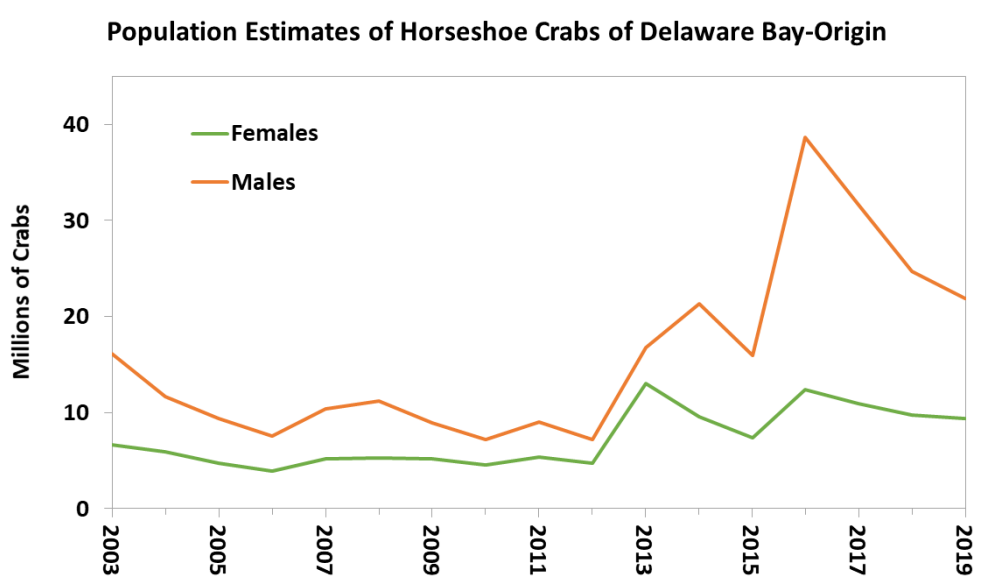
Commercial Data

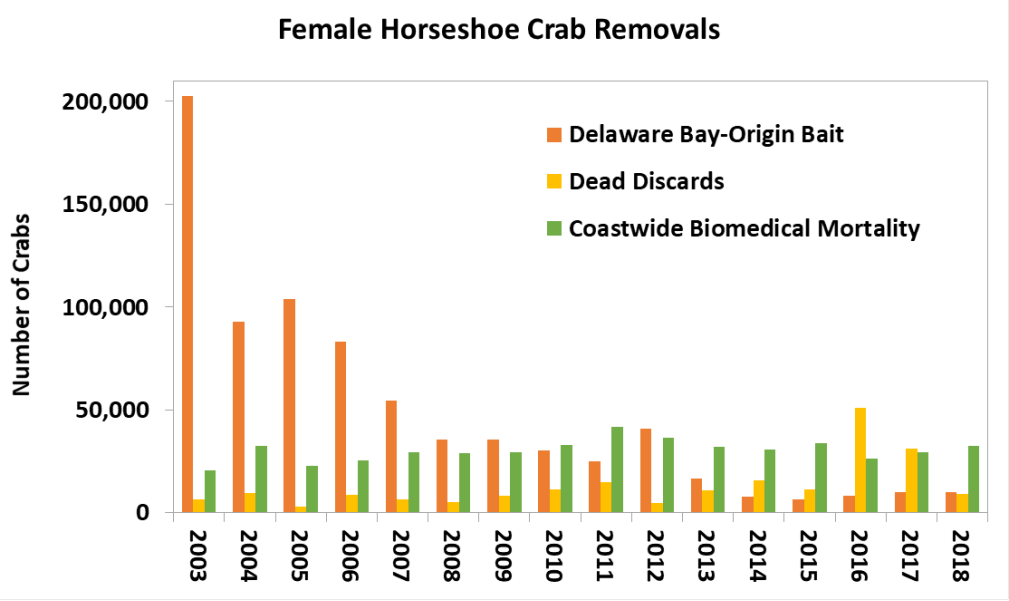
Horseshoe crabs in the Delaware Bay Region are harvested commercially as bait for the commercial American eel and conch/whelk fisheries. Since 1998, states have been required to report annual landings to ASMFC through the compliance reporting process. Bait harvest in the Delaware Bay has been limited to 500,000 male-only Delaware Bay-origin horseshoe crabs since 2013.



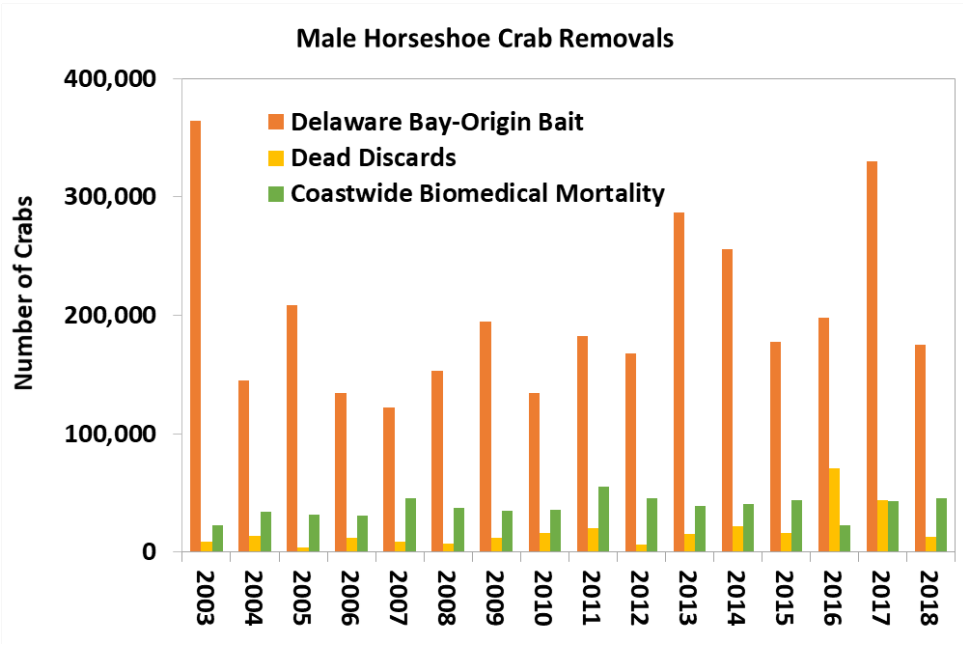
Horseshoe crabs are also collected by the biomedical industry and a portion of their blood is extracted to support the production of Limulus amebocyte lysate (LAL), a clotting agent that aids in the detection of endotoxins in patients, drugs, and intravenous

devices. Most crabs collected and bled by the biomedical industry are released alive to the water from where they were collected; however, a portion of these crabs die from the procedure. A 15% mortality rate is applied to the number of horseshoe crabs bled and released alive to estimate the number of crabs that die each year. This source of removals was not accounted for in the previous ARM Framework but is now included in the ARM Revision. The biomedical harvest data for the Delaware Bay Region is confidential, so coastwide biomedical data has been used for the revised ARM model development. Annual harvest recommendations will be determined based on the region-specific confidential biomedical data if the ARM Revision is used for management.





Horseshoe crabs are also encountered as bycatch in several other commercial fisheries. Commercial dead discards were estimated for the Delaware Bay Region as part of this ARM Revision with data from the Northeast Fisheries Science Center's Northeast Fisheries Observer Program. Commercial dead discards were not considered as a source of removals in the previous ARM Framework, but are now included in this ARM Revision.



What Population Models Were Used?

The previous ARM used a horseshoe crab model based on life history information taken from the literature, some of which came from areas outside the Delaware Bay. In

this ARM Revision, a catch multiple survey analysis (CMSA) was used to estimate male and female horseshoe crab population estimates for 2003-2019 using all quantifiable sources of mortality (i.e., natural mortality, bait harvest, coastwide biomedical mortality, and commercial dead discards). The CMSA indicated that adult abundance in the Delaware Bay was stable from 2003-2013 and then began increasing in the past few years for both sexes. This finding is consistent with stock rebuilding due to a period of significantly reduced commercial landings and tight management controls on the fishery beginning in the 2000s in this region. In 2019, the CMSA estimates there were 21.9 million male and 9.4 million female horseshoe crabs.

The previous models describing red knot population dynamics were also largely based on life history information taken from the literature and not specific to the Delaware Bay. For the ARM Revision, an integrated population model (IPM) was developed to quantify the effects of horseshoe crab abundance on red knot survival and recruitment based on data collected in the Delaware Bay. Estimates of adult red knot survival was consistently high. Estimates of recruitment rate were fairly low and showed little year-to-year variation. Estimates of population growth rate indicate the red knot population was most likely stable to increasing from 2005-2018. While the IPM showed a positive effect of horseshoe crab abundance on red knot survival, the same correlation was not found between horseshoe crab abundance on red knot recruitment.

Projection models were developed to simulate the system state into the future. Because the state of the Delaware Bay system is represented in the ARM model by abundances of horseshoe crabs and red knots, population projection models are required for both species. The horseshoe crab projection model used in the ARM Revision derives directly from the CMSA population estimates and model structure. The revised red knot projection model mirrors the structure of the IPM.

Revised ARM Framework

The previous ARM Framework used Adaptive Stochastic Dynamic Programming (ASDP) software to determine an optimal harvest level of horseshoe crabs. This software is now antiquated, not supported, does not run on current computer operating systems, and was limited in its capacity to incorporate uncertainty when determining optimum harvest strategies. This ARM Revision uses an Approximate Dynamic Programming (ADP) approach that incorporates uncertainty of all life history information for both horseshoe crabs and red knots.

The ADP approach seeks to maximize the average total reward from the system. In this case, reward is a combination of horseshoe crab harvest (within the maximum of 210,000 females and 500,000 males) and the abundance of red knots. Many simulations of the red knot and horseshoe crab model are run and the model solves for the harvest that maximizes the total average reward over all the simulations. The model produces equations known as “harvest policy functions” representing the optimal harvest to implement given the estimated number of horseshoe crabs and red knots at a given point in time. To implement the revised ARM approach, annual estimates of horseshoe crabs and red knots will be used as input to the harvest policy functions, which then output the optimal harvest for the next horseshoe crab harvest season.

Previously there were five harvest package options that could be chosen each year. The values of those harvest packages could not change due to the limitations of the ASDP software. Additionally, harvest of male horseshoe crabs and female horseshoe crabs were linked, so different values of harvest could not be selected independent of each other. Harvest recommendations under the ARM Revision are now based on a continuous scale rather than the fixed harvest packages in the previous Framework. Therefore, any harvest number between zero and the maximum allowable harvest can be selected, not just the fixed harvest packages. Also, the harvest of females is decoupled from the harvest of males in this revision so that each are determined separately. However, the Revision maintains the maximum possible harvest for both females and males at 210,000 and 500,000, respectively, that were in the

original ARM Framework. Although harvest is treated as continuous in the new ARM Framework, harvest could be rounded to some fixed values to more closely approximate previous harvest packages and minimize changes to allowable harvest between years. For example, an optimal continuous harvest of 135,400 females could be rounded down to 100,000 females.

What is the Status of the Stock?

To date, no overfishing or overfished definitions have been adopted by the Commission's Horseshoe Crab Management Board for horseshoe crabs in the Delaware Bay. The 2019 benchmark stock assessment characterized the status of the Delaware Bay area as "neutral" based on trend analysis. The purpose of the ARM Revision was not to determine stock status in the traditional sense of commercial fishery management (e.g., overfished and/or overfishing). Rather, the purpose was to determine the optimal harvest strategy given the abundance of horseshoe crabs and red knots. Based on the base run of the revised ARM model, the recommended harvest in 2019 would have been 500,000 male horseshoe crabs and 144,803 female horseshoe crabs.

The ARM Revision was developed using coastwide biomedical data due to data confidentiality rules. Therefore, the population estimates for horseshoe crabs from the CMSA represent an overestimate. If the 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. As such, the final harvest recommendations are likely to be marginally lower than those reported here. No other model inputs were affected by data confidentiality.

This revision of the ARM Framework represents several advancements in not only the knowledge of the population dynamics of horseshoe crabs and red knots, but also how to efficiently model them. The population dynamics models for both species are now parameterized with empirical data from the Delaware Bay rather than based on literature values for life history parameters coming from elsewhere. Because they are based on empirical data from the Delaware Bay, model updating will be more efficient and transparent as new data for both species is collected through routine monitoring efforts.

Next Steps

At its January 26th meeting, the Horseshoe Crab Management Board accepted the ARM Revision for management use and directed staff to begin the development of a draft addendum to formally allow its implementation in setting annual specifications for horseshoe crabs of Delaware Bay-origin. At a subsequent meeting, the Board will review and consider approval of the draft addendum for public comment. If approved, the draft addendum will be released for public comment with opportunities to submit comment through public hearings and written comments. Following the public comment period, the Board will meet to review submitted comment and consider final action on the addendum.

Whom Do I Contact For More Information?

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Glossary

Approximate Dynamic Programming (ADP): a decision-making modeling approach, implemented in R software, used in the ARM Revision to determine an optimal harvest level of horseshoe crabs

Adaptive Resource Management (ARM): a structured, iterative process for decision making in the face of uncertainty whereby predictive population or ecosystem models are regularly updated with new information from scientific monitoring programs and associated management plans are adjusted accordingly.

Adaptive Stochastic Dynamic Programming (ASDP): a decision-making modeling approach and software used to determine an optimal harvest level of horseshoe crabs in the previous ARM Framework.

Catch multiple survey analysis (CMSA): a stock assessment method that divides the population into two or more life stages, then uses relative catch of animals in those stages within multiple surveys over time to estimate population abundance and fishing mortality.

Multiparous horseshoe crabs: mature horseshoe crabs that participate in spawning, or mature adults.

Primiparous horseshoe crabs: newly mature horseshoe crabs that are capable of spawning but have not yet spawned.

Projection models: an approach to forecast future stock conditions based on information from a stock assessment.

References

Atlantic States Marine Fisheries Commission (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.

Atlantic States Marine Fisheries Commission (ASMFC). 2012. Addendum VII to the Fishery Management Plan for Horseshoe Crab. Fishery Management Report of the Atlantic States Marine Fisheries Commission. Washington D.C. 10pp.

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Atlantic States Marine Fisheries Commission (ASMFC). 2021. Revision to the Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Inclusive of Red Knot Conservation and Peer Review Report. Arlington, VA. 302 pp. (This will be posted at http://www.asmfc.org/species/horseshoe-crab under Stock Assessment Reports the week by February 4).