



September 30, 2022

Horseshoe Crab Management Board
Atlantic States Marine Fisheries Commission
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VIA ELECTRONIC MAIL

Re: Draft Addendum VIII to the Horseshoe Crab Fishery Management Plan for Public Comment

Dear Members of the Horseshoe Crab Management Board:

I write on behalf of New Jersey Audubon and Defenders of Wildlife to urge you to reject Addendum VIII to the Horseshoe Crab Fishery Management Plan. Since the Board instituted the Adaptive Resource Management (“ARM”) Framework in 2012, red knot¹ abundance at Delaware Bay has fallen to historically low levels, and the U.S. Fish & Wildlife Service (“FWS”) has listed the species as “threatened” under the Endangered Species Act (“ESA”). Horseshoe crabs, too, remain severely depleted compared to historical benchmarks. These circumstances demand greater protections and a precautionary strategy. But Addendum VIII would instead weaken the protections currently in place. Among other harmful outcomes, the Addendum almost certainly would reinitiate the female horseshoe crab bait harvest. Recognizing that neither red knots nor horseshoe crabs have recovered, the ARM Framework, until this proposal, has prohibited female harvest to protect the eggs on which the red knots rely.

Horseshoe crab eggs are critical to the red knot’s ability to survive its 9,000-mile migration from as far south as Tierra del Fuego and to breed successfully in the Arctic Circle. The importance of horseshoe crab eggs to red knot success has long been recognized by scientists, government agencies, and the Atlantic States Marine Fisheries Commission (“ASMFC” or “Commission”), and the overharvest of horseshoe crabs has been a primary cause of the red knots’ decline over the past three decades.

Nevertheless, despite the well-established link between horseshoe crab eggs and red knot survival and reproduction, Draft Addendum VIII proposes a starkly different version of reality. Through a combination of modeling defects and risk-prone decision-making, the revised ARM Framework now determines that the relationship between these species is scarcely perceptible, and that red knots would be virtually indifferent to the renewed harvest of female horseshoe crabs.

¹ In this document, “red knot” refers to the *rufa* subspecies.

As detailed in these comments and the attached expert reports by Dr. Kevin Shoemaker and Dr. Romuald Lipcius, this depiction of the relationship between horseshoe crab eggs and red knot demography is deeply flawed. Contrary to the conclusions represented in Draft Addendum VIII, adopting a new management approach that would enable resumption of the harvest of female horseshoe crabs at this juncture, when both red knots and horseshoe crabs are depleted, would harm red knots and present risks to the horseshoe crab population itself. Accordingly, the revised ARM Framework is not suitable for recommending horseshoe crab bait harvest quotas.

More specifically, the Board should reject Addendum VIII for reasons including but not limited to:

- **The revised ARM Framework errs in concluding that red knots are not highly dependent on horseshoe crabs at Delaware Bay.**
 - After flying thousands of miles, red knots arrive at Delaware Bay to renourish on horseshoe crab eggs. Under ideal conditions, red knots can double their body weight in less than two weeks. In the late 20th century, the peak count of red knots at Delaware Bay usually exceeded 40,000 and sometimes exceeded 90,000.
 - Horseshoe crabs were overharvested in the 1990s. In 2015, FWS listed red knots as “threatened” under the ESA and called horseshoe crab overharvest and corresponding egg depletion a “primary causal factor” in red knot decline. The peak red knot count has stayed below 13,000 for each of the past two years.
 - Despite this strong evidence of the importance of horseshoe crab eggs to red knots, the revised ARM Framework posits a weak link between the two species. By so doing, the revised ARM Framework subverts the premise of ASMFC’s management regime for the horseshoe crab fishery, which is to manage the horseshoe crab harvest for red knot recovery.
- **New analysis reveals significant technical flaws that make the revised ARM Framework unsuitable for managing the horseshoe crab harvest.**
 - The revised ARM Framework abandons the well-established understanding of the importance of horseshoe crab eggs to red knots in favor of an extreme, contrary reconstruction of the ecosystem that defies history and reality. Even if horseshoe crabs vanished entirely today, the revised ARM Framework’s computer model predicts that red knot abundance would remain stable on average or even increase over the next 50 years. The model clearly would not have predicted the decline of red knots that resulted from horseshoe crab overharvest in the 1990s, which discredits its usefulness in making projections that could help both species recover.
 - The revised ARM Framework also undermines sustainable management of horseshoe crabs. By miscalculating uncertainty, the horseshoe crab projection model generates artificially stable horseshoe crab population projections, when there actually exists a significant threat of decline.
 - The horseshoe crab population projections are significantly influenced by nonsensically high recruitment rates that were plugged in for years when recruitment was not measured empirically, thus further undermining the reliability of its projections.

- The horseshoe crab population model bears very little correlation even to the data that the model is based upon, raising significant additional doubt about its predictive power and usefulness.
- **The revised ARM Framework’s risk-prone assumptions and decisions are inappropriate, especially when a threatened species is at stake.**
 - Horseshoe crab demographic information, including size and sex ratio, strongly suggests that the species is not recovering and that a risk-averse management approach is required.
 - The Framework does not consider the availability of horseshoe crab eggs, which is the most direct measure of food resources for red knots. Analysis of horseshoe crab demographic trends indicates that egg production may be declining more than abundance estimates suggest.
 - The model finds a weak relationship between horseshoe crabs and red knots partly because it is based on data from years when both species had already declined rather than when the ecosystem was flourishing. Modeled projections of a depleted ecosystem offer no guidance on managing to achieve recovery of either red knots or horseshoe crabs.
 - The Framework does not assess whether Delaware Bay provides adequate food for Southern wintering red knots, which are especially dependent on horseshoe crab eggs.
 - The Framework would eliminate protective population thresholds that must be met prior to any female harvest, creating risks to red knots and horseshoe crabs and contravening stakeholders’ precautionary intent.
 - For population estimates, the model equally weights three surveys, despite stakeholders’ express preference—and ASMFC’s practice until now—to rely exclusively upon the model that is purpose-designed for counting horseshoe crabs. This results in artificially inflated horseshoe crab population estimates.
- **ASMFC has repeatedly excluded input from stakeholders and the broader public.**
 - In addition to its other flaws, the revised ARM Framework is based on a model that has never been released to the public. Analysis of even the limited information made available to the public to date indicates significant problems with the model, as discussed above. If the Board approves Addendum VIII now and the model is subject to public evaluation, new concerns and critiques will inevitably arise after the revised ARM Framework is already in use.
 - The ARM Subcommittee failed to solicit formal stakeholder input in this proceeding, in violation of its own procedures and past practice.
 - By designating Addendum VI the “No Action” alternative, the Board artificially narrowed its options to two addenda that would reinitiate the female horseshoe crab harvest, thus deciding the most important issue before the public comment period even began.

- **The flaws in the revised ARM Framework must be addressed now.**
 - The authority of ASMFC to deviate from the ARM Framework’s harvest quotas in the future is not a rationale for approving Addendum VIII based on a flawed modeling framework now. Prematurely approving Addendum VIII would set the stage for contentious and arbitrary decisions about annual quotas for years to come.
 - The authority of states to set lower quotas than ASMFC provides does not lessen the Board’s obligation to ensure that the revised ARM Framework is fully vetted and reflects stakeholder values.
 - Updating the revised ARM Framework’s model as new data become available will not correct its fundamental flaws, many of which—as explained in these comments—are apparent from expert reviews of even the limited data made publicly available to date.

- **Approving Addendum VIII would likely lead to a violation of the Endangered Species Act by ASMFC.**
 - The ESA requires a precautionary approach to protecting threatened species.
 - By reinitiating the bait harvest of female horseshoe crabs, ASMFC would commit “take” of red knots. ASMFC is responsible under the ESA for harvests conducted pursuant to the quotas it sets.
 - FWS’s purported “evaluation” of the revised ARM Framework merely repackages ASMFC’s modeling, with all of its flaws, and uses it to generate an unreliable conclusion regarding the impact of red knots. It therefore sheds no new light on the Board’s stewardship responsibilities or the Commission’s legal obligations.

The objections listed above are elaborated in the comments and expert reports that follow. Each objection is an independently sufficient reason to reject Addendum VIII. Collectively, they demonstrate that Addendum VIII is incompatible with the Board’s mandate to maintain the ecosystem integrity of Delaware Bay and to comply with the Endangered Species Act.

Respectfully submitted,

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I. THE REVISED ARM FRAMEWORK ERRS IN CONCLUDING THAT RED KNOTS ARE NOT HIGHLY DEPENDENT ON HORSESHOE CRABS AT DELAWARE BAY.

Each year, a population of red knots 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 Delaware Bay, where their stopover coincides with another ecological marvel: the spawning of millions of horseshoe crabs that emerge from the water and lay clusters of approximately 4,000 eggs, with the potential for an individual to lay more than 100,000 eggs over the course of several nights.² 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 fewer than 14 days, versus 21 to 28 days at comparable stopovers where they eat clams and mussels.³ This unique resource fuels the duration of their journey and enhances breeding success in the Arctic.⁴

The abundance of red knots and horseshoe crabs at Delaware Bay as recently as the 1990s is almost unimaginable today. From 1981 to 2002, the peak red knot count in Delaware Bay usually exceeded 40,000 and twice surpassed 90,000.⁵ One participant in an aerial survey of shorebirds during that period described “lines of deposited horseshoe crab eggs set like mineral veins in smooth white marble, virtually an unlimited food supply.”⁶ In a single day, his survey tallied 62,000 red knots and 318,000 total shorebirds on just the New Jersey side of Delaware Bay.⁷

In the 1990s, increasing and unregulated horseshoe crab harvest by the bait and biomedical industries crashed the population of horseshoe crabs.⁸ Red knots, no longer able to rely on the irreplaceable horseshoe crab eggs, declined in tandem. ASMFC adopted a fishery management plan for horseshoe crabs in 1998 and instituted adaptive management in 2012. Since then, the female bait harvest has been prohibited. But the fate of horseshoe crabs remains highly uncertain, and red knots have continued to decline. Red knot peak counts that previously topped 90,000 have, for the past two years, languished below 13,000, including a record low of 6,800 in 2021. Twenty years have passed since the population topped a modest 33,000.⁹ Instead of these peak

² NOAA Fisheries, *Horseshoe Crabs: Managing a Resource for Birds, Bait, and Blood* (July 31, 2018), <https://www.fisheries.noaa.gov/feature-story/horseshoe-crabs-managing-resource-birds-bait-and-blood>.

³ Lawrence Niles et al., *Effects of Horseshoe Crab Harvest in Delaware Bay on Red Knots: Are Harvest Restrictions Working?*, 59 *BioScience* 153, 154 (2009); New Jersey Department of Environmental Protection, *Wildlife Populations: Red Knot 1-2* (2020), <https://www.nj.gov/dep/dsr/trends/wildlife-redknot.pdf>.

⁴ Sjoerd Duijns et al., *Body Condition Explains Migratory Performance of a Long-Distance Migrant*, 284 *Proceedings of the Royal Society of London B* 20171374, at 4-6 (2017).

⁵ FWS, *Rufa Red Knot Background Information and Threats Assessment* 100 tbl. 12 (2014) (excluding 1984-1985, when the survey was not conducted).

⁶ Pete Dunne, *Tales of a Low-Rent Birder* 10 (1986).

⁷ *Id.* at 13-14.

⁸ FWS, *Rufa Red Knot Background Information and Threats Assessment* 232 (“Evidence that commercial harvests caused horseshoe crab population declines in recent decades comes primarily from a strong temporal correlation between harvest levels . . . and population levels.”).

⁹ *Id.* at 100 tbl. 12 (for years 1981-2014); ASMFC, *Revision to the Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Inclusive of Red Knot Conservation (Draft for Board Review)* 155 tbl.

counts, the revised ARM Framework uses modeled estimates of the total number of red knots passing through Delaware Bay. While these modeled estimates face criticism for overrepresenting red knots' use of Delaware Bay, they have fallen as well, from as high as 152,900 in 1989, to an average of 77,000 per year for 1998-2001, to numbers in the 40,000s over the past several years.¹⁰

In 2015, FWS formally listed the red knot as a threatened species under the Endangered Species Act.¹¹ At the time of the listing, FWS cited several studies indicating that red knot abundance had declined, “probably sharply,” since the 1980s.¹² 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.”¹³ 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 and which FWS views as “a bellwether for the subspecies as a whole.”¹⁴ 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 2000s.”¹⁵

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 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.¹⁷

Until now, the well-established link between horseshoe crabs and red knots has been the cornerstone of ASMFC's management of the horseshoe crab fishery at Delaware Bay. Addendum VIII would subvert that regime. While the proposed model nominally bases harvest quotas on red knot and horseshoe crab abundance estimates, it assigns an extremely weak correlation between the abundance of the two species. It thereby concludes that red knots would be essentially unaffected by the resumption of the female horseshoe crab bait harvest.

As explained below, Addendum VIII's baseline assumption—that increasing the horseshoe crab harvest would only marginally impact red knots at Delaware Bay—is unsupported. It relies on evaluating a limited dataset that omits years when the ecosystem flourished. (For example, its dataset about horseshoe crab abundance is drawn entirely from the last 20 years, after the crash

12 (2021) (“ARM Report”) (for years 2011-2020); Larry Niles, “2022 Delaware Bay Stopover Project Final Update-5 June 2, 2022,” *A Rube with a View* (June 15, 2022), <https://www.arubewithaview.com/2022/06/15/2022-delaware-bay-stopover-project-final-update-5-june-2022/> (for years 2021-2022).

¹⁰ FWS, *Rufa Red Knot Background Information and Threats Assessment* 101 tbl. 13; ASMFC, *ARM Report* 155 tbl. 12.

¹¹ FWS, “Endangered and Threatened Wildlife and Plants; Final Threatened Status for the Rufa Red Knot,” 79 Fed. Reg. 73,706 (Dec. 11, 2014). The listing became effective on January 12, 2015. *Id.* at 73,706.

¹² FWS, *Rufa Red Knot Background Information and Threats Assessment* 85. While FWS primarily analyzed red knot population trends within individual regions, it “note[d] a temporal correlation between declines at Tierra del Fuego and Delaware Bay.” *Id.* at 84.

¹³ 79 Fed. Reg. at 73,707.

¹⁴ FWS, *Draft Recovery Plan for the Rufa Red Knot* 13 (May 2021).

¹⁵ *Id.* at 14.

¹⁶ *Id.* at 25; FWS, *Rufa Red Knot Background Information and Threats Assessment* 254.

¹⁷ FWS, *Rufa Red Knot Background Information and Threats Assessment* 253.

of the horseshoe crab population and during a period when red knot abundance has been comparatively low.) And it suffers from modeling defects that, among other things, erroneously overstate the size and stability of the horseshoe crab population.

For these reasons and others detailed below, Addendum VIII is not a pathway for sustaining red knots, much less restoring a thriving ecosystem, nor does it honor the precautionary approach required when a threatened species is at stake. Instead, it risks a violation of ASMFC's legal obligations, including its obligation to avoid "take" of red knots under the ESA. The Board therefore should reject Addendum VIII and instead adopt adequate protections for horseshoe crabs and red knots at Delaware Bay.

II. NEW ANALYSIS REVEALS SIGNIFICANT TECHNICAL FLAWS THAT MAKE THE REVISED ARM FRAMEWORK UNSUITABLE FOR MANAGING THE HORSESHOE CRAB HARVEST.

As detailed in the following sections, the parties to this letter solicited independent expert reviews of the revised ARM Framework. These reviews reveal significant technical and methodological flaws that render the Framework unreliable for ASMFC management decisions.

For the first expert review, Dr. Kevin Shoemaker conducted an independent analysis of the horseshoe crab abundance and projection model that informs the revised ARM Framework. Dr. Shoemaker demonstrates that the Framework contains significant flaws that make it unsuitable for managing the horseshoe crab harvest. These flaws are especially alarming given the implications of the Framework for a threatened species such as the red knot. This section details many of Dr. Shoemaker's key findings, all of which are explained in more detail in the attached expert report.

At the outset, it is important to note that most of the components of the revised ARM Framework's model still have not been made available to the public. As a result, Dr. Shoemaker was unable to evaluate the components that link horseshoe crab abundance to red knot abundance or generate horseshoe crab harvest recommendations. Although Dr. Shoemaker was able to draw some conclusions about those aspects of the model, most of the analysis below necessarily focuses on the horseshoe crab model. As these comments proceed to discuss, the analysis that Dr. Shoemaker was able to conduct reveals severe issues concerning the reliability of the modeling. Nevertheless, Dr. Shoemaker's focus on the publicly available modeling information should not be interpreted to suggest that the unreleased components do not also contain significant flaws. To the contrary, given the flaws that are apparent in the information released to date, it is vital that *all* components of the model be subject to public evaluation before the Board takes any action to approve Addendum VIII.

A. The revised ARM Framework Is an Inappropriate Tool for Helping to Reverse the Decline and Promote the Recovery of Red Knots.

Considering that adaptive management is premised on the link between horseshoe crabs and red knots, the weakness of that link in the revised ARM Framework is breathtaking. By way of illustration:

- Dr. Shoemaker shows that, even if the horseshoe crab population in Delaware Bay completely collapsed to zero, the revised ARM Framework would predict that red knot abundance would remain stable or even increase over the next 50 years on average.¹⁸
 - Furthermore, “This simulation exercise makes it very clear that the REKN model used in the revised ARM would not be able to predict or explain the decline in the REKN population observed during the 1990s.”¹⁹ In other words, the model could not even have diagnosed the problem that it is supposed to solve.
- The data informing the revised ARM Framework actually show a negative correlation between female horseshoe crab abundance and red knot recruitment.²⁰ That is, according to the model, as female horseshoe crab abundance *increases*, red knot recruitment *decreases* on average.
- Due to the weak relationship between red knot and horseshoe crab abundance, it is not implausible that, with future updates to the revised ARM Framework, the relationship will disappear entirely or even become negative. Dr. Shoemaker observes that “[t]his outcome would pose an existential problem for the ARM framework There does not appear to be a contingency plan for this outcome.”²¹
- Whatever weak signal the model has detected in historical data appears to be overwhelmed by random noise. As Dr. Shoemaker explains, it is highly likely that the model’s “information about the HSC/REKN relationship would explain little if any of the variation in independent validation data.”²²

Due to the weak relationship between red knots and horseshoe crabs represented in the revised ARM Framework, it is unlikely that the model would outperform—much less significantly improve upon—a “null” model that entirely omits any effect of horseshoe crab abundance.²³ Yet it was impossible for Dr. Shoemaker to explore this key issue further because of the limitations on the materials made publicly available to date. Nevertheless, the concerns raised by the analysis that Dr. Shoemaker was able to perform are profound and call into question the revised ARM Framework’s utility to guide any decision-making about the status or management of the affected species.

In sum, while the revised ARM Framework nominally recommends harvest quotas based on the relationship between horseshoe crabs and red knots, it effectively decouples the fates of the two species, unjustifiably transforming the methodology and philosophy that underlie the management of this fishery. This is an independently sufficient reason for the Board to reject Addendum VIII.

¹⁸ Kevin Shoemaker, *Review of 2021 ASMFC ARM Revision 6-9 & fig. 1* (Sept. 2022) (“*Shoemaker Expert Report*”).

¹⁹ *Id.* at 8.

²⁰ *Id.* at 9 fig. 2.

²¹ *Id.* at 10.

²² *Id.* at 26.

²³ *Id.* at 25-26.

B. The Horseshoe Crab Population Simulation Model Does Not Properly Account for Uncertainty, Resulting in Artificially Stable Abundance Projections.

The revised ARM Framework profoundly underestimates uncertainty in the horseshoe crab recruitment rate, thereby calling into question its projections concerning the impact of harvest. As Dr. Shoemaker explains, the rate at which new recruits join the reproductive population “is the most consequential empirically fitted component of the HSC simulation model.”²⁴ Other components of the model, such as natural and biomedical mortality, are fixed values, but the recruitment rate is calculated based on data.

Dr. Shoemaker shows²⁵ that the model errs by conflating two distinct types of uncertainty: (i) natural, year-over-year variation and (ii) the potential that the model incorporates incorrect parameters (most importantly, the mean horseshoe crab recruitment rate). The model treats both types of uncertainty as natural, year-over-year variation, with the consequence that the abundance estimates regress to a mean. In other words, the variations cancel each other out, making the projected population appear highly stable. But if evaluated properly, parameter uncertainty would likely compound over time, yielding a very different picture of the population. For example, if average recruitment is actually lower than the rate used in the model, that uncertainty would *not* cancel out over time. Instead, the horseshoe crab population could be headed for a one-way decline. Notably, the revised ARM Framework accounts for the two types of uncertainty separately in the *red knot* projection model, suggesting that the modelers recognized the importance of that approach, but nevertheless they did not implement it when projecting horseshoe crab abundance.

The consequences of this error are significant for estimates of the population’s trajectory. Properly accounting for uncertainty, Dr. Shoemaker found that the horseshoe crab population faces a very real threat of declining well below levels acknowledged by the revised ARM Framework’s projection model. Notably, he used the same estimates of uncertainty as the revised ARM Framework (as well as the same values for natural mortality, biomedical mortality, etc.). All that changed in his analysis was the method of evaluating uncertainty. Dr. Shoemaker’s analysis²⁶ reveals that:

- Even under a scenario with *no* bait harvest, *no* biomedical mortality, and *no* discard mortality, the female horseshoe crab population has a 17.4% probability of declining below 4 million, and a 3.8% probability of declining below 3 million, over the next 50 years.
 - For comparison, 4 million is the lowest female abundance estimated for any year from 2003 to 2019 (the years upon which the model was based).
 - In contrast, by incorrectly accounting for uncertainty, the revised ARM Framework’s model does not project female abundance values below 4 million within the 95% confidence interval under optimal harvest scenarios, *including* bait harvest, biomedical mortality, and discard mortality.²⁷

²⁴ *Id.* at 12.

²⁵ The information in this paragraph is drawn from *Shoemaker Expert Report* 12-18 & figs. 3-4.

²⁶ Except where noted, these findings are presented in greater detail at *Shoemaker Expert Report* 15, 18 fig. 4.

²⁷ ASMFC, *Supplemental ARM Report* 35 fig. 15.

- Under a scenario in which horseshoe crabs are harvested for bait under the maximum quotas of 500,000 males and 210,000 females but are still *not* subject to biomedical or discard mortality, the female population has a 33% probability of declining below 4 million, an 11% probability of declining below 3 million, and a 2% probability of declining below 2 million, over the next 50 years.

Dr. Shoemaker concludes that, “if sources of error in the recruitment process are properly accounted for, the outlook for the HSC population in Delaware Bay is uncertain even in the absence of any harvest pressures.”²⁸ If the Board approves Addendum VIII, it would increase harvest pressure through a model that fails to properly account for the risk of a declining horseshoe crab population.

C. The Horseshoe Crab Projection Model’s Recruitment Estimates Are Strongly Influenced by Nonsensical, Unverified Estimates from the Virginia Tech Gap Years.

The revised ARM Framework’s conclusions are further undermined by its reliance on fantastical recruitment projections to fill in a key gap in actual population-monitoring data for horseshoe crabs. Of the three trawl surveys that inform the catch multiple survey analysis (“CMSA”) component of the framework, only the Virginia Tech survey measures primiparous (i.e., newly mature) females to provide an empirically based estimate of recruitment. Thus, the CMSA does not incorporate any direct measurement of recruitment during the 2013-2016 period when the Virginia Tech survey was not conducted. Instead, it indirectly estimates annual recruitment rates, but two of these estimates are many times higher than any estimate from years with direct observations. Since the average recruitment rate in the population projection model treats all of the estimates as equally valid—whether or not they were based on empirical observations or hypothetical estimates—the model’s estimated annual recruitment rate is heavily influenced by the nonsensical estimates from the Virginia Tech gap years.

To understand the impact of the nonsensical gap year estimates, first consider the years with empirically derived recruitment estimates. The average annual estimated recruitment for 2003-2012 was 1.2 million primiparous females. The average annual estimated recruitment for 2017-2019 was 1.9 million. Now consider the non-empirically derived gap year estimates. In 2013, the estimate was *9.6 million*—roughly eight times larger than the average over the previous ten years, and four times larger than the maximum annual estimate from that period.²⁹ In 2014, the estimate dropped to only two primiparous females across all of Delaware Bay, but the estimate is so uncertain that the upper limit of the confidence interval approaches infinity.³⁰ All told, the *average* estimate for the four Virginia Tech gap years was 4.2 million primiparous females, which is nearly *2 million* higher than the *maximum* ever estimated for any year with empirical observations.³¹

²⁸ Shoemaker Expert Report 17.

²⁹ ASMFC, *Supplemental Report to the 2021 Revision to the Adaptive Resource Management Framework* 16 tbl. 3 (2022) (“*Supplemental ARM Report*”).

³⁰ *Id.* at 25 fig. 5.

³¹ *Id.* at 16 tbl. 3.

The nonsensical estimates from the Virginia Tech gap years compromise the horseshoe crab projection model because they significantly affect its recruitment estimate. As Dr. Shoemaker shows,³² in the original ARM report, the ARM Subcommittee based the recruitment rate exclusively on data from 2013 to 2019, which relied overwhelmingly on estimates from the gap years and generated an annual recruitment estimate of 3.1 million primiparous females. Following criticism from the Peer Review Panel, the Subcommittee expanded the dataset to include 2003-2019, which reduced the recruitment estimate to 1.67 million. But if the nonsensical data from the gap years were excluded, this estimate would fall to 1.26 million. Dr. Shoemaker illustrates how the difference in these estimates has huge implications for the model's projection of future horseshoe crab abundance.

Dr. Shoemaker concludes that “the inflated estimates of recruitment during the VT gap years are likely to be an artifact of the CMSA model specification (and the lack of data on recruitment for those years) and are unlikely to be reflective of true HSC recruitment rates. . . . [A] conservative (precautionary) approach would be to exclude the VT gap years when computing recruitment for the HSC population simulations.”³³ Doing so would yield a substantially lower recruitment estimate with a commensurately lower capacity to withstand a resumption of female harvest.

D. The Horseshoe Crab Population Model Has a Poor Correlation to Existing Data.

The CMSA's usefulness is cast further into doubt by its failure to correlate with any source of data about horseshoe crab abundance. As Dr. Shoemaker shows from an analysis of female horseshoe crab abundance estimates, the model does not correlate even with the data sources upon which it was based, much less any independent validation data.

For the years 2003-2019, the CMSA's correlation with the Delaware Adult Trawl Survey is extremely weak, and any correlation that exists is entirely attributable to the model's apparent ability to predict that horseshoe crab populations rose during 2013-2016, when the Virginia Tech survey was not conducted.³⁴ For the years before and after the Virginia Tech gap—that is, for the vast majority of years evaluated—the coefficient of determination (R^2) between the CMSA model and the Delaware Survey was *negative*, meaning that the model performed worse than a null model. The CMSA performs almost as poorly against data from the New Jersey Ocean Trawl Survey, with a weak positive correlation for the years prior to the Virginia Tech gap and a negative R^2 for the years after. The CMSA's worst performance comes when measured against the Virginia Tech survey, with a negative R^2 across the full time series for which data are available. To test the CMSA against independent validation data, Dr. Shoemaker compared it to the results of Delaware Bay spawning surveys and found no detectable relationship whatsoever between the results.

As this summary makes clear, the CMSA's modeled outcomes bear little relationship to actual data on the Delaware Bay horseshoe crab population. For this reason, Dr. Shoemaker recommends comparing the CMSA's horseshoe crab estimates to a null model that omits all information about horseshoe crab harvest from the model fitting process. Given its poor fit to

³² The data discussed in this paragraph can be found at *Shoemaker Expert Report* 22-24 & fig. 7.

³³ *Id.* at 23.

³⁴ The findings in this paragraph are presented in greater detail at *Shoemaker Expert Report* 19-22 & figs. 5-6.

existing data, the CMSA’s horseshoe crab projection model is “unlikely to outperform” even a relatively simple null model.³⁵ Dr. Shoemaker concludes, “If the HSC simulation model fails to outperform a model in which population dynamics are driven by noise instead of harvest, it should prompt managers to acknowledge that our current understanding of the effects of harvest on HSC populations remains insufficient for robust forecasting.”³⁶ Absent a sound basis for robust forecasting, adoption of Addendum VIII and its attendant resumption of the female harvest cannot be justified.

III. THE REVISED ARM FRAMEWORK’S RISK-PRONE ASSUMPTIONS AND DECISIONS ARE INAPPROPRIATE, ESPECIALLY WHEN A THREATENED SPECIES IS AT STAKE.

In addition to its technical flaws, the revised ARM Framework incorporates risk-prone assumptions and decisions that further render it unsuitable as a management tool. It neglects important variables related to horseshoe crab demography and egg density that cast doubt upon the recovery of horseshoe crabs and their ability to provide adequate food resources for red knots. It draws conclusions from data collected when both red knots and horseshoe crabs were already depleted and therefore does not understand how the species would interact in a healthy ecosystem. It also reverses precautionary decisions made by stakeholders in the original ARM Framework—without soliciting renewed stakeholder input—in order to eliminate protections against the female horseshoe crab harvest and utilize previously-rejected surveys that inflate horseshoe crab abundance estimates.

The findings in this section draw heavily from an independent analysis of the revised ARM Framework and related materials conducted by Dr. Romuald Lipcius, as well as the analysis of Dr. Shoemaker. Both expert reports are attached.

A. Demographic Trends Indicate that the Horseshoe Crab Population Is Not Recovering.

Despite the Subcommittee’s assertion that horseshoe crab abundance is increasing in Delaware Bay, Dr. Lipcius has identified troubling indicators that are inconsistent with a recovering population. The revised ARM Framework ignores these trends and treats abundance estimates as a comprehensive indication of population health. That would be a risk-prone approach even if the abundance estimates were fully reliable (which they are not).

As shown in Dr. Lipcius’s report, the mean size (prosomal width) of female horseshoe crabs has recently declined. In the most recent three years of available data (2018-2020), adult female horseshoe crabs recorded the lowest mean sizes of any year since data collection began in 2002.³⁷ The same is true for newly mature females over the most recent two years of available data.³⁸

³⁵ *Id.* at 25.

³⁶ *Id.*

³⁷ Romuald Lipcius, *Expert Report 6* (Sept. 2022) (“*Lipcius Expert Report*”).

³⁸ *Id.*

Dr. Lipcius explains that, given constant recruitment, a prohibition on female harvest would typically lead to an increase in size due to reduced harvest pressure on older, larger females.³⁹ The declining size of female horseshoe crabs is inconsistent with the premise that the female segment of the population has recovered.⁴⁰ It is further evidence that the revised ARM Framework does not properly account for the population dynamics of horseshoe crabs.

A female harvest prohibition would also be expected to decrease the ratio of males to females in the population. But the data indicate that the male-to-female ratio increased between 1999 and 2019, suggesting *fewer* females for every male.⁴¹ This is another warning sign that the population has not recovered, and the harvest of female horseshoe crabs should not resume.⁴² Resuming such harvest would only further deplete a critical component of the population that has failed to show expected signs of recovery even under the female harvest prohibition.

Abundance data for immature and newly mature females raise additional concerns about the recovery of the female population. In 2019 and 2020, the Virginia Tech survey estimated the lowest abundance of newly mature female horseshoe crabs since data collection began in 2002, “indicating low influx of young mature females into the spawning stock.”⁴³ Moreover, abundances of immature females and males for 2016-2020 were similar to those before 2013, when there was no female harvest prohibition in place. That is again contrary to expectations, since a prohibition on harvesting females should correlate to an increase in younger individuals.⁴⁴

Dr. Lipcius explains that estimates of abundance can be less sensitive to serious problems in a population than variables including female size, female size structure, spawning stock biomass, and sex ratio. But the revised ARM Framework relies on abundance estimates to the exclusion of these other important variables. That is a risk-prone strategy and is not suitable for protecting horseshoe crabs or the threatened red knots.

B. The Revised ARM Framework Fails to Consider Horseshoe Crab Egg Density, the Most Direct Measure of Food Availability for Red Knots.

Another critical omission in the revised ARM Framework is its exclusion of data about the most direct measure of the adequacy of food resources for red knots: the availability of horseshoe crab eggs on the beach. As explained above, for red knots arriving at Delaware Bay after flying thousands of miles, horseshoe crab eggs provide energy-rich, easily digestible nutrition as the birds prepare to complete their journey northward and breed in the Arctic Circle. Red knots flying from South America shrink their digestive organs for the journey, and no other food source can replace easily digestible horseshoe crab eggs in enabling red knots to quickly rebuild their organs and muscles.⁴⁵ When conditions permit, a red knot at Delaware Bay can double its

³⁹ *Id.*

⁴⁰ *Id.*

⁴¹ *Id.* at 10.

⁴² *Id.*

⁴³ *Id.* at 6, 7 fig. 1.

⁴⁴ *Id.*

⁴⁵ Niles et al., *Effects of Horseshoe Crab Harvest* 154.

body mass in as little as 12 days by feasting on horseshoe crab eggs.⁴⁶ Research indicates that the red knots that have flown the farthest, from Tierra del Fuego, are particularly dependent on the density of horseshoe crab eggs (i.e., the number of eggs per square meter of beach).⁴⁷ Nevertheless, the revised ARM Framework has failed to consider actual data on egg density in the Delaware Bay region. Whatever concerns may have existed about such data at the time the original ARM Framework was developed, egg density should now be considered in light of new scholarship (discussed below) and the importance of horseshoe crab eggs for red knots. The revised ARM Framework's failure to do so represents another key flaw.

1. Egg density is the most direct measure of food availability for red knots.

Scientific studies link food availability at Delaware Bay to red knot survival and fecundity. Under favorable conditions including abundant horseshoe crab eggs, red knots at Delaware Bay roughly double their body mass from 90-120 grams to 180-220 grams before departing for the Arctic.⁴⁸ Individual red knots can gain up to 15 grams per day, “probably when horseshoe crab eggs are superabundantly available,” allowing even late-arriving red knots to gain adequate mass in a brief period.⁴⁹ Researchers have observed that red knots experience “striking fitness consequences . . . correlated with the amount of nutrient stores accumulated in Delaware Bay.”⁵⁰ Specifically, research has found a positive correlation between the mass of birds leaving Delaware Bay in the spring and the speed at which they complete their migration to the Arctic, reproductive success, and survival to the autumn.⁵¹

A superabundance of horseshoe crab eggs is required to meet the nutrition needs of red knots, other shorebirds, and the many other species that rely on this unique resource. Horseshoe crabs lay eggs too deep in the sand for red knots to access. But as more horseshoe crabs spawn on the beach, they disturb the sand, churning some of the eggs closer to the surface.⁵² It is this churning, as well as wave action, that makes horseshoe crab eggs accessible to red knots.⁵³ The system depends on the successive spawning of large numbers of horseshoe crabs.⁵⁴

2. Egg Density Has Declined Dramatically in Recent Decades, Correlating with the Decline in Red Knots.

Research strongly demonstrates that the abundance of horseshoe crab eggs near the beach surface (where the eggs are accessible to red knots) used to be at least ten times greater than the

⁴⁶ New Jersey Department of Environmental Protection, *Wildlife Populations: Red Knot* 1-2.

⁴⁷ FWS, *Species Status Assessment Report for the Rufa Red Knot* (Version 1.1) 9 (Sept. 2020) (“*Species Status Assessment Report*”).

⁴⁸ Allan J. Baker et al., *Rapid Population Decline in Red Knots: Fitness Consequences of Decreased Refuelling Rates and Late Arrival in Delaware Bay*, 271 *Proceedings of the Royal Society of London B* 875, 876 (2004).

⁴⁹ *Id.* at 876.

⁵⁰ *Id.* at 881.

⁵¹ Duijns et al., *Body Condition Explains Migratory Performance* 5-6.

⁵² Niles et al., *Effects of Horseshoe Crab Harvest* 155.

⁵³ *Id.*

⁵⁴ *Id.*

abundance in recent years.⁵⁵ Measurements from 1985 to 1987 conservatively indicate that egg density averaged 156,000 eggs per square meter of beach. In recent years, egg density averaged only around 10,000 eggs per square meter of beach.⁵⁶

This decline in egg density correlates with the dramatic decline of migratory shorebirds, especially red knots. The trends mirror each other over decades but also converge on smaller timescales. Among years when measurements were taken, the nadir for horseshoe crab egg density appears to have been the early 2000s, shortly after the unregulated overexploitation of horseshoe crabs in the 1990s.⁵⁷ This corresponds to a “changepoint” for red knots when the peak count dropped from more than 43,000 to fewer than 16,000.⁵⁸

3. Horseshoe Crab Abundance Is Not an Adequate Proxy for Egg Availability.

Notwithstanding the research documenting a dramatic decline in the availability of horseshoe crab eggs, the revised ARM Framework posits that the abundance of female horseshoe crabs is increasing. That is a dubious claim, as explained in section III.A of these comments. But even assuming for the sake of argument that it were correct, it would not necessarily result in more eggs for horseshoe crabs. To the contrary, demographic trends suggest that the production of eggs per horseshoe crab is likely decreasing.

Dr. Lipcius describes how egg production is directly proportional to the weight of horseshoe crabs, such that heavier crabs produce more eggs.⁵⁹ Data from the Virginia Tech Horseshoe Crab Trawl Survey indicate that the average prosomal width of female horseshoe crabs has fallen considerably, with an especially marked drop in the largest crabs over the past few years (2018-2020). Weight is an exponential function of prosomal width, meaning that even a modest decline in crab width could signify a very significant decline in weight and therefore in egg production. The trend toward smaller female horseshoe crabs may partially explain the low egg density numbers in recent years. Dr. Lipcius concludes that “total reproductive (egg) output has likely not improved, which hampers recovery of the HSC and RK populations.”⁶⁰

4. The ARM Report Presents No Compelling Reason to Ignore Egg Density.

There is no defensible rationale for completely excluding from the revised ARM Framework any direct measure of the most direct indicator of the adequacy of the red knot food supply: egg density. None of the ARM Subcommittee’s reasons for excluding data about food availability withstands scrutiny.

⁵⁵ Joseph A.M. Smith et al., *Horseshoe Crab Egg Availability for Shorebirds in the Delaware Bay: Dramatic Reduction After Unregulated Horseshoe Crab Harvest and Limited Recovery After 20 Years of Management*, Aquatic Conservation: Marine and Freshwater Ecosystems (2022) (in press) (“*Horseshoe Crab Egg Availability*”).

⁵⁶ *Id.*

⁵⁷ *Id.*

⁵⁸ *Id.*

⁵⁹ The information in this paragraph is drawn from *Lipcius Expert Report* 7-10 & figs. 2-6.

⁶⁰ *Id.* at 10.

First, the Subcommittee asserted that the protocol for measuring egg density over the years was too variable to provide reliable comparisons.⁶¹ Even if that was previously a legitimate concern, scientists have now demonstrated a long-term reduction in the surface availability of horseshoe crab eggs based on multiple studies using similar methods and sampling from comparable or even identical locations.⁶² More fundamentally, in the context of a threatened species, major warning signs should not be disregarded on the basis of uncertainty in the data, especially when the data that exist point strongly in the same troubling direction. As Dr. Lipcius explains, “Lack of use of HSC egg density data, as a proxy for RK food availability, amounts to a failure to incorporate all available scientific information into the analysis to guide management decisions in a risk-averse manner.”⁶³

The Subcommittee next asserted that habitat loss had not been “adequately rule[d] out” as the cause of declining egg density. This argument is equally misplaced. Recent research demonstrates that egg density has declined even where habitat continues to be suitable, such as where sand depth exceeds 40 centimeters.⁶⁴ Moreover, habitat loss does not provide a basis for disregarding the availability of horseshoe crab eggs for red knots. As Dr. Lipcius explains, while the Board does not have control over all sources of stress on horseshoe crabs, the existence of multiple stressors demands a *more* risk-averse approach with respect to factors such as harvest quotas that are fully within the Board’s control.⁶⁵

In addition, the Subcommittee denied the ability to link horseshoe crab egg abundance with red knot nutrition or survival.⁶⁶ However, as shown above, there is a strong correlation between declining egg density and declining red knot abundance.

Regardless of the Subcommittee’s concerns that egg density data are not sufficiently conclusive, or that habitat loss is a contributing factor, multiple studies over several decades uniformly point in the same direction: egg density has declined to an alarming degree, as have the red knots that consume the eggs. At a minimum, the Commission must recognize that plentiful eggs are a necessary and critical element of red knot recovery and solicit formal stakeholder input on incorporating that principle into harvest decisions in light of recent research.

C. The Revised ARM Framework Finds a Weak Relationship Largely Because It Relies on Data from Years When Both Red Knots and Horseshoe Crabs Were Already Depleted.

In contrast to all of the scientific information discussed above demonstrating a critical connection between horseshoe crabs and red knots, the revised ARM Framework finds a weak link between these species partly because it is based entirely on data from after the ecosystem

⁶¹ ARM Subcommittee, *Majority Response to Niles and Justification for Why Opinion Not Adopted* (in *ASMFC, ARM Report*) 105-06.

⁶² Smith et al., *Horseshoe Crab Egg Availability*.

⁶³ *Lipcius Expert Report* 12.

⁶⁴ Smith et al., *Horseshoe Crab Egg Availability*.

⁶⁵ *Lipcius Expert Report* 13.

⁶⁶ ARM Subcommittee, *Majority Response to Niles* 104.

crashed in the late 1990s.⁶⁷ The most the model can do is interpret the interaction between two perilously depleted species, without any concept of how a healthy ecosystem would function. In defiance of historical and scientific evidence, the revised ARM Framework seems to assume that a supposedly minimal correlation between horseshoe crabs and red knots when both species are degraded is indicative of how the ecosystem would operate when both species are plentiful. Rather than viewing its finding of a weak link appropriately as a symptom of an ailing ecosystem, the revised ARM Framework leverages it to justify greater exploitation.

As one example of why recent data may not represent the historic relationship between the two species, consider the population of red knots migrating from southern South America. These birds travel the farthest to reach Delaware Bay and need to rebuild their digestive organs upon arrival, making them particularly dependent upon easily digestible horseshoe crab eggs.⁶⁸ Even more than other red knots, this Southern wintering population has suffered “sharp and well-documented declines” in recent decades due to reduced food availability at Delaware Bay.⁶⁹ As a result, the relatively small number of red knots that pass through Delaware Bay may be increasingly skewed toward birds that winter farther north, with fewer of the birds that most heavily depend upon horseshoe crab eggs. The revised ARM Framework would interpret these conditions to mean that red knot abundance is less affected by horseshoe crab abundance and that greater exploitation is acceptable. It would thus ignore the impact of egg scarcity on the most vulnerable population of red knots.

While the revised ARM Framework may necessarily be limited by the years from which data are available, it should not draw overbroad conclusions from a constrained dataset. As Dr. Shoemaker explains, these constraints give the model a “limited scope of historical variation Using these models to forecast system dynamics under conditions outside the range of values used to fit the model (e.g., lower HSC abundances, higher REKN abundances) therefore requires extrapolation, which can be highly uncertain (and often inaccurate).”⁷⁰ Based on Dr. Shoemaker’s expert judgment, “[I]t does not seem prudent to implement management ‘experiments’ that could potentially imperil a threatened or endangered species (TES), even under the rubric of adaptive management.”⁷¹

D. The Revised ARM Framework Would Arbitrarily and Unjustifiably Remove Abundance Thresholds Below Which the Harvest of Female Horseshoe Crabs Is Prohibited.

The revised ARM Framework would arbitrarily lift the protective abundance thresholds intended to preserve the availability of food for red knots. Specifically, under the existing Framework, the female harvest quota is zero until the estimated abundance of female horseshoe crabs exceeds 11.2 million or the estimated abundance of red knots exceeds 81,900 in Delaware Bay.⁷² These

⁶⁷ *E.g.*, *ARM Report* 156 tbl. 13 (illustrating that the catch multiple survey analysis for horseshoe crabs uses data starting from 2003). Compounding the chronological limitations on the data informing the model, the revised ARM Framework also imposes geographic constraints by including only data from Delaware Bay.

⁶⁸ FWS, *Species Status Assessment Report* 9.

⁶⁹ *Id.* at 28; FWS, *Draft Recovery Plan for the Rufa Red Knot* 14.

⁷⁰ *Shoemaker Expert Report* 11.

⁷¹ *Id.*

⁷² ASMFC, *ARM Report* 21.

thresholds reflect stakeholders' desire to take a precautionary approach to managing the delicate relationship between horseshoe crabs and red knots. Because neither species has reached its threshold since the original ARM Framework was implemented, the model has never recommended a female harvest. Under the revised ARM Framework, the model could (and likely would) recommend a significant female harvest even when neither red knot nor female horseshoe crab abundance has exceeded its protective threshold. Indeed, the Subcommittee's calculations show that the model would have recommended a female harvest of approximately 150,000 for 2017-2019, years when the original ARM Framework recommended a female harvest of zero.⁷³

1. ASMFC Has Provided No Defensible Rationale for Removing the Protective Thresholds.

Removal of the protective thresholds received significant criticism in the minority opinions submitted by ARM Subcommittee members.⁷⁴ In rejecting these critiques, the Subcommittee relied on two primary arguments, neither of which is defensible.

First, the Subcommittee stated, "The presence of these threshold constraints in the utility function was criticized during this revision for not being consistent with adaptive management and optimization procedures and therefore they were removed from the utility functions."⁷⁵ But the Subcommittee's argument assumes that stakeholder values have no role in adaptive management, and that adaptive management is inconsistent with any constraint that arises from something other than an optimization model. This view squarely defies the adaptive management process as described in Addendum VII, which highly values stakeholder input, as explained in section IV.B of these comments. Moreover, the Subcommittee's view is internally inconsistent, as the revised ARM Framework appropriately maintains precautionary limits on the maximum harvest of male and female horseshoe crabs,⁷⁶ which represents a constraint on the model in deference to precautionary values. Thus, the revised ARM Framework is arbitrarily selective about its willingness to consider precautionary constraints.

Second, the Subcommittee described the thresholds as a "knife-edge utility function[]" and stated that, once the thresholds were exceeded, the existing ARM Framework would immediately recommend the maximum harvest package, with its female quota of 210,000.⁷⁷ According to the Subcommittee's calculations, the model is unlikely to ever select the interim harvest package, with a female quota of 140,000.⁷⁸

The Subcommittee's argument misses the mark. The immediate issue is whether female harvest is allowed *below* the thresholds. The Subcommittee may have concerns about what

⁷³ ASMFC, *Supplemental ARM Report* 21 tbl. 11.

⁷⁴ E.g., Wendy Walsh, *Walsh Minority Opinion* (in ASMFC, *ARM Report*) 113-14.

⁷⁵ ARM Subcommittee, *Majority Response to Niles* 107.

⁷⁶ ASMFC, *ARM Report* 81 ("[O]ne feature from the packages used in the original ARM version was retained: the maximum harvest for females was set to 210,000 and for males 500,000."). The Subcommittee pointed to these limits as an example of maintaining an "earlier decision[] made by stakeholders." ARM Subcommittee, *Majority Response to Walsh and Justification for Why Opinion Not Adopted* (in ASMFC, *ARM Report*) 125.

⁷⁷ ARM Subcommittee, *Majority Response to Walsh* 124.

⁷⁸ *Id.*

recommendations the current model would make in the unprecedented event that the thresholds were exceeded, but that is a separate question. In addition, if the current model would catapult over the interim harvest package and immediately recommend the maximum harvest package in the event that red knots or female horseshoe crabs met their abundance threshold, that would seem to indicate a defect in the existing model. A more reasonable correction would be to adjust the existing model to facilitate a gradual increase in female harvest recommendations once an abundance threshold is met. It is not at all clear why removing the thresholds altogether is a necessary or logical solution. Regardless, a potential defect in the current model's response to the achievement of protective thresholds for horseshoe crabs or red knots cannot offer any justification for eliminating the thresholds well before they are met. At the very least, the Subcommittee should have made its decision in consultation with stakeholders, not unilaterally.

2. The Elimination of the Protective Thresholds Illustrates the Improper Exclusion of Stakeholder Input.

In section IV.B, these comments detail why the exclusion of formal stakeholder input from the development of the revised ARM Framework was inappropriate and violated the requirements for adaptive management. This section explains why excluding stakeholders from decisions about the protective thresholds was particularly improper and contravened the views of the Commission's own experts and peer review panel.

During the Board's early consideration of developing Addendum VIII, the ARM Subcommittee Chair explained what process would be required to change (much less eliminate) the protective thresholds:

[M]oving forward with this new Population Dynamics Model, where that threshold is at 11.2 million, you know that could change. It is a possibility to have a different utility function. *That is something that would have to be discussed amongst stakeholders* and among the ARM Workgroup members.⁷⁹

Despite the Chair's acknowledgement that changing the female horseshoe crab threshold would require stakeholder input, the revised ARM Framework would eliminate the threshold even in the absence of stakeholder input.

The exclusion of stakeholders and elimination of the thresholds was criticized in the minority opinion of Subcommittee member (and Chair of the Delaware Bay Ecosystem Technical Committee) Dr. Wendy Walsh, the national lead for red knot recovery at FWS. Dr. Walsh meticulously detailed the role of stakeholder input in adaptive resource management and observed that the ARM Subcommittee had "failed to consult a broad array of stakeholders in the reinterpretation of previously agreed-upon objectives."⁸⁰ With respect to the abundance thresholds, Dr. Walsh explained:

⁷⁹ Comments of John Sweka, ARM Subcommittee Chair, *Proceedings of the Atlantic States Marine Fisheries Commission Horseshoe Crab Management Board 5* (Oct. 29, 2019) (emphasis added), <https://www.asmf.org/uploads/file/5fb2ea02HorseshoeCrabBoardProceedingsOct2019.pdf>.

⁸⁰ *Walsh Minority Opinion* 113.

These threshold values act as a constraint on female harvest, which was the express intent of the stakeholders. . . . [T]he formulation of these values as a constraint was an explicit and clear choice in the development of the existing framework. . . . [T]he high risk-aversion to female crab harvest by the stakeholders is clear, and thus it can be presumed that the new utility function . . . would be of considerable concern to those same stakeholders.⁸¹

The ASMFC-convened Peer Review Panel echoed these concerns. Recognizing that the Subcommittee had not convened stakeholders for this proceeding, the Panel tentatively stated that it “does not disagree” with the revised modeling functions, “as long as they truly reflect the objectives related to HSC harvest and REKN recovery and the risk associated with the HSC harvest.”⁸² The Panel reiterated its concern in its list of recommendations:

The new utility and harvest functions are a representation of values, and the Panel understands that convening a group of stakeholders for this revision was not possible. Therefore, the Panel recommends the WG fully consider whether the new utility and harvest functions represent stakeholder values as articulated in 2009.⁸³

The rejection of Dr. Walsh’s minority opinion indicated a troubling misunderstanding of the Subcommittee’s assignment. The Subcommittee wrote that retaining the threshold values “is more consistent with a simple harvest control rule” and “would not be adaptive management and would not require the Framework developed in this assessment.”⁸⁴ By this statement, the Subcommittee revealed that it viewed stakeholder input as an impediment to adaptive management—an obstacle to the Framework the Subcommittee had already devised. But as explained in more detail below in section IV.B, stakeholder input has consistently been recognized as the foundational step of adaptive management. There is no adaptive management without stakeholder input, and the revised ARM Framework is therefore not an exercise in adaptive management.

E. The Horseshoe Crab Population Estimates Are Improperly Based, in Large Part, on Two Surveys that Stakeholders Have Rejected.

The omission of stakeholder input was particularly harmful because it obscured stakeholder objections to new survey data upon which the revised ARM Framework extensively relies. Since its inception, the ARM Framework has based horseshoe crab abundance estimates entirely on data from the Virginia Tech Horseshoe Crab Trawl Survey, which reflected the original stakeholders’ greater confidence in that survey compared to other surveys of horseshoe crabs in Delaware Bay. The Virginia Tech survey is purpose-designed to count horseshoe crabs, as opposed to general surveys that count horseshoe crabs just incidentally, and FWS has called it

⁸¹ *Id.* at 113-14.

⁸² ASMFC, *Horseshoe Crab Adaptive Resource Management Revision Peer Review Report* (in ASMFC, *ARM Report*) 10 (277 of PDF) (“*Peer Review Report*”). Significantly, the Peer Review Panel’s tentative approval of the revised ARM Framework was uninformed by independent expert reviews such as those offered by Drs. Shoemaker and Lipcius in this comment process.

⁸³ *Id.* at 12.

⁸⁴ ARM Subcommittee, *Majority Response to Walsh* 122.

“the best benthic trawl survey to support the ARM.”⁸⁵ Yet the revised ARM Framework would drastically downgrade the model’s reliance on the Virginia Tech survey, rendering it one of three equally weighted surveys.⁸⁶ The two additional surveys that would comprise the abundance estimates—the New Jersey Ocean Trawl Survey and the Delaware Adult Trawl Survey—are general trawl surveys and not purpose-designed to count horseshoe crabs.

In her minority opinion, Dr. Walsh explained (as the Subcommittee acknowledged) that the revised approach would generate significantly higher abundance estimates,⁸⁷ which will lead to higher harvest recommendations for female horseshoe crabs. Dr. Walsh urged that, if the Subcommittee determined to rely upon all three surveys, it should at least accord greater weight to the Virginia Tech survey based on its “technical rigor and deliberate design” and “the high level of confidence that stakeholders have expressed in” it, among other reasons.⁸⁸ As Dr. Walsh noted, using all three surveys generates such high estimates that it would sometimes have resulted in female harvest recommendations even under the existing ARM Framework.⁸⁹

The original decision to rely exclusively on the Virginia Tech survey reflected explicit stakeholder input. By introducing two additional surveys that stakeholders previously disfavored, and weighting all three surveys equally, the revised ARM Framework alters yet another stakeholder-driven component of the model without soliciting formal stakeholder input.

IV. ASMFC HAS REPEATEDLY EXCLUDED INPUT FROM STAKEHOLDERS AND THE BROADER PUBLIC.

The development of Draft Addendum VIII omitted input from stakeholders and the public throughout the process. The Atlantic Coastal Fisheries Cooperative Management Act of 1993 requires the Commission to “provide[] adequate opportunity for public participation in the [fishery management] plan preparation process.”⁹⁰ ASMFC has violated legal requirements and its own guidelines by severely limiting public participation in this proceeding. Specifically, the Commission held a public comment period before essential information was publicly available, failed to solicit formal stakeholder input, and decided to artificially limit its range of options to adopting Addendum VIII or reverting to Addendum VI—both of which would lead to resuming the female horseshoe crab harvest—without any public input whatsoever.

⁸⁵ FWS, *Rufa Red Knot Background Information and Threats Assessment* 247.

⁸⁶ ASMFC, *ARM Report* 55.

⁸⁷ Walsh Minority Opinion 111; ARM Subcommittee, *Majority Response to Walsh* 123 (“[I]t was noted in the 2019 assessment that equally weighting the surveys resulted in higher population estimates and that characterization by Walsh is accurate.”); ASMFC, *Supplemental ARM Report* 21 tbl. 11 (for a comparison of abundance estimates under the current and proposed methodologies).

⁸⁸ *Walsh Minority Opinion* 111.

⁸⁹ *Id.* at 111-12.

⁹⁰ 16 U.S.C. § 5104(a)(2)(B).

A. ASMFC Held the Public Comment Period Before the Revised ARM Framework's Core Model Was Publicly Available.

The public comment period for Addendum VIII occurred while crucial, material information was being withheld from the public. Specifically, the public still has not been allowed to see the model that generates bait harvest recommendations for horseshoe crabs in Delaware Bay.

New Jersey Audubon and Defenders of Wildlife requested the model on February 23, 2022, in FOIA requests submitted to the U.S. Geological Survey (“USGS”) and FWS, as well as a record request submitted to ASMFC. While ASMFC provided certain components related to the horseshoe crab estimates, USGS controls the core component that links horseshoe crabs and red knots to generate harvest recommendations. In a letter prior to the Board’s August 2022 meeting, New Jersey Audubon and Defenders of Wildlife explained that USGS had not yet released the model and urged the Board not to initiate the public comment period on Draft Addendum VIII until the public could access the model that underlies the revised ARM Framework.⁹¹ At the Board meeting, several members expressed concern about the unavailability of the model, noted USGS’s stated intent to release the model following internal review,⁹² and asked to be kept apprised of developments in the public’s access to the model.

As of September 30, 2022—the close of the public comment period on Draft Addendum VIII—USGS has still not released the model. As a result, the public’s ability to submit substantive technical comments has been severely constrained. As this comment letter demonstrates, public evaluation is essential for identifying significant issues for the Board’s consideration. Indeed, many of Dr. Shoemaker’s critiques were enabled by the limited model components released by ASMFC. But the preponderance of the model underlying the revised ARM Framework still has not been subject to public evaluation. Dr. Shoemaker listed several questions that he could have investigated more thoroughly if that model were available,⁹³ including:

- Does the red knot projection model outperform a null model that excludes any effect of horseshoe crab abundance?
- How much variation in apparent survival in the red knot IPM model is explained by the horseshoe crab effect compared to random among-year variation?
- Would an index of horseshoe crab egg density explain more variation in red knot survival and fecundity than the CMSA-derived estimate of horseshoe crab abundance?

While the Board should resolve the issues that have already been raised before further considering Addendum VIII, it is impossible to anticipate all of the additional questions that will

⁹¹ Letter from Benjamin Levitan, Earthjustice, to ASMFC Commissioners re *Consideration of Draft Addendum VIII on the Implementation of Recommended Changes from 2021 Adaptive Resource Management Revision and Peer Review Report for Public Comment* (July 26, 2022).

⁹² In an email accompanying its denial of a Freedom of Information Act Request for the model, a U.S. Geological Survey representative wrote, “We have withheld the two USGS models, but they and their associated use publications will be published following the required USGS Fundamental Science Practices reviews.” Email from Janis Wilson, USGS, to Benjamin Levitan, Earthjustice, re: *FOIA: DOI-USGS-2022-002312 – Response* (July 28, 2022). On August 15, 2022, New Jersey Audubon and Defenders of Wildlife administratively appealed the denial of access to the model, but USGS has not yet responded.

⁹³ *Shoemaker Expert Report* 26-27.

be identified once the model is released. New issues will inevitably arise. The proper time to address those questions is before the Board approves Addendum VIII. Enabling the public to identify additional questions only after the revised ARM Framework has been approved would subject red knots and horseshoe crabs to unacceptable risk and raise difficult administrative questions about how to limit the harm even as the Framework is in place.

B. The Subcommittee Violated ASMFC’s Procedures by Failing to Solicit Formal Stakeholder Input.

The ARM Subcommittee’s failure to solicit formal stakeholder input in this proceeding violated the principles and process of adaptive management. When the Board first approved the ARM Framework in Addendum VII more than a decade ago, stakeholder input was integral to the process. The *first sentence* of the “ARM Framework” section of Addendum VII was, “A goal of the ARM Framework is to transparently incorporate the views of stakeholders along with predictive modeling to assess the potential consequences of multiple, alternative management actions in the Delaware Bay Region.”⁹⁴ The ARM Subcommittee expressed the same sentiment about the “ARM approach” in the current proceeding: “First, there is a great emphasis on complete elicitation of objectives and management actions from a full range of stakeholders.”⁹⁵ The Subcommittee took that sentence verbatim from the Commission’s Framework for Adaptive Management from 2009,⁹⁶ demonstrating how consistently stakeholder input has been acknowledged as the cornerstone of adaptive management.

The Board formalized the role of stakeholder input when it approved Addendum VII, which implemented an adaptive management framework for the Delaware Bay horseshoe crab fishery. Addendum VII required that the ARM Framework’s “[i]mplementation *shall* be comprised of two cycles.”⁹⁷ The *first step* of the “Longer Term Cycle,” which was to occur “every 3 or 4 years,” was to “[s]olicit formal stakeholder input on ARM Framework to be provided to the relevant technical committees.”⁹⁸

The ARM Subcommittee’s failure to convene stakeholders in preparing Addendum VIII violated the Board’s express requirements, as well as the principles underlying the adoption of adaptive management. And if the Board approves Addendum VIII, the exclusion of stakeholders is unlikely to be rectified anytime soon. Addendum VIII sets forth a default period of “every 9 or 10 years” for revising the ARM Framework, which “should incorporate” soliciting “formal stakeholder input.”⁹⁹ Pursuant to that schedule, if the Board approves Addendum VIII in 2022—which it should not do—the ARM Framework will be due for a revision in the early 2030s. Assuming that stakeholders are formally consulted at that time (unlike this time), roughly 20

⁹⁴ ASMFC, *Addendum VII to the Interstate Fishery Management Plan for Horseshoe Crabs for Public Comment: Adaptive Resource Management Framework 2* (2012), https://www.asmfc.org/uploads/file/hscAddendumVII_Feb2012.pdf (“*Addendum VIII*”).

⁹⁵ ASMFC, *ARM Report 21*.

⁹⁶ ASMFC, *Stock Assessment Report No. 09-02 (Supplement B): A Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Constrained by Red Knot Conservation 1* (2009), <https://www.asmfc.org/uploads/file/2009DelawareBayARMReport.pdf>.

⁹⁷ ASMFC, *Addendum VII* at 4 (emphasis added).

⁹⁸ *Id.*

⁹⁹ ASMFC, *Horseshoe Crab Draft Addendum VIII for Public Comment 8* (Aug. 2022).

years will have elapsed between such consultations, a striking contrast to the “3 or 4 year[]” interval required by Addendum VII. That would also mean that stakeholders would not be formally consulted for roughly *17 years* after FWS’s 2015 determination to list red knots under the Endangered Species Act. While it is impossible to know all the ways that soliciting stakeholder input would have affected the current proceeding, the revised ARM Framework’s elimination of the protective abundance thresholds (described above in section III.D.2) demonstrates that this concern is not merely theoretical.

It bears repeating how significantly the revised ARM Framework departs from the paradigm that the stakeholders accepted in preparation for Addendum VII, which instituted harvest recommendations based on the relationship between horseshoe crabs and red knots. The revised Framework would weaken that relationship almost to the point of nonexistence and recommend quotas accordingly. While presented as a technical update, the revised ARM Framework cannot plausibly be considered a reflection of the stakeholders’ articulated values. At the very least, stakeholders should have been involved in designing a revised approach. Failure to involve them represents another reason for rejecting the current proposal.

C. Even Before the Public Comment Period, ASMFC Purported to Limit Its Options to Those that Would Reinitiate the Female Horseshoe Crab Harvest.

In addition to the inaccessibility of crucial information and the exclusion of stakeholder input, there was no public notice or comment for arguably the most critical decision presented by Draft Addendum VIII, which ASMFC now presents as a foregone conclusion: designating a reversion to Addendum VI as the “No Action” alternative if the Board does not approve Addendum VIII.¹⁰⁰ Addendum VI would increase the Bay-wide horseshoe crab harvest quota and *allow for the resumption of the female harvest* in Maryland and Virginia. Thus, the Board has effectively foreclosed public comment on the pressing question of *whether* to resume female harvest for this fishery. Under the terms of draft Addendum VIII, whichever option the Board selects—and regardless of any information that might surface during the public comment period—that decision is preordained.

On the merits, selecting Addendum VI as the “No Action” alternative was arbitrary, unnecessary, and misleading. Addendum VI would completely transform the management framework. The transition from Addendum VI to Addendum VII was arguably the most significant event in ASMFC’s management of the horseshoe crab fishery, and reverting to Addendum VI would be equally significant.

To justify the selection of Addendum VI, Draft Addendum VIII indicates that Addendum VII is unavailable as the “No Action” alternative because the model underlying it was built on obsolete software and can no longer be utilized.¹⁰¹ Even if the software is obsolete, that does not back the Board into a corner with no option but to adopt an addendum with a female harvest. The current ARM Framework has generated the same harvest quota for ten consecutive years, and the legitimate “No Action” alternative would be to apply the same quota to the 2023 fishing season. In fact, Addendum VII contains two “fallback option[s]” for when the data required to run the

¹⁰⁰ *Id.* at 5.

¹⁰¹ *Id.*

ARM model are not available: use the quotas from Addendum VI *or* use the same quotas as the previous year.¹⁰² It is unclear why the Board would have fewer options when the Addendum VII model cannot be run. The natural understanding of “No Action” would be to maintain the current status quo—i.e., the current addendum and current quotas—not to revert to an addendum and quotas that mark a major departure from the status quo.

At the August 2022 Board meeting, ASMFC staff explained that simply reusing last year’s quotas is not appropriate because that would not qualify as “adaptive resource management.”¹⁰³ Even if that were so, the solution should not be to reinstate the 12-year-old static quotas from Addendum VI. If the Board has authority to impose such a drastic change, then surely it has authority to continue relying on the most recent outputs of the current ARM Framework. It may be that neither option offers a satisfactory long-term solution, but the question now is what to do while questions about the revised ARM Framework are being addressed. The Board is not required to rush through a new (or old) addendum. It can temporarily maintain the current Framework to allow for thorough consideration of the appropriate next step, which clearly does not include accepting Addendum VIII as currently proposed.

V. THE FLAWS IN THE REVISED ARM FRAMEWORK MUST BE ADDRESSED NOW.

The Board’s decision on Addendum VIII is highly consequential and could determine the course of the horseshoe crab fishery for many years to come. It is vital that the revised ARM Framework be subject to full vetting, and that foreseeable flaws be identified, prior to implementation by the Board. There will not be realistic opportunities to remedy defects in the revised ARM Framework in the future—at least not without imposing large burdens on both the Board and the public.

A. Flaws in the Revised ARM Framework Cannot Realistically Be Remedied at the Quota-Setting Stage.

At the Board’s meeting in August 2022, some speakers observed that Addendum VIII will not, in itself, set binding quotas because the Board will retain discretion to deviate from the ARM Framework’s harvest recommendations, and states will retain discretion to set quotas below those set by the Board.¹⁰⁴ But that is not a valid rationale for approving an addendum that has not been fully vetted and has been demonstrated to be flawed based on even the limited amount of information that has been made publicly available.

The purpose of the ARM process is to generate harvest recommendations based on rigorous science and sound policy.¹⁰⁵ As these comments detail, the revised ARM Framework incorporates many substantive and procedural flaws, and additional flaws are likely to emerge

¹⁰² ASMFC, *Addendum VII* at 6.

¹⁰³ ASMFC, *Horseshoe Crab Management Board Proceedings Aug2022*, at 5:11, <https://www.youtube.com/watch?v=OZvpdTTPj8c>.

¹⁰⁴ *E.g., id.* at 28:00, 1:12:57.

¹⁰⁵ 16 U.S.C. § 5104(a)(2)(B) (requirement in the Atlantic Coastal Fisheries Cooperative Management Act of 1993 for ASMFC to follow “standards and procedures to ensure that . . . [fishery management] plans promote the conservation of fish stocks throughout their ranges and are based on the best scientific information available.”).

when the underlying model is released to, and evaluated by, the public. Regardless of the Board's or states' ability to deviate from those recommendations, the Board must ensure that the Framework represents the best available—and properly vetted—science and policy. To do otherwise would call into question the purpose of the ARM process and the harvest recommendations.

It would also not be practical for the Board or states to resolve the flaws in the revised ARM Framework at the quota-setting stage. If Addendum VIII were approved and the Board were unable to rely upon the Framework's flawed harvest recommendations, there would be no clear criteria or guidelines for establishing quotas, leading to a confusing, burdensome, and arbitrary quota-setting process. Similarly, if the Board approved Addendum VIII and adopted the revised ARM Framework's flawed harvest recommendations, states would need to determine the proper course in the absence of reliable information or direction from ASMFC. That would undermine the Horseshoe Crab Fishery Management Plan's purpose of creating “[a] coordinated and consistent management strategy.”¹⁰⁶

B. Flaws in the Revised ARM Framework Cannot Be Addressed Through Updates to the Model.

While the revised ARM Framework can be “updated based on the annual routine data collected in the region,”¹⁰⁷ updates will not remedy its flaws. Many of the defects identified in these comments cannot be addressed by new data but rather demand a deeper restructuring of the model. For example, the model's miscalculation of the uncertainty in horseshoe crab abundance projections will persist despite new data. The same is true for all of the variables that are omitted from the model but indicate an unstable horseshoe crab population: egg density, prosomal width, sex ratio, etc.

Other defects would theoretically be alleviated by new data, but not on any relevant timescale. For example, the effect of the nonsensical horseshoe crab recruitment rates from the Virginia Tech gap years will gradually be diluted as new data are added, but they will continue to have perilously high influence for many years—realistically, for as long as Addendum VIII will be in effect. And even if, for the sake of argument, the estimated recruitment rate will slowly become more accurate over the years, that does not justify neglecting to fix a clear defect before implementing the revised ARM Framework.

Finally, some defects may be compounded by the addition of more data. As explained above in section III.C, the model is based entirely on data from when both horseshoe crabs and red knots had already crashed. It does not reflect the dynamics of a properly functioning ecosystem. As more data from the post-crash years are added, the model may only grow more confident that the current state of the ecosystem represents the norm. As Dr. Shoemaker observes, additional data may even yield a negative relationship between the abundance of horseshoe crabs and red knots, which would pose an existential problem for the Framework.¹⁰⁸

¹⁰⁶ ASMFC, *Fishery Management Report No. 32 of the Atlantic States Marine Fisheries Commission: Interstate Fishery Management Plan for Horseshoe Crab 1* (1998).

¹⁰⁷ ASMFC, *Draft Addendum VIII* at 8.

¹⁰⁸ *Shoemaker Expert Report* 10.

VI. APPROVING ADDENDUM VIII WOULD LIKELY LEAD TO A VIOLATION OF THE ENDANGERED SPECIES ACT BY ASMFC.

In addition to the other bases for rejecting Addendum VIII discussed above, the Endangered Species Act provides a powerful further reason: adopting Addendum VIII would threaten to violate the federal prohibition against “taking” a threatened species. The ESA prohibits any person from “tak[ing] any [endangered] species within the United States or the territorial sea of the United States.”¹⁰⁹ 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.”¹¹⁰ 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.¹¹¹ By regulation, that prohibition extends to the taking of most threatened species, including the red knot.¹¹²

A. The Endangered Species Act Requires a Precautionary Approach.

In the Endangered Species Act, Congress adopted a precautionary approach. As the Supreme Court has stated, “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.’”¹¹³ This principle is echoed in the ARM Framework’s objective statement, which calls for “*ensur[ing]* that the abundance of horseshoe crabs is not limiting the red knot stopover population or slowing recovery.”¹¹⁴ Within the context of the ESA’s legal framework, to ensure against such harms means taking a precautionary approach of “giv[ing] the benefit of the doubt to the species.”¹¹⁵ By setting ASMFC on a path to harm a threatened species whose population shows no sign of recovery, the revised ARM Framework would fall far short of ESA requirements and ASMFC’s own objective.

As shown above, in many instances, Addendum VIII would enshrine a risk-prone approach instead of the risk-averse, precautionary approach required under the ESA. Even as it would allow the renewed harvest of female horseshoe crabs, Addendum VIII would utilize a model that, among other risky decisions:

- rejects the significant connection between horseshoe crabs and red knots,

¹⁰⁹ 16 U.S.C. § 1538(a)(1)(B).

¹¹⁰ 50 C.F.R. § 17.3.

¹¹¹ *Strahan v. Coxe*, 127 F.3d 155, 163 (1st Cir. 1997); 16 U.S.C. § 1538(g).

¹¹² 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.).

¹¹³ *Tenn. Valley Auth. v. Hill*, 437 U.S. 153, 194 (1978).

¹¹⁴ ASMFC, *ARM Report* 25 (emphasis added).

¹¹⁵ *See, e.g., Roosevelt Campobello Int’l Park Comm’n v. U.S. Envtl. Prot. Agency*, 684 F.2d 1041 (1st Cir. 1982) (quotations and citation omitted); *see also Defs. of Wildlife v. U.S. Dep’t of the Interior*, 931 F.3d 339, 351 (4th Cir. 2019) (same regarding scientific determinations).

- neglects egg-density data, which provide the most direct measure of the adequacy of food for red knots,
- rejects protective populations thresholds that were essential to the only group of stakeholders that ASMFC ever formally consulted about this matter,
- assumes that horseshoe crabs are recovering despite negative demographic trends, and
- uses horseshoe crab projections that fail to account for uncertainty and are scarcely more accurate than a null model.

The exclusion of public input at multiple stages of this proceeding exacerbates the risk of an ESA violation because ASMFC has evaded the public scrutiny that would be appropriate for such a consequential proceeding. A risk-averse approach would be to welcome public input in order to identify and address weaknesses that create unacceptable risk for the red knot. But the Board has taken a different, risk-prone approach: hastening a vote on Addendum VIII even as the underlying model continues to be withheld, despite record requests submitted more than seven months ago. The Board will therefore make a decision without the benefit of crucial public input and the important considerations such input would raise.

Both ASMFC and FWS suggest that the model will be improved by future updates.¹¹⁶ As shown above in section V.B, updates cannot remedy the flaws in the revised ARM Framework. But even if they could, relying on future updates is not appropriate when an ecosystem is dangerously degraded and a threatened species hangs in balance. Future updates are likely to come too late.

B. By Utilizing the Revised ARM Framework, ASMFC Would Harm Red Knots.

Like any other association or governmental entity, ASMFC is subject to the ESA taking prohibition.¹¹⁷ Under the Atlantic Coast Fisheries Cooperative Management Act of 1993,¹¹⁸ ASMFC’s fishery management plans are legally binding upon affected states. Once the Commission issues a plan, states “shall implement and enforce the measures of such plan within the timeframe established in the plan.”¹¹⁹ Because ASMFC’s quotas cannot be exceeded, states have been prohibited from authorizing female horseshoe crab bait harvest in Delaware Bay under the existing framework. States may authorize a female bait harvest only if ASMFC sets a non-zero female harvest quota.¹²⁰

¹¹⁶ ASMFC, *Draft Addendum VIII* at 8; FWS, *U.S. Fish and Wildlife Service Evaluation of the Atlantic States Marine Fisheries Commission Horseshoe Crab/Red Knot Adaptive Resource Management Revision* at 3 of PDF (2022) (“*Evaluation*”), <https://www.fws.gov/sites/default/files/documents/service-evaluation-of-atlantic-states-marine-fisheries-commission-horseshoe-crab-red-knot-adaptive-resource-management-revision.pdf>.

¹¹⁷ The ESA applies to any “person,” which is broadly defined. 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.”).

¹¹⁸ 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.*).

¹¹⁹ *Id.* § 5104(b)(1).

¹²⁰ *Cf. Defs. of Wildlife v. U.S. Env’tl. Prot. Agency*, 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).

ASMFC's fishery management decisions therefore have a direct causal connection to the ultimate bait-harvesting actions that impact horseshoe crabs and red knots.¹²¹ Indeed, the connection between the Board's management decisions and red knot demographics is the premise and intent of the ARM Framework's 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.¹²²

Draft Addendum VIII shows that, if the revised ARM Framework had been utilized in 2017-2019, it would have allowed for the harvest of around 150,000 female horseshoe crabs each year,¹²³ compared to the actual quota of zero for each of those years. Going forward, allowing such an increase in the harvest of female horseshoe crabs, upon 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.¹²⁴

As explained above, the revised ARM Framework raises serious questions that the Board has not answered or publicly considered. After 24 years of ASMFC management, including 10 years under an ARM Framework, neither red knots nor horseshoe crabs are on a trajectory to recover. There are serious reasons to doubt even the modest increase in the horseshoe crab population that ASMFC reports. ASMFC's red knot abundance estimates are essentially flat at low numbers, while other estimates based on direct counting have shown a dangerous decline in recent years.

Now, in the Board's first addendum since red knots were listed as threatened, Addendum VIII would result in the increased harvest of horseshoe crabs, including the resumed harvest of females, thus magnifying the factors imperiling red knots. This poses an enormous risk to the ecosystem, which is precisely the wrong response to a species being listed under the ESA.

C. FWS's "Evaluation" Does Not Offer Independent Support for Addendum VIII.

Recent statements from FWS do not bolster the credibility of the revised ARM Framework. When FWS listed red knots as threatened under the ESA, it stated, "[A]s long as the ARM is in place and functioning as intended, ongoing HSC bait harvests should not be a threat to the red knot."¹²⁵ In her minority opinion raising concerns about the revised ARM Framework, Dr. Walsh

¹²¹ *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).

¹²² ASMFC, *ARM Report 25*.

¹²³ ASMFC, *Draft Addendum VIII* at 12 app'x A tbl. 1 (showing annual female harvest quotas ranging from 144,803 to 154,483).

¹²⁴ 50 C.F.R. § 17.3 (defining "[h]arm").

¹²⁵ 79 Fed. Reg. at 73,709.

wrote 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 intended.”¹²⁶

In contrast to Dr. Walsh’s minority opinion, the document that FWS released on August 16, 2022, styled as an “evaluation” of the revised ARM Framework, did not offer any independent assessment of the revised ARM Framework. Rather, it repackaged the revised ARM Framework’s modeling with all of its flaws detailed above, at times appearing to copy and paste figures directly from the Subcommittee’s materials, and stated that the revision “poses negligible risk to red knot recovery and negligible risk of take under the Endangered Species Act.”¹²⁷ Nowhere did FWS question the validity of the revised ARM Framework or any of the underlying assumptions or decisions, including on any of the bases discussed in these comments and accompanying expert reports.

With its complete deference to ASMFC’s flawed modeling, assumptions, and conclusions, FWS unsurprisingly reached the same flawed result but did not bolster its validity. As these comments have shown, the revised ARM Framework incorporates numerous erroneous methodologies and assumptions. In its document, FWS propagated the same errors and replicated the same flaws as ASMFC. Moreover, since FWS relied on ASMFC’s non-public model, its assertions are effectively unverifiable. The revised ARM Framework is unreliable for the reasons demonstrated in these comments. The Framework also still needs a legitimate, thorough, independent review based on all underlying information—not just the information released publicly to date. FWS’s imprimatur does not resolve the defects of Addendum VIII.

VII. CONCLUSION

The window to save red knots is closing rapidly, especially for Southern wintering birds that fly the farthest and are most reliant upon horseshoe crab eggs at Delaware Bay. The revised ARM Framework would increase the pressure on this species, which is already vastly diminished on the beaches that once hosted its extraordinary migration. The Framework does not appreciate the importance of horseshoe crabs to red knots or the fragility of the horseshoe crab population itself. The weak relationship that it perceives between red knots and horseshoe crabs may well become a self-fulfilling prophecy, as the computer model continues to run while the ecosystem around it fades away.

The Horseshoe Crab Management Board has an obligation to restore red knots and horseshoe crabs at Delaware Bay. Just as importantly, it has a real—and maybe a final—opportunity to do so. For the reasons described above and in the attached expert reports, the Board should reject Addendum VIII.

¹²⁶ *Walsh Minority Opinion* 117.

¹²⁷ FWS, *Evaluation* at 3 of PDF. While the document is dated January 18, 2022, it was not released to the public until August 16. For an example of a copied figure, compare ASMFC, *Supplemental ARM Report* 30-31 figs. 10-11, with FWS, *Evaluation* at 5 of PDF fig. 1.

Review of 2021 ASMFC ARM revision

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September 2022

This is an expert review of the Adaptive Resource Management plan (ARM) proposed by ASMFC to guide management of the Horseshoe Crab fishery in Delaware Bay, performed by Kevin Shoemaker, Ph.D.

Dr. Shoemaker has a Ph.D. in Conservation Biology, a Master of Science degree in Conservation Biology, both from SUNY-ESF in Syracuse, NY, and a Bachelor of Science degree in Biology from Haverford College. He is a former Postdoctoral Fellow in the Department of Ecology and Evolution at Stony Brook University and a former Senior Scientist at Applied Biomathematics, an ecological research and development company located in Setauket, NY. Dr. Shoemaker is currently employed as an Associate Professor of Population Ecology at the University of Nevada, Reno. He has over 15 years of experience as a wildlife conservation scientist and has authored over 45 peer-reviewed scientific articles and book chapters on topics in wildlife ecology and conservation. He has expertise in Bayesian inference, machine learning, population ecology, and ecological modeling.

OVERVIEW

This report presents my review of the Adaptive Resource Management plan (ARM) proposed for use by the Atlantic States Marine Fisheries Commission (ASMFC) as a tool for guiding management of the horseshoe crab (HSC) fishery in Delaware Bay and protecting the Federally Threatened *Rufa* Red Knot (*Calidris canutus rufa*; REKN). Delaware Bay is a critical stopover site for REKN in their spring migration to breeding grounds in the high arctic from wintering grounds as far south as Tierra del Fuego (USFWS 2021). Specifically, HSC eggs deposited on coastal beaches provide a necessary high-calorie food resource for REKNs and other migrating shorebird

species as they replenish fat reserves depleted from their long migration and prepare for breeding. At the heart of the proposed ARM framework is an optimization model that provides harvest recommendations for female and male HSC, conditional on current estimates of HSC and REKN abundance. These recommendations are calibrated to maximize HSC harvest while causing minimal risk to the REKN population. The optimization model is based on a linked two-species simulation model (comprising a HSC and a REKN simulation model) that incorporates a one-way biotic interaction in which annual REKN survival and recruitment depend on female HSC abundance in Delaware Bay (among other covariates). While the stated objectives of the revised ARM are sensible, my review identified several concerns that suggest the revised ARM framework is not an appropriate tool for managing risk to HSC or REKN populations. Specifically, this report identifies six main areas of concern:

- (1) **The fitted relationship between HSC abundance and REKN vital rates (survival and fecundity) is of insufficient magnitude to forecast a decline in mean projected REKN population growth even under a total collapse of the HSC population.** The extremely weak REKN/HSC relationship used in the revised ARM is inconsistent with previous research documenting HSC eggs as a critical food resource for migrating REKN and with the documented decline of the REKN population over recent decades, which experts have linked to increases in HSC bait harvest during the 1990s (Niles et al. 2009; USFWS 2014). If the REKN population model is inconsistent with what has been observed in the recent past, it seems unlikely to yield robust forecasts of future risk to the REKN population (or recovery of this population) from which to base management decisions. The inclusion of a REKN population model within the ARM framework (both the initial and revised versions) presupposes that HSC harvest could put REKN populations at risk, at least under some scenarios. As it stands, the apparent inability of the revised ARM model to predict a decline of the REKN population even under a total collapse of the HSC population seems to violate this premise, and practically guarantees that the REKN population model will play an insignificant role in setting optimal HSC harvest rates.
- (2) **The HSC population simulation model fails to correctly propagate uncertainty about mean recruitment rates.** In specifying the bivariate normal distribution used to generate

annual male and female HSC recruitment rates (the most consequential empirically fitted parameters of the HSC simulation model), the proposed ARM framework treats uncertainty about annual recruitment rates as representative of temporal process variance (natural year-to-year fluctuations) rather than as a mixture of parameter uncertainty and process variance (Link and Nichols 1994; Regan et al. 2002; McGowan et al. 2011). This subtle but significant shortcoming will tend to manifest in simulation replicates that closely resemble one another, since key sources of uncertainty “regress to the mean” (good years cancel out bad years) instead of propagating over time. The importance of this distinction is magnified for long-lived iteroparous species like HSC, since these populations tend to be resilient to short-term fluctuations in reproduction or recruitment (Lovich et al. 2015). When this issue is corrected (using the same Bayesian approach used to treat process variation and uncertainty in the REKN simulation models in the revised ARM framework), preliminary simulation results suggest a highly uncertain outlook for the HSC population in Delaware Bay, especially when faced with harvest pressures. In sharp contrast to the ARM report and supplement, the population of HSCs in Delaware Bay appears to have a substantial (17.5%) probability of falling below the lowest previously estimated levels even in the absence of all direct anthropogenic sources of mortality (bait harvest, biomedical bleeding and discard mortality) over the next 50 years. Furthermore, a scenario in which HSCs are harvested annually at the current maximum allowable rates is accompanied by a severe risk of decline (33.45%) and disruption to the population age structure (lower multiparous/primiparous ratios than previously observed). Finally, an extreme harvest scenario in which two million male and female HSCs are harvested each year results in near-certain catastrophic population collapse over the 50-year time horizon, in contrast to the (original) ARM report, which suggests a relatively stable HSC population even under this extreme scenario (which greatly exceeds current maximum allowable rates).

- (3) **The Catch Multiple Survey Analysis (CMSA) exhibits poor fit to training and independent data, raising concerns about its use in projecting future HSC abundance.** Aside from being able to explain the apparent difference in mean HSC abundance before and after the “VT gap years” (see below; higher HSC abundance is both predicted and observed after the

period 2013-2016), the CMSA model explains very little, if any, of the observed variation in the primary data sources (three trawl surveys conducted in and around Delaware Bay). The CMSA results exhibit relatively good fit ($R^2 > 0.5$) to the recruitment data (primiparous abundance); however, this is unsurprising since there is only one source of data (VT swept area surveys) for estimating annual primiparous abundance versus three sources for estimating adult (multiparous) and total abundance. Given the overall lack of fit to training data, the HSC simulation model is unlikely to perform well for predicting independent validation data (data not used to fit the model). Indeed, when the CMSA results are challenged against the HSC spawning surveys – an independent estimate of HSC abundance for this region – there is no detectable relationship between these two independent estimates of HSC abundance. This lack of fit to both training and validation data raises concerns about the utility of the CMSA model, which informs all aspects of the proposed ARM, including the REKN IPM (where it represents the abundance of female HSC each year), the HSC projection model, and the annual harvest recommendation.

- (4) **The “gap years” in the VT trawl survey data raise concerns about HSC recruitment estimates from the Catch Multiple Survey Analysis (CMSA).** As noted above, the CMSA is fundamental to all aspects of the proposed ARM framework. For the HSC population simulation models, the primary role of the CMSA is to parameterize HSC recruitment rates (which are the most consequential empirically derived inputs for the HSC simulation model). Unfortunately, of the three trawl surveys used to fit the CMSA models, the only survey that provides information for estimating recruitment – the Virginia Tech (VT) trawl surveys – was not conducted during a critical four-year period from 2013 to 2016 (hereafter referred to as the “VT gap”, during which no direct information was available for estimating annual HSC recruitment rates). The CMSA results suggest that the HSC population underwent a substantial state transition during the VT gap years in which the population was small but stable prior to the gap, and larger and more variable after the gap. More concerning, the CMSA predicts much higher average recruitment rates during the VT gap (for which no data are available for estimating recruitment) than at any single year before or after. The inflated average recruitment rates during the VT gap period are subsequently used for estimating

mean HSC recruitment rate for the HSC simulation models (thereby increasing estimated population resilience to harvest) – but unfortunately these high recruitment rates cannot be verified empirically. If average recruitment rates were computed from only those years in which recruitment could be verified empirically (i.e., excluding estimates from the VT gap years) the expected resilience of the HSC population to harvest would be substantially reduced.

(5) **The proposed ARM framework lacks ‘null model’ benchmarks and independent performance validation.** Null models are simplified representations of a system that lack many or all the proposed mechanisms that may help to explain the system dynamics; the typical null model in statistics assumes all observed variation is the result of a single random error process. By comparing complex models such as those used in the revised ARM with one or more null-model benchmark(s), researchers can determine whether the more complex models represent useful learned knowledge about a system (Koons et al. 2022). If a complex model fails to outperform a null model in terms of bias or precision (typically using independent validation data), the complex model is likely to be improperly specified or “overfitted” (whereby parameters are fitted to “noise” rather than true signal; Radosavljevic and Anderson 2014) and therefore not useful for prediction. The CMSA model fails to outperform even the simplest statistical null model (single intercept term with sampling error) for at least one data source (the VT swept-area estimate of female multiparous abundance). For the REKN component of the revised ARM, it would be informative to compare the performance of the REKN simulation model against a null model that omits any effect of female HSC abundance. It was recently demonstrated (Koons et al. 2022) that the ARM framework for guiding North American mallard harvest was unable to outperform a null model, and it would be instructive to pose a similar challenge to the REKN simulation model. If either model fails to outperform a null model, it should prompt managers to acknowledge that our current understanding of the effects of harvest on HSC populations remains insufficient for robust forecasting (Dietze 2017), and that a more precautionary approach may be warranted.

(6) **Lack of transparency.** The public still has no access to the data and code used for estimating

REKN population parameters, simulating REKN and HSC population dynamics, and running optimization routines (the CMSA code and data were made available). Without this data and code, it is difficult to fully assess the proposed ARM framework and to run scenario tests. If granted access to the code and data, there are a number of important null model tests (see above) and scenario tests that can be run, including (1) developing and testing the HSC and REKN models against a “null model” benchmark, (2) determining the ‘optimal’ female HSC harvest rates from the “canonical” versions of the HSC and REKN models in the absence of defined harvest limits, and (3) running the REKN simulation model under a scenario representing near-total collapse of the HSC population. The concerns identified above, which arise from analysis of the limited data and code made available to date, demonstrate, at a minimum, that such further testing is warranted. It seems prudent to delay implementation of the new ARM framework until the public and outside experts have had adequate time to scrutinize the statistical and simulation models that play such a central role in this proposed decision-making framework.

SUPPORTING EVIDENCE AND ANALYSES

The remainder of this report provides additional supporting details for the six major areas of concern identified above, including results and figures from re-analyses of the data presented in the ARM report.

1. The fitted relationship between HSC abundance and REKN vital rates (survival and fecundity) is of insufficient magnitude to forecast a decline in mean projected REKN population growth even under a total collapse of the HSC population

Including a model of REKN population dynamics as part of the previous and revised versions of the ARM framework implicitly acknowledges that reduction of the HSC population could, under some circumstances, have a negative impact on REKN populations. This assumption has a strong empirical basis, as multiple lines of evidence suggest that HSC eggs are an extremely important resource for migrating REKNs during their spring migration (e.g., Karpanty et al. 2006; Niles et al. 2009; USFWS 2014; USFWS 2021). Therefore, it is surprising that the fitted relationship between HSC abundance and REKN survival used in the revised ARM is very weak and appears to be

overwhelmed by random among-year variation (Fig. 47 from ARM Report; Fig. 9 from Supplemental Report; hereafter, I will use the notation 'ARM Fig. 47/9'). In fact, it appears from the ARM report that estimated REKN survival rates have generally decreased weakly over time despite an estimated increase in HSC abundance (ARM Fig. 44/7). Years with the lowest HSC abundance in the study period (at or near the lowest HSC abundances ever recorded in Delaware Bay) are coincident with the highest estimated REKN survival rates (ARM Fig. 47/9). Given this weak fitted relationship, simulated REKN abundance based on this model seems unlikely to be very sensitive to changes in HSC abundance. Indeed, a 'back of the envelope' calculation based on the REKN vital rates presented in the ARM report (and the slightly modified numbers presented in the Supplement) shows that the mean population growth rate (Λ) of the REKN population is likely to remain at or above replacement levels ($\Lambda \geq 1$) even at HSC population size equal to zero (Fig. 1). This calculation was produced by using the mean survival from Supplemental Table 8, mean recruitment estimated from Supplemental Fig. 7b, and the standardized logistic regression coefficients from Supplemental Table 9 (effect size = 0.37 for survival and -0.14 for recruitment) to model REKN survival and recruitment as a function of HSC abundance. As a brief aside, the regression coefficients presented in the ARM report (e.g., effect of HSC on survival) are standardized and are on the logit (log-odds) scale, making them difficult to interpret. A quick example may help to aid interpretation of the effect size of this relationship: given a coefficient of 0.37 (the mean regression coefficient for the relationship between HSC abundance and REKN survival from the ARM Supplement, Table 8), a loss of 1 million female horseshoe crabs from Delaware Bay would result in REKN survival rate declining by only 0.004 (from 0.93 to 0.926). This is consistent with visual inspection of ARM Fig. 47/9.

Although I did not have access to the code and data used to fit the relationships between HSC abundance and REKN survival and recruitment, the relationships I used to generate Fig. 1 closely match the relationships presented in ARM Fig. 46/8 (Fig. 2). Interestingly, the value for mean recruitment provided in Supplemental Table 8 ($\rho_{\text{mean}} = 0.063$) yields a declining REKN population ($\Lambda = 0.99$) even under average conditions from 2005 to 2017. Since this result is inconsistent with the reported Λ of 1.04 during that same period from ARM Table 25 (and the generally increasing population trajectories indicated in ARM Fig. 58/15), I chose to use the

mean annual recruitment estimated from Supplemental Fig. 7b, which I calculated to be 0.109 (or geometric mean of 0.099). Using these mean recruitment values resulted in a Lambda of 1.035 (for arithmetic mean) or 1.027 (for geometric mean), more closely resembling but still below the reported baseline Lambda of 1.04 from the ARM report; setting baseline Lambda to 1.04 would only make a stronger case that REKN populations would not be expected to decline under an HSC population collapse (Fig. 1). This simulation exercise makes it very clear that the REKN model used in the revised ARM would not be able to predict or explain the decline in the REKN population observed during the 1990s, which has been attributed to unregulated harvest of HSCs in Delaware Bay (Niles et al. 2009; USFWS 2014). If this framework is unable to explain the decline of the REKN population in the first place, it does not appear to be an appropriate tool for helping to reverse the decline and promoting the recovery of this threatened subspecies.

Note that the population vital rates used to generate Fig. 1 represent point estimates. Because there was uncertainty associated with the estimate of Lambda (CI from 1.00 to 1.06; ARM Table 25), and with the effect size of HSC abundance on survival rate (CI from 0.12 to 0.63; ARM supplemental Table 9), some simulation runs (i.e., those with small Lambda and larger effect size sampled randomly from the joint posterior distribution) are likely to indicate REKN population decline at low HSC abundances. It is likely that these (probably rare) simulations drive the shape of the REKN “harvest function” yielded by the approximate dynamic programming algorithm. However, without access to the IPM and simulation code, I am not able to formally test the behavior of the REKN simulation model under scenarios of HSC population decline or collapse.

Scenario: HSC population collapse

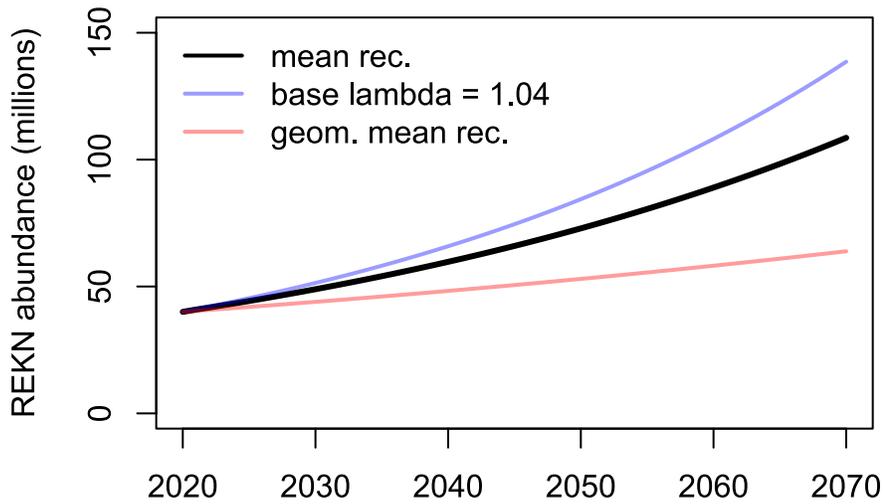


Figure 1. Results from a ‘back of the envelope’ calculation of REKN population growth under a scenario with depleted HSC population (female HSC abundance = 0 based on numbers presented in the ARM report. Mean recruitment rate was computed in three ways: arithmetic mean of values from ARM Supplemental Fig. 7b (“mean rec”), the geometric mean of these same values (“geom. mean rec.”), and a value fitted to ensure a population growth rate (Lambda) of 1.04, as indicated in the ARM report. Although somewhat simplistic, this figure illustrates that the reduction in REKN survival due to the collapse of HSCs in Delaware Bay appears to be insufficient to induce a meaningful REKN population decline. This figure is based on a simple age-structured population model and does not incorporate a density-dependence mechanism (the revised ARM includes a density ceiling that prevents the REKN population from growing above ~150k).

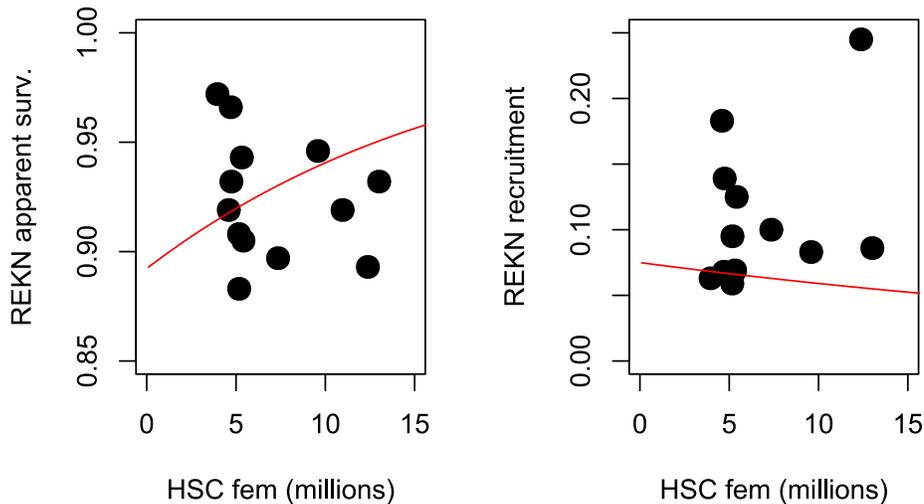


Figure 2. Relationships between female HSC abundance and REKN survival (left panel) and recruitment (right panel), recreated from information in the ARM supplemental report for the purpose of calculating the expected REKN population response to changes in the HSC population. Solid black dots represent annual vital rates estimated from ARM Supplement Fig. 9, and the red lines represent the fitted relationships presented in ARM Supplement Table 9.

Due to the weakness of the HSC/REKN relationship used in the revised ARM, and due to the complexity of the Integrated Population Model (IPM) framework used to represent the REKN population in the revised ARM, the relationship between HSC abundance and REKN population vital rates are likely to be unstable (sensitive to new data and alternative model specifications). Therefore, it is not implausible that the fitted relationship may disappear (become “non-significant”) – or even flip sign to become a negative relationship – when the IPM is fitted to additional observations. This outcome would pose an existential problem for the ARM framework, decoupling the two-species framework and rendering the REKN model unusable in the context of management. There does not appear to be a contingency plan for this outcome. More generally, the REKN IPM appears to have gone through several distinct versions before researchers settled on a final set of decisions to incorporate into the final model (there are several important differences between an earlier version of the IPM presented in Tucker [2019] and the ARM report). Ideally, the results from alternative representations of the REKN system should be considered in aggregate to better represent structural uncertainty about this system (Williams 2011).

The linked two-species modeling framework in the revised ARM assumes the relationship between REKN and HSC is independent of REKN densities (i.e., it assumes a prey-dependent functional response). Under this assumption, larger REKN populations do not require larger abundances of HSC females (i.e., more HSC eggs deposited) to support adequate per-capita weight gain; in other words, the ARM model assumes that a REKN population of 40k would experience the same per-capita survival and fecundity as a population of 400k for a given abundance of female HSC. Implicitly, this assumes a lack of interference among REKN individuals, and no decline in the mean quality or accessibility of HSC egg resources at elevated REKN abundances (Karpanty et al. 2011). Some researchers have argued convincingly that a ratio-dependent functional response – in which per-capita prey consumption depends on the ratio between prey and predator abundances – is likely to be more realistic for simulation models with discrete time steps that span the entire reproductive periods of predator and prey (Abrams and Ginzburg 2000), such as the linked two-species model used in the revised ARM.

The previous ARM framework used data gathered from multiple sources of data outside

Delaware Bay to parameterize the simulation models. The revised ARM attempts to use Delaware Bay data sources wherever possible – which is a significant advance in many ways, as the revised ARM is “fine-tuned” for the system and can be updated relatively easily as new data are collected. However, this modeling decision also limits the analyses to a small geographic area over a short period of time, potentially ignoring relevant evidence from other regions and/or time periods. Furthermore, the time frame over which data are available for fitting the population models used in the revised ARM represents a limited scope of historical variation during which populations of REKN and HSC were relatively small in comparison with earlier estimates. Using these models to forecast system dynamics under conditions outside the range of values used to fit the model (e.g., lower HSC abundances, higher REKN abundances) therefore requires extrapolation, which can be highly uncertain (and often inaccurate). Since both the HSC and REKN simulation models tend to produce forecasts that differ from current conditions (e.g., larger numbers of both species), and because the optimization routine relies on these simulated results, the management recommendations emerging from the revised ARM rely on highly uncertain extrapolations about HSC and REKN population dynamics and about how these two species may interact (analogous to extrapolations of species and community distributions under climate change; Araujo and Rahbek 2009). On one hand, the ARM framework is designed to be able to refine management policies as new data become available and as sources of uncertainty are reduced (Nichols et al. 2007). On the other hand, it does not seem prudent to implement management “experiments” that could potentially imperil a threatened or endangered species (TES), even under the rubric of adaptive management.

In summary, the relationship between HSC abundance and REKN survival appears to be too weak to induce a decline in REKN abundance (Fig. 1). If all HSCs in Delaware Bay disappeared today, the model would continue to predict a generally stable or increasing population of REKN over the next 50 years. Therefore, the revised ARM model would be unable to predict the decline of REKNs that was observed in recent decades, and which has been attributed in part to the decline in the HSC population (Niles et al. 2009; USFWS 2014). This lack of consistency between the revised ARM model and recent historical observations raises significant doubts about the ability of this model to accurately reflect future risks to the REKN population or to guide HSC

harvest decisions in a way that promotes REKN survival and recovery. Furthermore, the decision to include a REKN population model as part of the ARM framework (in both the original and revised versions) presupposes that HSC harvest could result in risk to the REKN population; the apparent inability of the ARM model to predict a decline in REKN abundance under a total HSC population collapse violates this premise and undermines the apparent purpose of the model.

2. The HSC population simulation model fails to propagate uncertainty about mean recruitment rates

The HSC recruitment process is the most consequential empirically fitted component of the HSC simulation model. Other elements of the HSC simulation model are not fitted to data – for example, natural mortality rate, the biomedical mortality rate, and bait harvest rates are fixed by the modelers. In the revised ARM, the recruitment process is fitted to data indirectly via the CMSA model; annual male and female recruitment estimates were used to fit a bivariate log-normal distribution (defined by a mean and standard deviation for each sex, along with a covariance between sexes – all on a logarithmic scale), which was then used to represent annual recruitment in the simulation model. The only other parameter fitted in the CMSA model – initial abundance – is not directly used in the simulation model. Recruitment is critical for any assessment of population resilience to harvest, since (in the absence of immigration, which is not included in the revised ARM), it is the only process that enables the population to overcome sources of mortality. Therefore, it is not surprising that the HSC simulation model is highly sensitive to changes in mean (log) fecundity (ARM Fig. 33; note that when I omit any reference to the supplemental report, I am referring to the primary ARM report). Given the high sensitivity of the HSC simulation model to the (log) mean HSC recruitment for males and females, it is critical that uncertainty about these parameters is properly represented in simulation models. However, the revised ARM framework incorrectly treats uncertainty about annual recruitment rates as representative of temporal process variance (natural year-to-year fluctuations) rather than as a mixture of parameter uncertainty and process variance (Link and Nichols 1994; Regan et al. 2002; McGowan et al. 2011). This is a subtle but consequential error, as sources of uncertainty will tend to “regress to the mean” (with good years cancelling bad years) instead of propagating over time.

To estimate the parameters for the log-normal recruitment process in the revised ARM, the following steps were taken: (1) log-normal distributions were separately fitted to each estimate of primiparous abundance (separately for each year and sex), based on estimates of parameter uncertainty (95% confidence intervals) derived from the CMSA results, (2) this collection of lognormal distributions (representing parameter uncertainty) was used to simulate annual male and female primiparous abundance for the years represented in the CMSA model (confusing parameter uncertainty with temporal process variation), and then (3) data from these simulations were used to fit a bivariate lognormal distribution (via maximum likelihood) for representing annual HSC recruitment in the ARM model. In general, parameter uncertainty should be represented in simulation models by drawing a single sample per replicate from a distribution of values representing parameter uncertainty (or by running replicates with “worst-case” and “best case” values for key parameters). However, the “canonical” version of the HSC projection model fails to address parameter uncertainty – most notably, uncertainty about the mean HSC recruitment rate, to which the HSC projection model is highly sensitive (ARM Fig. 33). Therefore, there is more uncertainty about the future of the HSC population in Delaware Bay than the revised ARM acknowledges. It is important to note that a sensitivity analysis was run in which expected recruitment was allowed to vary across simulation replicates within ca. 5% or 10% of the median recruitment value. This sensitivity test demonstrates an appropriate method for modeling parameter uncertainty; however, this test fails to represent the extent of uncertainty about the median HSC recruitment, which extends far beyond 10% of the mean estimated value (Fig. 3). Furthermore, this treatment of uncertainty was only run as a scenario test and was omitted from the ‘canonical’ version of the ARM that is proposed for use in managing the HSC harvest in Delaware Bay.

Interestingly, the REKN projection model in the revised ARM appears to represent parameter uncertainty appropriately. The key parameters of the REKN model were estimated using an Integrated Population Model (IPM), which were fitted in a Bayesian framework. In this framework, parameter uncertainty is represented by a joint posterior distribution that embodies the set of values that are consistent with the observed data. Furthermore, temporal process variation in the REKN population model is treated by explicitly modeling annual variability in key

vital rates (survival and recruitment) via annual random effects fitted with hyperparameters (Kery and Schaub 2011). This Bayesian hierarchical approach enables parameter uncertainty and process variation to be interpreted and modeled separately in a straightforward and intuitive manner. Specifically, parameter uncertainty is incorporated by running multiple replicates with different values drawn from the joint posterior distribution, and temporal process variation is included by sampling from the hyperparameters across years within each replicate (Goodman 2002).

To enable sensible propagation of parameter uncertainty in the HSC simulation model (analogous to the REKN model in the ARM), I constructed and fitted a hierarchical Bayesian version of the CMSA model. This model was fitted using the same data and model structure as the CMSA model included in the revised ARM. However, instead of estimating annual recruitment separately for each year and sex, the Bayesian CMSA model included an explicit representation of temporal process variance in recruitment (i.e., a “random effect” describing inter-annual variation in recruitment). This temporal process model was specified using a bivariate lognormal distribution exactly analogous to the HSC simulation model included in the ARM model, which included “hyperparameters” for male and female (log) mean recruitment, male and female (log) standard deviation, and a correlation term. By estimating temporal process variation directly, the Bayesian CMSA closely mirrors the HSC simulation model (analogous to the direct relationship between the IPM and the REKN simulation model), circumventing the multi-step process used in the ARM to generate the bivariate lognormal distribution from the CMSA results, and (most importantly) enabling the parameters of the bivariate lognormal distribution to be estimated directly from the data. To simulate HSC abundance over time, parameters for each replicate were drawn from the joint posterior distribution (representing parameter uncertainty), and temporal process variation within each replicate was simulated by sampling from the bivariate lognormal distribution. For the simulations, I incorporated the same restrictions in the stock-recruitment relationships indicated in the ARM report (driven by abundance and sex ratios for the years in which recruits were expected to have hatched).

Results from the Bayesian CMSA model indicate substantial uncertainty around mean HSC recruitment rates for both males and females (Fig. 3). Simulations (50 year time horizon) from

this model in the absence of any direct anthropogenic sources of mortality (no bait harvest, biomedical mortality or discard mortality) indicate that the future of the HSC population in Delaware Bay is uncertain; the population has a 17.4% chance of declining below 4 million females (combined multiparous and primiparous abundance) at least once in the next 50 years, equivalent to the lowest abundances estimated from 2003 – 2019 (period for which the CMSA model was fitted) (Fig. 4). This no-harvest scenario also had a 3.8% probability of falling below 3 million females over the 50-year simulation, well below any estimate from the VT swept area surveys. In contrast, the HSC projection model in the revised ARM indicates a large and sustainable HSC population under a scenario with no bait harvest but including other anthropogenic sources of mortality including biomedical harvest and discard mortality (ARM Fig. 30; note that this figure does not reflect changes in mean HSC recruitment following peer review—the Supplement does not update this figure but contains other figures indicating a sustainable HSC abundance even with a bait harvest; Supplemental Fig. 15). Simulations from the Bayesian CMSA also indicate a much higher probability of decline under a scenario in which males and females are harvested at their respective maximum allowable rates (but are not subject to biomedical and discard mortality); this scenario had a 33% probability of declining below 4 million females over the next 50 years, 11% probability of declining below 3 million females, and a 2% probability of declining below 2 million females (Fig. 4). This scenario also appeared to disrupt the age structure in many simulations, resulting in fewer multiparous adults than primiparous adults. In contrast, the HSC simulation model in the revised ARM suggests a stable or increasing HSC population even under maximum allowable harvest scenarios that also include biomedical and discard mortality (ARM Fig. 31; see above caveat). Finally, a scenario in which both female and male HSCs were harvested at a rate of 2 million per year (much higher than the current maximum rate) results in a high probability of decline or even extirpation over the 50-year simulation; there was a >99% probability of declining to below 3 million females, a 92% probability of declining below 1 million females, and a 12% chance of falling below 10k females (Fig. 4). In contrast, the HSC simulation model in the revised ARM predicted a relatively sustainable population of HSC even under this extreme scenario, with no risk of population collapse (ARM Fig. 32; note that the HSC simulation model in the supplemental report may not

sustain this level of harvest due to the reduced mean recruitment rate relative to the model used to generate ARM Fig. 32).

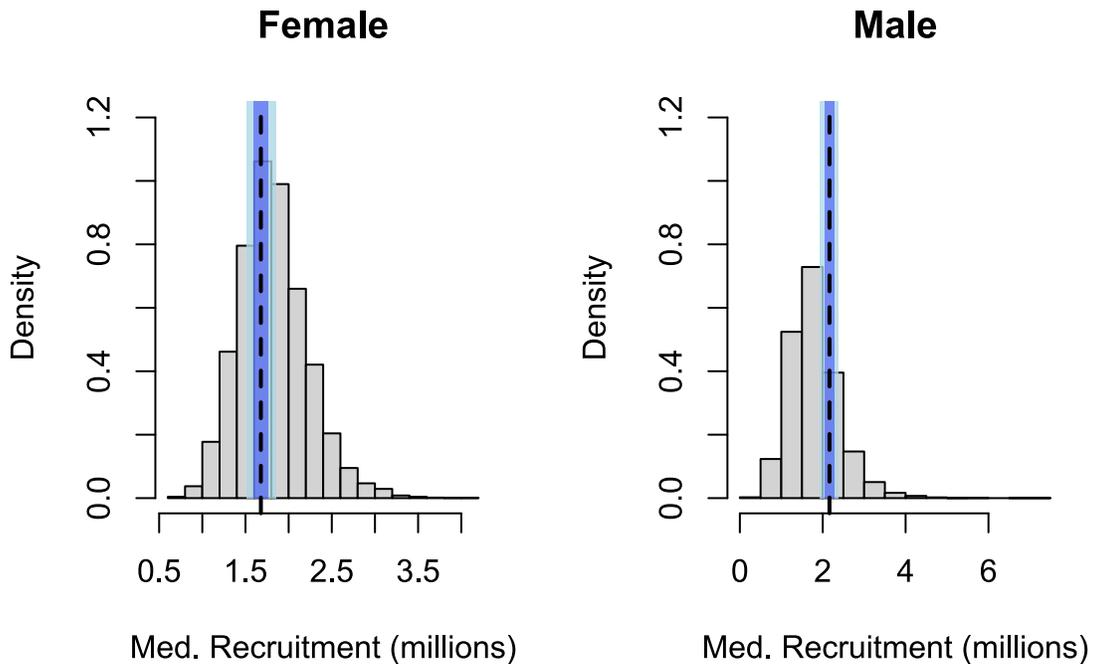


Figure 3. Posterior distributions representing parameter uncertainty for median female and male HSC recruitment rates, fitted using a Bayesian reanalysis of the CMSA model from the revised ARM (same data and model structure used to fit the CMSA model). Vertical dashed lines denote the median HSC recruitment values used in the base HSC projection model in the revised ARM. Light and darker blue shaded polygons represent the “added variation in expected recruitment” sensitivity tests from the ARM report (e.g., Fig. 69, 70). Note that the true range of parameter uncertainty falls well beyond the bounds of these sensitivity tests.

This critique is focused primarily on uncertainty about the annual HSC recruitment (primiparous abundance) parameters since they represent the ultimate source of projected resilience (or non-resilience) to harvest pressures and are therefore the most consequential fitted parameters in the CMSA simulation model. However, there are several other sources of uncertainty that should be accounted for in the HSC simulations. For example, natural mortality of HSC is set at exactly 0.3 (30%) across all sexes and age classes (primiparous and multiparous) in the revised ARM model, whereas there is substantial uncertainty about this parameter. The value of 0.3 was based on tag recovery data (assuming negligible harvest), but other lines of evidence seem to suggest natural mortality may be closer to 20% or even lower (as noted in the ARM

report). Lower estimates of mortality (higher survival and greater longevity) could imply lower resilience to harvest of adults (Midwood et al. 2015). Interestingly, natural mortality is an estimable parameter in the CMSA model; when modeled as a free parameter in the Bayesian CMSA, the model suggests that natural mortality is lower than 30%, but higher for females than males (note that Figs 3 and 4 are based on a model with natural mortality set at 30%, to match the ARM models). Other sources of uncertainty in the HSC population model include discard mortality (where 5% mortality was assumed for trawl and dredge surveys, while 12% mortality applied for gill nets) and biomedical mortality (assumed to be 15%). Although the ARM report documents a limited set of sensitivity analyses that were designed to test the degree to which key results changed under alternative parameter values (including mortality; ARM Table 18, 19), the relatively small set of sensitivity tests does not appear to comprehensively address these sources of uncertainty and seem inadequate for characterizing uncertainty about this system. Furthermore, uncertainty about these processes is not propagated through the HSC projection models.

In summary, if sources of error in the recruitment process are properly accounted for, the outlook for the HSC population in Delaware Bay is uncertain even in the absence of any harvest pressures. Based on a reanalysis of the existing data (using the same model specification used in the CMSA and HSC projection model), I found that harvest at the current maximum allowable rates has a high risk (11%) of causing the female HSC population to decline below the lowest levels ever recorded (3 million females). The HSC population models presented in the ARM report and supplement are not useful because they mis-characterize the risk of harvest pressures to the HSC population in Delaware Bay.

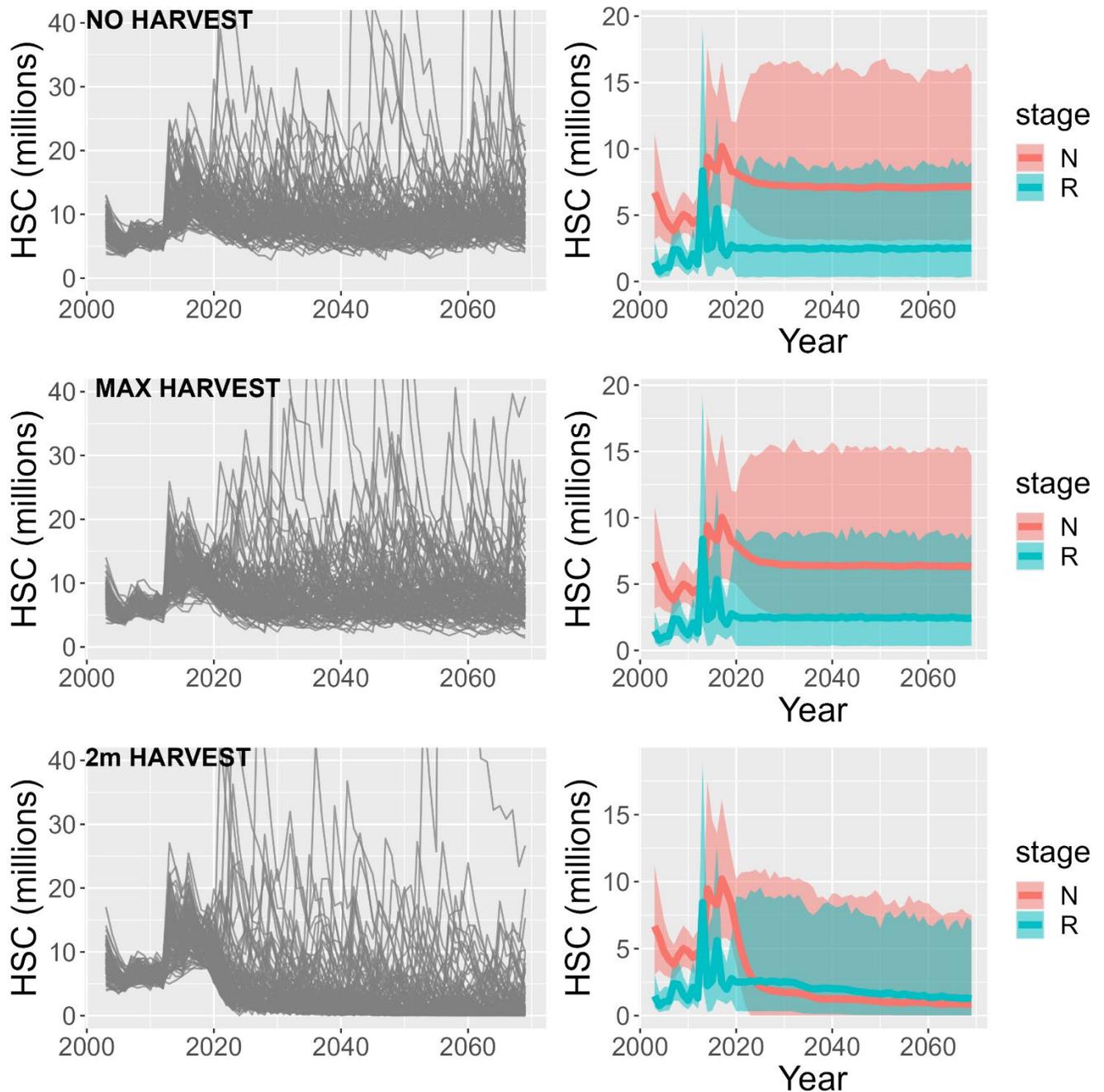


Figure 4. Female HSC population simulations run using fitted parameters (joint posterior distribution) from a Bayesian CMSA model, with uncertainty propagation performed in a manner analogous to the REKN projection model. The top row depicts simulations run under a no exploitation scenario (no bait harvest nor biomedical/discard mortality), the middle row depicts maximum allowable harvest rates (but also without biomedical and discard mortality), and the bottom row depicts an extreme harvest scenario (2 million females, 2 million males harvested annually). The left-hand panels depict trajectories of total abundance (primiparous and multiparous) for individual simulation replicates. Right-hand panels depict the 95% credible intervals for primiparous abundance (R) and multiparous abundance (N). None of these scenarios include biomedical or discard mortality.

3. The Catch Multiple Survey Analysis (CMSA) appears to exhibit poor fit to both training and independent data, raising concerns about its use in projecting future HSC abundance

The CMSA model explains little (and, in at least one case, none) of the variation in the data sources used to train this model (comprising three different trawl surveys conducted in and around Delaware Bay; here I present results for the female CMSA only) (Fig. 5). Notably, the CMSA performs worse than a statistical null model (all variation is assumed to be random “noise”) for predicting the multiparous female abundance estimated from the VT trawl surveys, with R^2 of -0.42 for the full time series (negative R-squared value indicates the CMSA model performs worse than the null model). In contrast, the CMSA results appear to exhibit relatively good fit ($R^2 > 0.5$) to the recruitment data (primiparous abundance) from the VT trawl surveys (Fig. 5; ARM Fig. 21). However, this is not a fair test; with only one source of data for estimating annual primiparous abundance (the VT trawl surveys) – and with a separate recruitment parameter fitted for each year – the CMSA recruitment results are practically guaranteed to resemble the observed recruitment data.

For the remainder of the datasets used to train the CMSA (DE and NJ trawls), it is instructive to note that the majority of the observed variance ‘explained’ can be attributed to the apparent difference in mean HSC abundance before and after the period 2013-2016 (during which the Virginia Tech trawl surveys were not conducted and therefore no estimates of recruitment were available; hereafter, “VT gap”, see below). Indeed, for the DE surveys the R-squared value drops to negative values for the periods before ($R^2 = -0.07$) and after ($R^2 = -0.03$) the VT gap period (versus $R^2 = 0.14$ for the full time series). Similarly, for the NJ trawl survey, the R-squared value drops to 0.11 for the period before the gap and falls below zero for the period after the VT gap ($R^2 = -0.05$; compared to $R^2 = 0.57$ for the full time series). More concerning, the CMSA can “explain” the apparent increase in the HSC population after the VT gap period only by estimating extremely high recruitment during the VT gap period (during which no recruitment information was available; see below for more details). Because no data were available for fitting recruitment (primiparous abundance) during the VT gap, the CMSA model was free to “fill in” whatever recruitment estimates produced the best match to available data (DE and NJ surveys were the only available data sources during this period)—even if these recruitment estimates

were unrealistically high or low (with no data available for comparison, there was no penalty for producing unrealistic estimates). If the CMSA is only able to fit the training data via unrealistic estimates of recruitment (see below), this strongly suggests a poorly specified model and raises serious doubts about using the CMSA results to represent and forecast the HSC population in Delaware Bay.

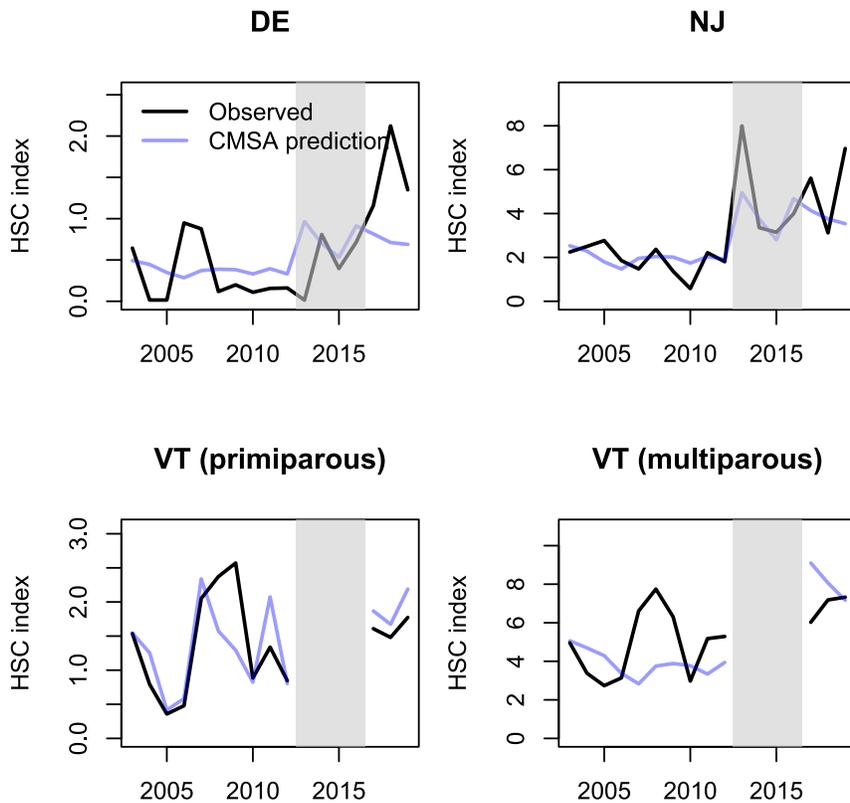


Figure 5. Illustration of the fit of the CMSA model to data on female HSC abundance derived from three trawl surveys: DE, NJ, and VT (the same sources of data that were used to fit the CMSA model). This figure presents the same information as ARM Fig. 21/4. The CMSA model performs well in predicting primiparous abundance (bottom left) but exhibits poorer performance for predicting adult (multiparous) abundance (bottom right) or total abundance (top row). The CMSA predicts little to no variation in adult/total abundance besides the difference in apparent mean abundance before and after the “VT gap years” (gray regions).

Given the lack of fit to training data, the HSC simulation model is unlikely to perform well when predicting to independent validation data (data not used to fit the model). Indeed, when the CMSA results are challenged against the Delaware Bay HSC Spawning Surveys (e.g., Zimmerman et al. 2020; <https://www.delawarebayhscsurvey.org/>), which provides an independent estimate of relative HSC abundance for this region, there is no detectable

relationship between these two independent estimates of HSC abundance (Fig. 6). This lack of fit to both training and validation data raises doubt about the utility of the CMSA results, which are central to all aspects of the proposed ARM, from fitting the HSC/REKN relationship to forecasting HSC abundance, to guiding annual decisions about HSC bait harvest.

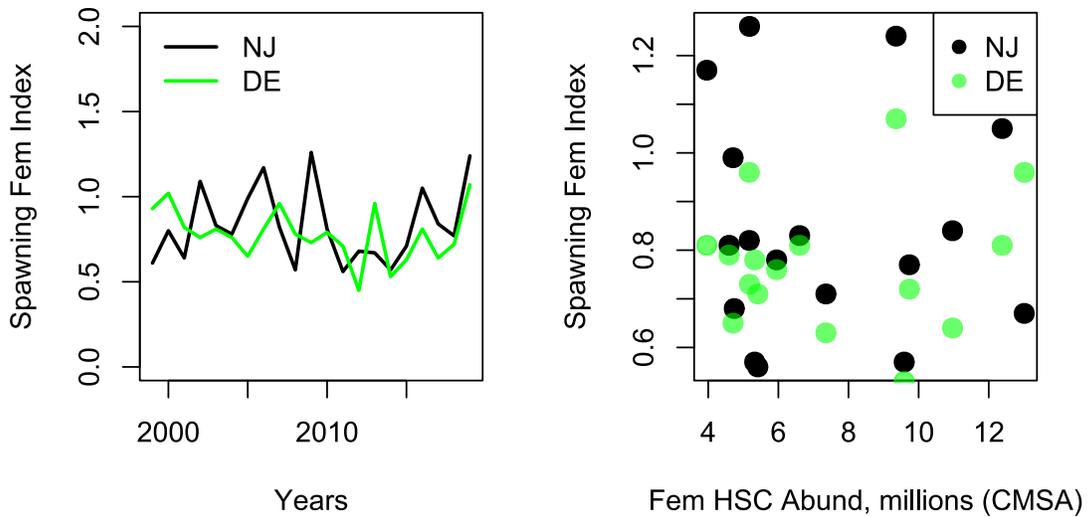


Figure 6. Comparisons of standardized HSC spawning female counts from DE and NJ beaches (an index of relative female HSC abundance analogous to trawl surveys) with (left) each other and (right) with the CMSA estimates of female HSC abundance in Delaware Bay (in millions). The two spawning surveys exhibit very little correlation between the NJ and DE sides of Delaware Bay from 1999 to 2018 (left panel; correlation = 0.25). In addition, there is no detectable relationship between spawning counts (on either the NJ or DE sides) and CMSA estimates of female HSC abundance (right panel).

In summary, the CMSA model does not perform well when predicting to the training data (the three sources of data used to fit the model). Although the model can explain some of the apparent difference in mean HSC abundance before and after the ‘VT gap years’, this ‘ability’ is driven by inflated recruitment rate estimates during the VT gap years that cannot be verified empirically (see below). Furthermore, the CMSA model explains virtually none of the observed variation in HSC spawning abundance from the same period, which represents an independent index of HSC population size. The poor performance of the CMSA model in predicting observed variations in HSC abundance in Delaware Bay calls into question the utility of this model – which is central to all aspects of the ARM model – as a robust system for characterizing and predicting

the HSC population in Delaware Bay.

4. The “gap years” in the VT trawl survey data raise concerns about HSC recruitment estimates from the Catch Multiple Survey Analysis (CMSA)

As noted previously, the CMSA is fundamental to the proposed ARM framework. For the HSC population simulation models, the primary role of the CMSA is to parameterize HSC recruitment rates (which are the most consequential empirically derived inputs for the HSC simulation model). Unfortunately, of the three trawl surveys used to fit the CMSA models, the only survey that provides information for estimating recruitment – the Virginia Tech (VT) trawl surveys – was not conducted during a critical four-year period from 2013 to 2016 (referred to in this report as the “VT gap”, during which no direct information was available for estimating annual HSC recruitment; note that the missing survey years were actually 2012-2015, but the VT results were lagged forward within the CMSA to ensure comparability with the DE and VT trawls). The lack of information on primiparous abundance during the VT gap years leads to several nonsensical results in the CMSA model. For example, in one year (2013; the first VT gap year) the estimated number of new female recruits is near 10 million – approximately 8 times larger than the average estimated recruitment rate from the 10-year period from 2003 to 2012 and 4 times larger than the maximum estimate during this 10-year time frame (ARM Supplemental Table 3). The following year (2014), the point estimate for primiparous abundance goes down to 2, i.e., 2 primiparous female individuals across Delaware Bay. Furthermore, the standard error estimates for primiparous abundance during the VT gap years are very large – in fact, the upper bound on the confidence intervals approaches infinity for one year (2014).

The CMSA results suggest that the HSC population underwent a substantial state transition during the VT gap years in which the population was small but stable prior to the gap, and larger and more variable after the gap. In the fitted CMSA model, this state transition appears to be driven by extremely high recruitment rates during the VT gap years. Concerningly, the CMSA model (including the Bayesian version of the CMSA model described above) predicts much higher mean annual recruitment rates during the VT gap (for which no data are available for estimating recruitment) than at any single year before or after (Fig. 7). Specifically, mean

annual recruitment during the VT gap years was estimated at 4.2 million (using the arithmetic mean, per the ARM report), versus 1.2 million before the gap and 1.9 million after the gap (using the geometric mean to represent the median of a lognormally distributed sample, per the ARM report). The inflated mean recruitment rates during the VT gap period are subsequently used for estimating the average HSC recruitment rate for the HSC simulation models (thereby increasing estimated population resilience to harvest) – but unfortunately these high recruitment rates cannot be verified empirically.

In summary, the CMSA model estimates abnormally high annual recruitment rates during the VT gap years (Fig. 7). These very high estimates are unverifiable, as no data on HSC recruitment was collected during these years. In the original ARM report, the average annual recruitment used in the HSC simulation model relied heavily on the inflated estimates of recruitment during the VT gap years, discounting the pre-gap years entirely. After peer-review, the ARM was altered to consider all years instead of discarding lower estimates from the pre-gap years. Nonetheless, the revised ARM model continues to treat the mean recruitment rate during the VT gap as reliable, allowing these inflated estimates to contribute to the estimate of average annual HSC recruitment used for the HSC simulation models (which are highly sensitive to the estimate of average recruitment; ARM Fig. 33). If the extremely high recruitment estimates during the VT gap years were to be excluded from this estimation process out of precaution, the average annual HSC recruitment rate would drop substantially (Fig. 7), further reducing the expected resilience of this population to harvest pressures. Ultimately, the inflated estimates of recruitment during the VT gap years are likely to be an artifact of the CMSA model specification (and the lack of data on recruitment for those years) and are unlikely to be reflective of true HSC recruitment rates. However, there remains no way to verify HSC recruitment rates during this period. Given this uncertainty, a conservative (precautionary) approach would be to exclude the VT gap years when computing recruitment for the HSC population simulations (Fig. 7).

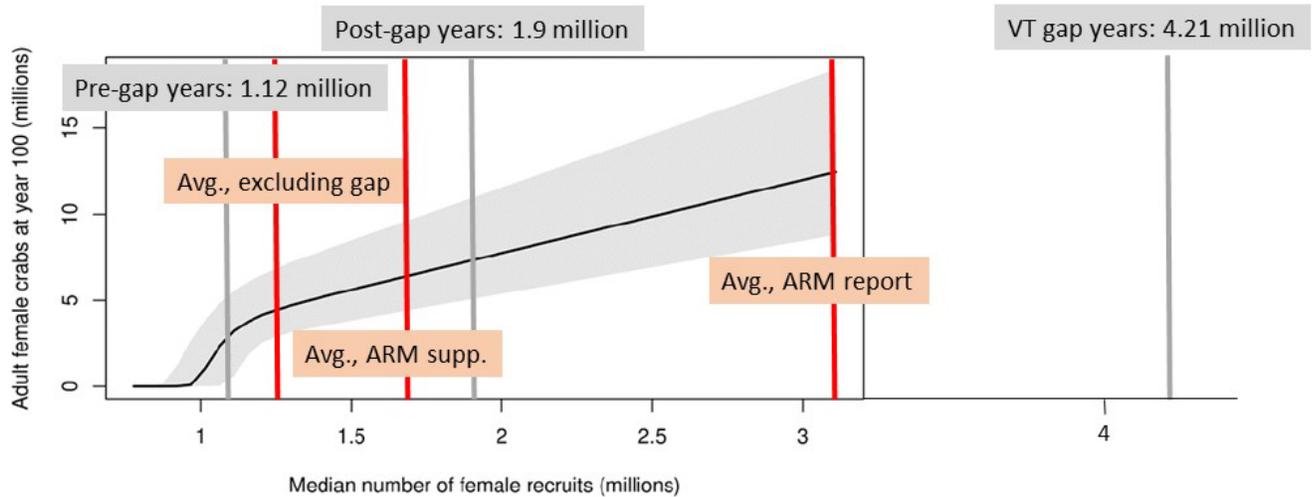


Figure 7. Annotated version of ARM Fig. 33, which (in its original form) illustrates the sensitivity of HSC simulation results to changes in average HSC recruitment rates. Annotations reflect the average female recruitment before, after and during the VT gap years (in gray), the average recruitment value used in the original 2021 ARM report (red, far right), the value used in the supplemental report produced after peer-review (red, middle) and the analogous estimate computed by excluding the VT gap years (red, left). Average recruitment estimated for the VT gap years (arithmetic mean of 4.21 million based on the latest CMSA results) falls well outside the range of estimates during years for which recruitment was an observable process (and well outside the range of the x-axis of the original figure). The ARM report ignored recruitment estimates from the pre-gap years, giving very high weight to the inflated estimates during the VT gap years. Based on the peer-review, which suggested that the pre-gap years should not be excluded from the estimation of average recruitment rates, the current proposed value (described in the ARM supplement) is much lower than the value used in the ARM report (1.67 million vs. 3.1 million). However, the new proposed value continues to include unverifiable estimates from the VT gap years. If the VT estimates were excluded out of precaution, the average annual HSC recruitment would drop to 1.26 million, perilously close to the sustainability threshold identified in this figure (i.e., ARM Fig. 33).

5. The proposed ARM framework lacks ‘null model’ benchmarks and independent performance validation

Null models are simplified representations of a system that lack many or all the explanatory mechanisms hypothesized to operate in the system. In statistics (e.g., linear regression analysis) the typical null model assumes all system variation is a result of unexplained variance in the form of random noise (often a single random error process). In other contexts, null models may include additional processes/mechanisms but omit a key focal mechanism, enabling researchers to test whether that focal mechanism contributes usefully to predictive performance. In the context of adaptive harvest management, a null model would at least omit

consideration of the impacts of harvest processes on system dynamics, which ultimately informs management decisions (Koons et al. 2022). By comparing complex models such as those used in the revised ARM with one or more null-model benchmark(s), researchers can determine whether the more complex models represent useful learned knowledge about a system (Koons et al. 2022). If a complex model fails to outperform a null model in terms of bias or precision (typically using independent validation data), the complex model is likely to be improperly specified or “overfitted” (whereby parameters are fitted to “noise” rather than true signal; Radosavljevic and Anderson 2014) and therefore not useful for prediction.

In the context of the HSC fishery in Delaware Bay, it would be informative to compare the performance of the HSC simulation model against a null model that omits all information about HSC harvest from the model fitting process; this would enable assessment of our current understanding of how estimated rates of harvest affect the HSC population. Given the poor fit of the HSC simulation model to training and validation data (see above), the HSC simulation is unlikely to outperform simpler null models. In fact, the CMSA model fails to outperform the simplest standard null model (single intercept term with sampling error) for at least one data source (the VT swept-area estimate of female multiparous abundance) despite its complexity (~20 parameters for the CMSA vs 1 parameter for describing expected abundance each year). If the HSC simulation model fails to outperform a model in which population dynamics are driven by noise instead of harvest, it should prompt managers to acknowledge that our current understanding of the effects of harvest on HSC populations remains insufficient for robust forecasting (Dietze 2017).

For the REKN component of the revised ARM, it would be informative to compare the performance of the REKN simulation model against a null model that omits any effect of female HSC abundance. It was recently demonstrated (Koons et al. 2022) that the ARM framework for guiding North American mallard harvest was unable to outperform a null model, and it would be instructive to pose a similar challenge to the REKN simulation model. Given that all the deterministic processes (fixed effects) included in the IPM model were very weak (i.e., the HSC effect on survival and fecundity; see above) or “non-significant”, it is already apparent that random noise overwhelms most signal in the training data regarding how the HSC population

affects REKN population dynamics. Therefore, it is likely that information about the HSC/REKN relationship would explain little if any of the variation in independent validation data. Furthermore, the lack of a relationship between the HSC model (CMSA) and the number of spawning females observed on coastal beaches (see above) makes it even more unlikely that the current REKN population model would outperform a null model that excludes any effect of HSC abundance (since the HSC/REKN relationship is based on the consumption by REKNs of HSC eggs deposited by spawning females).

In summary, null model benchmarks should be incorporated into the ARM framework to ensure that effective learning is occurring and that managers acknowledge uncertainty about how their decisions affect the populations they are charged with managing (Koons et al. 2022). If one or both simulation models that form the core of the revised ARM framework fail to outperform null models, it would strongly suggest that the ARM framework's current level of understanding about how management decisions are likely to affect the HSC and REKN populations is insufficient for robust forecasting of population-level risk to either species from HSC harvest. Although the ARM process is designed to treat management actions as opportunities for learning – updating harvest recommendations as new data become available (Nichols et al. 2007) – the fact that one of these species is federally threatened (USFWS 2014) justifies a more precautionary approach for risk management.

6. Lack of transparency

The public still has no access to the data and code used for (1) estimating REKN population parameters via a Bayesian integrated population model (IPM), (2) simulating REKN and HSC population dynamics, and (3) running the optimization routines via approximate dynamic programming (ADP). The CMSA code and data were made available, which enabled me to re-analyze the HSC survey data and run informative scenario tests (see above). Without the data and code for other components of the ARM model, it is not possible to re-analyze the data, test key assumptions, or simulate population dynamics under different hypothetical scenarios. Given the substantial concerns generated by the data and code that has been made publicly available to date (discussed above), such further re-analysis, testing, and simulation is warranted. If granted access to the code and data, there are several important questions that could be

addressed more thoroughly, including but not limited to:

- 1) How would HSC abundance projections change – and how would harvest functions change – under the lower mean recruitment estimate produced by excluding anomalous estimates from the VT gap years?
- 2) What would happen to the REKN population projections if female HSC abundance were set to zero?
- 3) Does the REKN projection model outperform a null model that excludes any effect of HSC abundance?
- 4) In the REKN IPM, does the effect of HSC abundance disappear (or flip sign to become a negative relationship) under alternative plausible model specifications?
- 5) What proportion of variation in apparent survival in the REKN IPM model is explained by the HSC effect vs. random among-year variation?
- 6) Does an index of HSC spawning or HSC egg densities explain more variation in REKN survival and fecundity than the CMSA-derived estimate of HSC abundance?

CONCLUSION

In this report I have outlined six major concerns about the revised ARM. First, the modeled relationship between REKN vital rates and HSC abundance does not appear to be strong enough to induce an expected decline in the REKN population even under a catastrophic collapse of the HSC population. The apparent inability of the model to predict a major population response of REKNs to the depletion of the Delaware Bay HSC stock invalidates the premise of including a REKN population model within the ARM framework, which implicitly assumes that (1) HSC eggs are a critical resource for REKN populations and (2) HSC harvest could inhibit or slow the recovery of the REKN population, at least under some circumstances. The apparent inability of the ARM model to show a strong population-level effect of HSC harvest on REKN populations is inconsistent with the observed decline of the REKN population in recent decades, which many researchers have attributed to increased HSC harvest rates in the 1990s. Therefore, the REKN model included as part of the revised ARM does not appear to be a useful tool for assessing and managing risks to the REKN population from HSC harvest – or for promoting recovery of the REKN population.

In addition, I have identified several concerns about the HSC data analysis and simulation models. First, the HSC model in the revised ARM does not appropriately address key sources of uncertainty – particularly with respect to HSC fecundity (the source of potential harvest resilience). When these sources of uncertainty are addressed, the outlook for the HSC population is more uncertain than indicated in the ARM report. My analyses indicate that harvest at the maximum allowable levels could put the population in jeopardy (~11% risk) of decline below 3 million females – well below the minimum level previously recorded – within the next 50 years. In addition, the Catch Multiple Survey Analysis (CMSA), which is central to all aspects of the ARM, appears to exhibit poor fit to both training and independent data. I was unable to detect any correlation between the CMSA estimate of female HSC abundance and the estimated number of spawning females on coastal beaches in Delaware Bay. Finally, the estimate of HSC recruitment (which determines harvest resilience in the projection models) used in the revised ARM incorporates questionable (and highly inflated) estimates from a four-year period during which direct information on HSC recruitment was not available. Taken together, the above concerns strongly suggest the ARM model is not a valid tool for managing risk to the HSC population in Delaware Bay.

My final concerns are more general. First, I suggest that both the REKN and HSC models should be subjected to more rigorous evaluation, including tests for whether these models are able to outperform “null model” benchmarks that assume no useful learned knowledge about population dynamics and population response to harvest and harvest management. Ecological null models provide a useful benchmark for gauging the degree to which knowledge is accrued through the adaptive management process, and a mechanism for keeping modelers and managers “honest” by acknowledging an incomplete or inadequate understanding of the systems they are charged with managing. My analysis demonstrates that the CMSA model fails to outperform the simplest statistical null model for at least one data source. Finally, I was not provided access with much of the data and code used to generate the models used in the revised ARM (except for the CMSA code and data). Given the concerns that are apparent based on analysis of the limited code and data made available to date, it seems prudent to, at a minimum, delay implementation of this framework until the public and outside experts have had adequate

time to scrutinize the statistical and simulation models that play such a central role in this proposed decision-making framework.

Despite the lack of transparency, I was able to run several informative re-analyses and scenario tests with the information provided in the ARM report and supplement, and with the CMSA code and data. Based on my analysis, there is sufficient evidence to conclude that the ARM framework is not useful for assessing the resilience of the HSC population to harvest pressures, nor for managing risk to the REKN population due to HSC harvest.

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EXPERT REPORT

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29 September 2022

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1 Scope of Work

I was asked by representatives of EARTHJUSTICE to evaluate the Atlantic States Marine Fisheries Commission’s Report and Supplemental Report to the 2021 Revision to the Adaptive Resource Management (ARM) Framework dealing with horseshoe crab (*Limulus polyphemus*) fishery management and implications for red knot (*Calidris canutus*) conservation. The red knot (RK hereafter) has been listed as “threatened” under the Endangered Species Act, and relies on horseshoe crab eggs buried along beaches of Delaware Bay to feed as it migrates along North and South America. The conclusions in the ARM report relate to an amendment proposed through the Atlantic States Marine Fisheries Commission (ASMFC) that would likely allow female horseshoe crab (HSC hereafter) harvest in Delaware Bay for the first time since 2012 and thereby potentially reduce food provisions (HSC eggs) needed by migrating RK. My primary goal is to evaluate the evidence in favor of the amendment objectively and determine if the amendment is justified.

In forming my opinions, I reviewed and considered various data sources regarding the HSC fishery and RK conservation along the Mid-Atlantic coast, with emphasis on Delaware Bay. My opinions are also based on my extensive experience conducting research and providing technical advice on fishery management and conservation of various marine species (see Section 8). My compensation is not contingent upon the conclusions or outcome of my review.

2 Summary Opinion

Based on my analysis and my expertise in conservation, fisheries and fishery management, I conclude to a reasonable degree of scientific certainty that:

The proposed amendment that would allow harvest of female horseshoe crabs is not justified by the available scientific evidence, due to various *risk-prone* decisions and assumptions that underlie the Adaptive Resource Management framework and model. The proposed amendment thereby poses a significant risk both to the Horseshoe Crab population and Red Knot recovery.

3 Abbreviations and Definitions

ARM: Adaptive Resource Management framework

HSC: Horseshoe Crab (*Limulus polyphemus*)

RK: Red Knot (*Calidris canutus*)

VTS: Virginia Tech HSC survey

DES: Delaware HSC survey

NJS: New Jersey HSC survey

Risk-prone: Conservation or management actions based on overly optimistic assumptions about the status of a population. The assumptions may be about data sources, observations or data, and often involve ignoring information to the contrary of optimistic conclusions about population status. For endangered or threatened species, a risk-averse, rather than risk-prone, strategy based on the precautionary principle is critical for population recovery, population conservation, and sustainable resource management.

4 Opinions

The following specific opinions describe various lines of evidence indicating that the HSC population is not in a healthy state and has not fully recovered despite a prohibition on female harvest since 2012. The different lines of evidence are effectively “red flags” leading to the conclusion that the current and proposed management strategies are risk-prone, such that harvest restrictions should not be relaxed at present. To the contrary, further management actions or improvements to the current management plan are necessary to stimulate HSC recovery. Furthermore, due to the lack of *substantial* improvement of the HSC spawning stock (i.e. mature females), the existing HSC management strategy has not significantly enhanced food availability for the threatened RK and therefore its recovery. A shift to risk-averse management based on the precautionary principle is essential for HSC and RK recovery.

4.1 Low Newly Mature Female, Recruit and Spawning HSC Abundance

An expectation from the female harvest prohibition is a rebound in young mature females and recruitment of immature males and females into the HSC population. In 2019 and 2020, abundance of newly mature females was at an all-time low; recruitment of immature females and males was extremely low and unchanged since before the prohibition; and female abundance in the spawning survey dropped sharply in 2019. These are warning signs that the HSC population has not fully recovered and may even be declining. Thus, female harvest should not be raised.

4.2 Smaller Body Size of Mature Female HSC

An expectation of the female harvest prohibition is that female body size would increase, given constant recruitment, which is a typical response in fisheries worldwide when harvest pressure on older, larger females is reduced. On the contrary, mean size of mature female HSC was smallest in the last 3 years (2018 to 2020) and of newly mature females in the last 2 years of the time series from 2002 to 2020, despite the prohibition on female harvest since 2012. These data are inconsistent with the previous expectation and the premise that the female segment of the HSC population has rebounded.

4.3 Loss of Large Mature Female HSC and Lower Egg Production

Population egg production is a function of spawning stock (= mature females) biomass (i.e. weight). Hence, changes in size distribution of mature females will affect total egg production, particularly the loss of large HSC females which contribute disproportionately to total egg production. Consequently, using only HSC abundance to estimate reproductive output and egg production is ignoring main biological drivers of population egg production—size structure and biomass—of the HSC spawning stock. Size distribution of mature females has shifted to smaller females. Abundance of females larger than 300 mm prosomal width (i.e. females with the highest egg production) has dropped recently, particularly from 2018 to 2020. Recent low recruitment means that smaller mature females are not compensating for the loss of larger mature females. Consequently, total reproductive (egg) output has likely not improved, which hampers recovery of the HSC and RK populations.

4.4 HSC Sex Ratio

When HSC harvest has been restricted to males, the ratio of males to females should have decreased. In contrast, male:female sex ratios have actually increased from 1999 to 2019. This represents another warning sign that the current management strategy has not been effective, that population dynamics are not well understood, and that harvest of females should not be increased.

4.5 High Mature Female HSC Mortality

The combination of discard mortality and bait harvest mortality for females has increased substantially in recent years and is comparable to levels before the prohibition. Assuming that the prohibition has worked is therefore risk-prone. The collective bait harvest and discard mortality is not being controlled effectively and inhibits HSC recovery.

4.6 Reliance on HSC Density as the Indicator of HSC Population Status

Female density (catch per unit area) is a primary variable used in HSC surveys and the ARM framework model. Reliance solely on HSC density or abundance ignores other variables that commonly produce warning signs about the status of a stock, such as female size, female size-frequency distribution, spawning stock biomass and female:male sex ratio. These variables are often more sensitive indicators of problems in a population, meaning that they can detect problems more effectively than abundance estimates. Hence, the current management strategy is risk-prone by ignoring these more sensitive indicators.

4.7 Low HSC Egg Density

Recent data indicate that HSC egg densities in HSC spawning habitats and RK feeding grounds remain an order of magnitude below densities when RK and HSC were relatively abundant. The ARM process has decided to ignore patterns in HSC egg density because of methodological “uncertainty” in the data. Under conditions where a population is not in danger, this may be acceptable, but absolutely not when it represents a potential warning sign about a population in danger, such as the RK. Thus, lack of use of HSC egg density data, as a proxy for RK food availability, amounts to a failure to incorporate all available scientific information into the analysis to guide management decisions in a risk-averse manner.

4.8 Lack of Correlation of HSC Surveys

Data from the DES and NJS of HSC in Delaware Bay are assumed to be correlated with the VTS and used to fill in survey gaps in the VTS. Survey data when all three surveys were conducted are not correlated, and data from the DES and NJS were relatively higher than that from VTS. These results lead to an overestimation of HSC abundance during VTS gap years, which is indicative of a risk-prone assumption.

4.9 Degraded HSC Spawning Habitat and RK Feeding Grounds

Spawning habitat (e.g. beaches) for HSC and feeding grounds for RK have been lost throughout the stopover range of RK in the Mid-Atlantic. Loss of habitat is an additional stress that demands risk-averse management of mortality sources (e.g. fishing) which management can control. There may be variables that are beyond ASMFC’s control, but that means they should be more precautionary

with variables they can control, and it's certainly not a valid basis for ignoring warning signs like reduced HSC egg density and abundance.

5 Evidence for Opinions

The VTS is based on robust experimental design principles, and is the only spatially widespread survey that includes the coastal zone along Delaware and New Jersey, as well as Delaware Bay. In addition, the VTS collects much more comprehensive demographic data, which enables more types of analysis. Thus, the VTS serves as a robust and independent measure of HSC population status. The remainder of the analysis therefore focuses on data from the VTS and other published information on horseshoe crabs and the red knot. All analyses were conducted using the statistical software package R, version 4.1.2 (2021).

5.1 Low Newly Mature Female, Recruit and Spawning HSC Abundance

An expectation from the female harvest prohibition is a rebound in young mature females and recruitment of immature males and females into the HSC population. In 2019 and 2020, abundance of newly mature females was at an all-time low; recruitment of immature females and males was extremely low and unchanged since before the prohibition; and female abundance in the spawning survey dropped sharply in 2019. These are warning signs that the HSC population has not fully recovered and that female harvest should not be raised.

Data from the VTS on abundance of newly mature female HSC in 2019 and 2020 were at the lowest levels in the time series since 2002, indicating low influx of young mature females into the spawning stock (Figure 1). Similarly, abundance of immature female and male HSC, representing future recruitment to the adult segment and spawning stock of the population, were at extremely low levels and unchanged from those before 2013 (Figure 1). Moreover, female abundance in the Delaware Bay Horseshoe Crab Spawning Survey dropped sharply in 2019 (Figure 2), despite the prohibition of female harvest since 2012.

5.2 Smaller Body Size of Mature Female HSC

An expectation of the female harvest prohibition is that female body size would increase, given constant recruitment, which is a typical response in fisheries worldwide when harvest pressure on older, larger females is reduced (Beverton and Holt, 1956; Gedamke and Hoenig, 2006). On the contrary, mean size of mature female HSC was smallest in the last 3 years (2018 to 2020) and of newly mature females in the last 2 years of the time series from 2002 to 2020, despite the prohibition on female harvest since 2012. These data are inconsistent with the previous expectation and the premise that the female segment of the HSC population has rebounded.

VTS data were examined in two ways (mean and mode of size-frequency histograms) to evaluate this expectation. First, the time series of mean size in the VTS (Figure 3) indicated that mean sizes of mature female HSC and of newly mature females from 2016 to 2020 were the smallest in the time series from 2002 to 2020, despite the prohibition of female harvest since 2012.

Given that the mean of a sample can be influenced by outliers, the size data were also examined using a non-parametric statistic, the mode. The median could not be calculated because the raw data were unavailable for this analysis. The mode for each year was visually estimated from the size-frequency histograms of mature females (Appendix Figures 10 and 11). As with the mean, modal sizes of mature females from 2018 to 2020 were the lowest in the time series (Figure 4). In contrast, modal sizes of mature males were relatively unchanged (Figure 4).

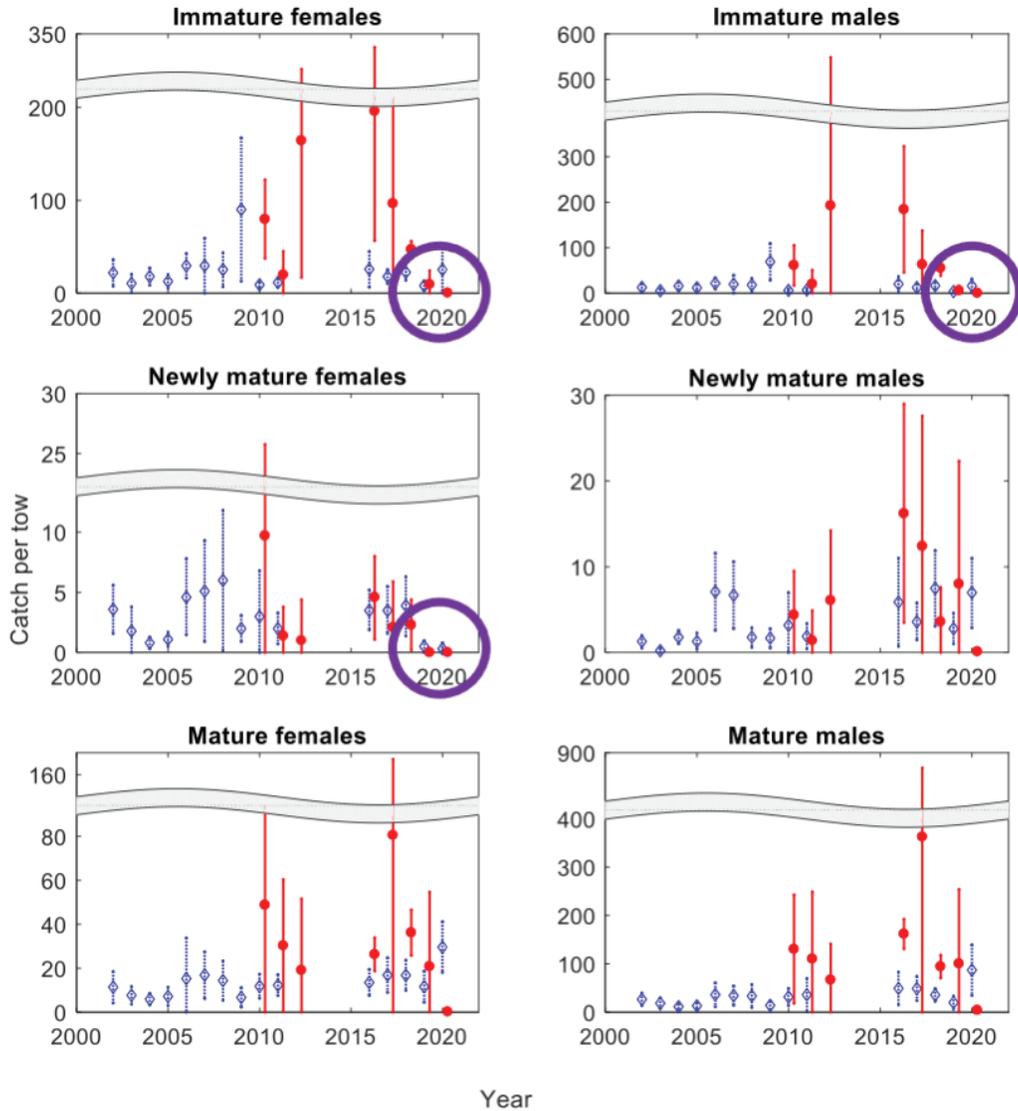


Figure 1: Densities of HSC males and females from Figure 3 of the VTS report (Hallerman and Jiao, 2021). Purple circles have been added to highlight the warning signs that the HSC population has not fully recovered.

Mean body size of spawning females could decrease over time if there was high recruitment of smaller, newly mature females shifting down the average size. However, the opposite (weak recruitment) appears to be the case, as described in section 5.1.

5.3 Loss of Large Mature Female HSC and Lower Egg Production

Population egg production is a function of spawning stock (= mature females) biomass (i.e. weight). Hence, changes in size distribution of mature females will affect total egg production, particularly large HSC females which contribute disproportionately to total egg production. Consequently, using only HSC abundance to estimate reproductive output and egg production is ignoring the main biological drivers of population egg production—size structure and biomass—of the HSC spawning stock. Size distribution of mature females has shifted to smaller females. Abundance of females larger than 300 mm prosomal width (i.e. females with the highest egg production) has dropped recently,

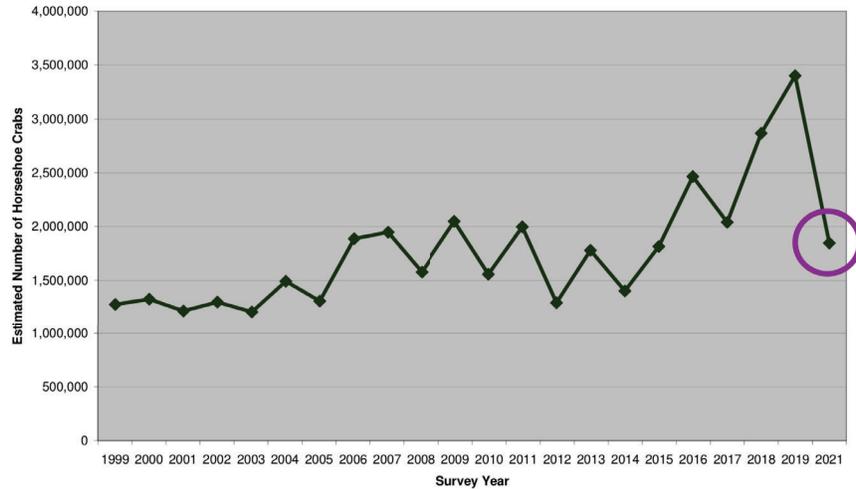


Figure 2: Spawning horseshoe crab survey data, highlighting low abundance of spawning horseshoe crabs in 2021 Swann and Hall (2019).

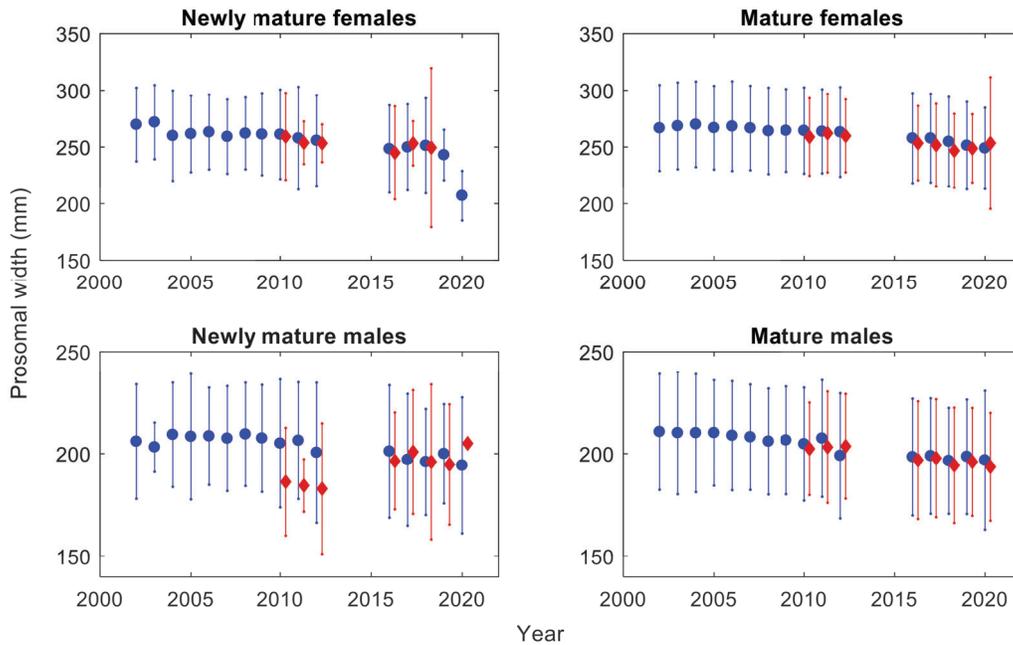


Figure 3: Mean sizes of newly mature and mature female and male horseshoe crabs over 2010 to 2020, with gap years from 2012 to 2015, from the VT survey in the coastal Delaware Bay area (Hallerman and Jiao, 2021).

particularly from 2018 to 2020. Recent low recruitment means that smaller mature females are not compensating for the loss of larger mature females. Consequently, total reproductive (egg) output has likely not improved, which hampers recovery of the HSC and RK populations.

For an individual HSC female, her egg production is directly proportional to individual weight, which is an exponential (not linear) function of prosomal width (Figure 5), as in other species of horseshoe crabs (Chatterji, 1995) and marine species in general (Barneche et al., 2018).

Changes in size distribution of mature females, particularly large HSC females which contribute disproportionately to total egg production due to the exponential increase in weight with size (Figure 6), will reduce population egg production. This was validated for an HSC population by

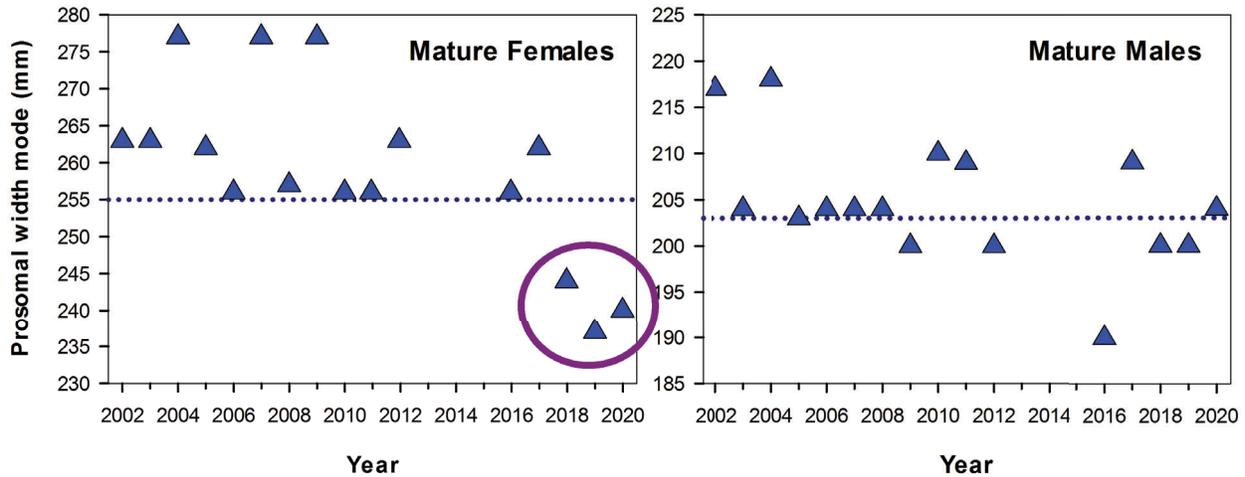


Figure 4: Size modes of mature female and male horseshoe crabs over 2002 to 2020 (gap years from 2013 to 2015) from the VTS in the coastal Delaware Bay area. Mode sizes were estimated from Figures 10 and 11.

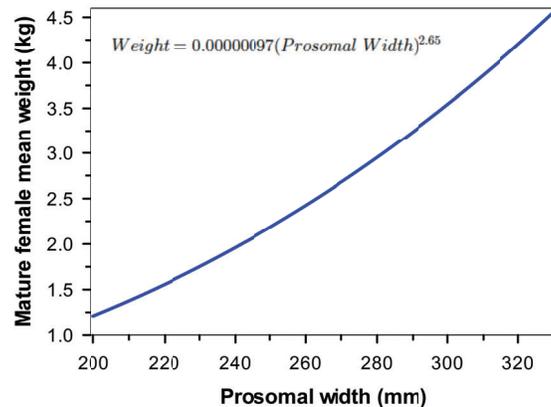


Figure 5: Exponential relationship between mature female HSC weight (kg) and prosomal width (mm) derived from Table 3 in Graham et al. (2009).

Leschen et al. (2006), who concluded that “larger females held a larger number of eggs (63,500) than smaller females (14,500) [and] laid a higher percentage of the eggs they contained. Thus they not only contain more eggs, but are more effective at laying them as well.”

Using only HSC abundance to estimate reproductive output and egg production is ignoring the main biological drivers of population egg production—size structure and biomass (weight)—of the HSC spawning stock. Abundance is a reliable proxy of HSC egg production only if size structure of the spawning stock is unchanged over time, which is not the situation with the HSC spawning stock. Size distribution of mature females has shifted to smaller females (Figures 3 and 4), and recruitment does not account for the recent shift in size distribution because abundance of newly mature and immature females in the past few years has been well below average (Figure 1).

Abundance of females larger than 300 mm prosomal width (i.e. females with the highest egg production) has dropped recently, particularly from 2018 to 2020 (Appendix Figures 10 and 11), which has substantially reduced egg production. Note in Figures 10 and 11 that females larger than 300 mm prosomal width were apparent in 6 of 8 years from 2002 to 2009 (Figure 10), but only in 1 of 8 years from 2010 to 2020 (Figure 11). Moreover, the recent low recruitment means that

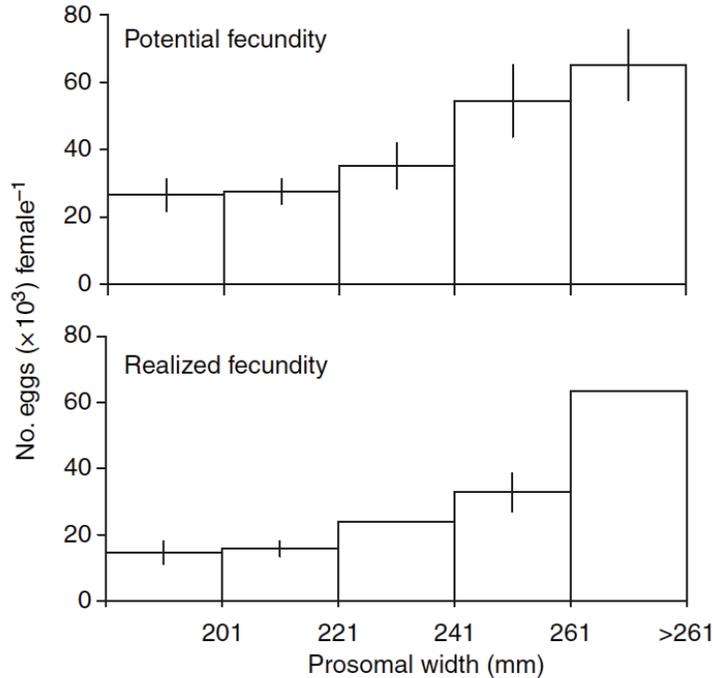


Figure 6: Positive relationship between HSC female fecundity and prosomal width (Leschen et al., 2006).

smaller mature females are not compensating for the loss of larger mature females. Consequently, total reproductive (egg) output has likely not improved, which hampers recovery of the HSC and RK populations.

5.4 HSC Sex Ratio

When HSC harvest has been restricted to males during the prohibition, the ratio of males to females should have decreased. In contrast, male:female sex ratios have actually increased from 1999 to 2019. This represents another warning sign that the current management strategy has not been effective, and that harvest of females should not be increased.

To assess HSC sex ratio over time, particularly since the prohibition on female harvest, I examined sex ratio data from the 2019 Delaware Bay Horseshoe Crab Spawning Survey, Table 5 (Figure 7). The time series shows an initial drop in the ratio of males to females during 2013, shortly after the prohibition on female harvest began. However, the ratio of males to females has increased since 2014 and even reached the highest ratios in the time series during 2018 and 2019.

5.5 High Mature Female HSC Mortality

The combination of discard mortality and bait harvest mortality for females has increased substantially in recent years and is comparable to levels before the prohibition. Assuming that the prohibition has worked is therefore risk-prone. The collective bait harvest and discard mortality is not being controlled effectively and inhibits HSC recovery.

Total mortality of females due to the bait fishery and its discards has increased substantially in recent years and is comparable to levels before the prohibition (Figure 8). Note that there is still a small amount of direct mortality due to the bait fishery (Figure 8), possibly due to inaccurate identification of female HSC by fishers. Thus, the prohibition on female harvest has not been

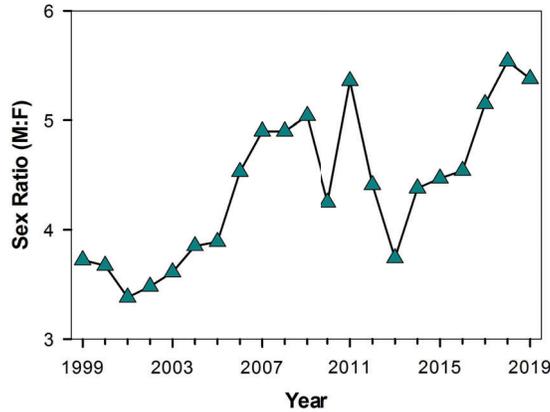


Figure 7: Sex ratio from the Delaware Bay Horseshoe Crab Spawning Survey Swann and Hall (2019).

effective in reducing female HSC mortality, and any further increase in female harvest is risk-prone and a danger to the HSC population and RK recovery.

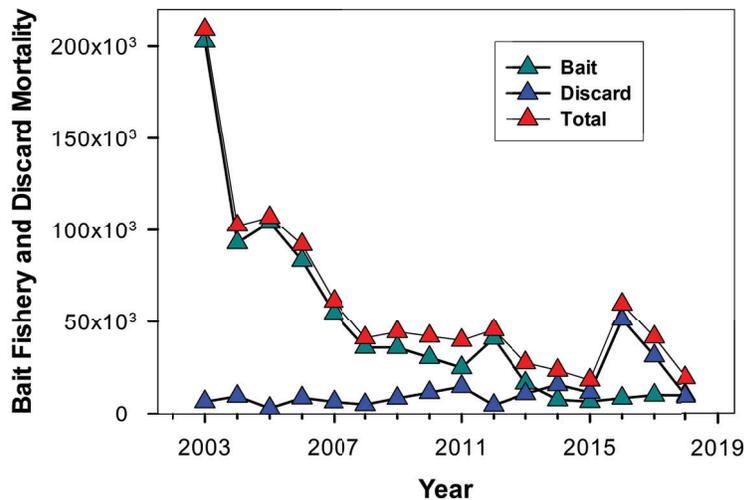


Figure 8: HSC mortality due to the bait fishery and discards (Adaptive Resource Management Subcommittee, 2022).

5.6 Reliance on HSC Density as the Indicator of HSC Population Status

Female density (catch per unit area) is a primary variable used in HSC surveys and the ARM framework model. Reliance solely on HSC density or abundance ignores other variables that commonly produce warning signs about the status of a stock, such as female size, female size-frequency distribution, spawning stock biomass and female:male sex ratio (Free et al., 2020; Punt et al., 2020). These variables are often more sensitive indicators of problems in a population, meaning that they can detect problems more effectively than abundance estimates alone. Hence, the current management strategy is risk-prone by ignoring these more sensitive indicators.

5.7 Low HSC Egg Density

Recent data indicate that HSC egg densities in HSC spawning habitats and RK feeding grounds remain an order of magnitude below densities when RK and HSC were relatively abundant. The ARM process has decided to ignore patterns in HSC egg density because of methodological “uncertainty” in the data. Under conditions where a population is not in danger, this may be acceptable, but absolutely not when it represents a potential warning sign about a population in danger, such as the RK. Thus, lack of use of HSC egg density data, as a proxy for RK food availability, amounts to a failure to incorporate all available scientific information into the analysis to guide management decisions in a risk-averse manner.

To assess changes in HSC egg density over time, I compared data for egg density before the peak of HSC harvest during 1985, 1986, 1988 and 1990 with data after the peak of HSC harvest from 1999 to 2021 (Smith et al., 2022). While the time series from 1999 to 2021 shows egg density increasing from an average of about 3,000 eggs per m^2 in 2000 to 9,000 eggs per m^2 in 2021 (Figure 6), egg density remains over an order of magnitude lower than that before the peak of HSC harvest during 1985 to 1990 (Figure 6).

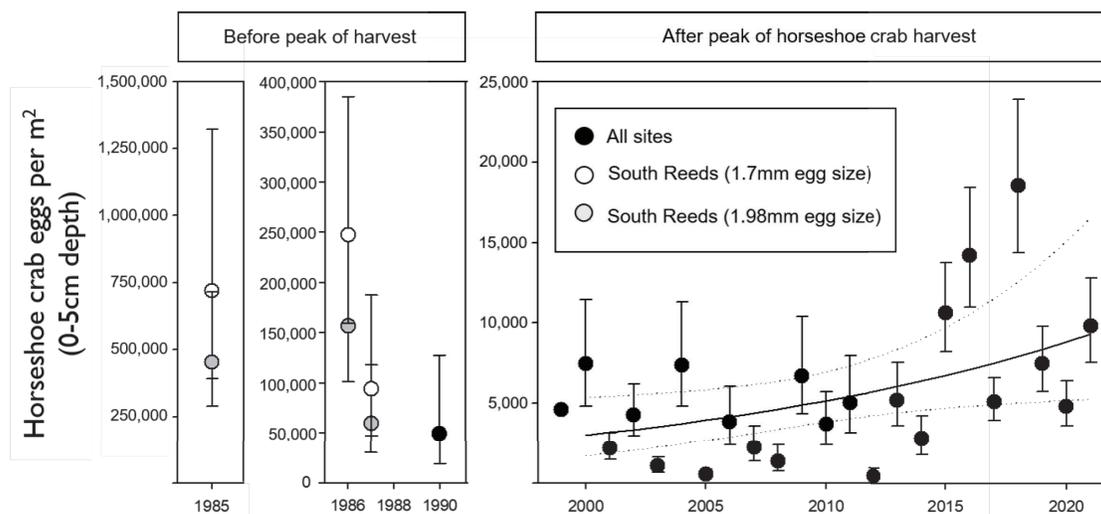


Figure 9: HSC egg density from spawning beaches, emphasizing the order of magnitude lower egg densities in recent years relative to historical levels in the spawning beaches. Note the different range of values in the left and right graphs. Figure from Smith et al. (2022).

5.8 Lack of Correlation of HSC Surveys

Data from the DES and NJS of HSC in Delaware Bay are assumed to be correlated with the VTS and used to fill in survey gaps in the VTS. Survey data when all three surveys were conducted are not correlated, and data from the DES and NJS were relatively higher than that from VTS. These results lead to an overestimation of HSC abundance during VTS gap years, which is indicative of a risk-prone assumption.

To evaluate the assumption of coherence between the three surveys, and justification for use of the DES and NJS in the four years when VTS data were unavailable, correlation between the three surveys was investigated. Data used in the analysis are those in Tables 1 and 2 from Adaptive Resource Management Subcommittee (2022) for indices VTS Multiparous Females, DES Adult and

NJS Ocean Trawl from 2003 to 2012, when indices were available for all three surveys prior to the 2012 prohibition.

Data for female and male HSC abundance from the three surveys were not correlated (Table 1), such that the use of data from two surveys (NJS and DES) to estimate data from the VTS survey during gap years when the VTS did not collect data is invalid. Furthermore, the NJS and DES produced data that were relatively higher than data from the VTS (positive intercepts in Table 1), indicating that the replacement data for the VTS using DES and NJS overestimate HSC abundance from the VTS.

Table 1: Correlation analysis for mature female HSC from VTS, NJS and DES.

Parameter	Estimate	Standard Error	t value	P
<i>Females</i>				
<i>DES as a function of VTS: $r^2 = 0.01$</i>				
Intercept	0.23	0.37	0.61	0.56
Slope	0.02	0.07	0.28	0.79
<i>NJS as a function of VTS: $r^2 = 0.001$</i>				
Intercept	1.96	0.67	2.91	0.02
Slope	-0.01	0.13	-0.07	0.95
<i>Males</i>				
<i>DES as a function of VTS: $r^2 = 0.12$</i>				
Intercept	0.03	0.23	0.12	0.91
Slope	0.02	0.02	1.03	0.34
<i>NJS as a function of VTS: $r^2 = 0.03$</i>				
Intercept	2.25	0.71	3.15	0.02
Slope	-0.03	0.06	-0.52	0.62

5.9 Degraded HSC Spawning Habitat and RK Feeding Grounds

Spawning habitat (e.g. beaches) for HSC and feeding grounds for RK have been lost throughout the stopover range of RK in the Mid-Atlantic. Loss of habitat is an additional stress that demands risk-averse management of mortality sources (e.g. fishing) which management can control. There may be variables that are beyond ASMFC's control, but that means they should be more precautionary with variables they can control, and it's certainly not a valid basis for ignoring warning signs like reduced HSC egg density.

A major threat to horseshoe crab population involves habitat degradation and loss, and is expected to worsen in the future due to sea level rise (Botton et al., 2022). Spawning habitat loss has been significant due to various factors such as shoreline management (e.g. bulkheading), coastal disturbances and sea-level rise (Smith et al., 2017, 2020). In some cases, whole beaches have been lost (Smith et al., 2017). Given that habitat loss is not under control by ASMFC, precautionary management demands consideration of such stressors to the population by control of fishery harvest to compensate for external stressors.

5.10 Appendix Figures

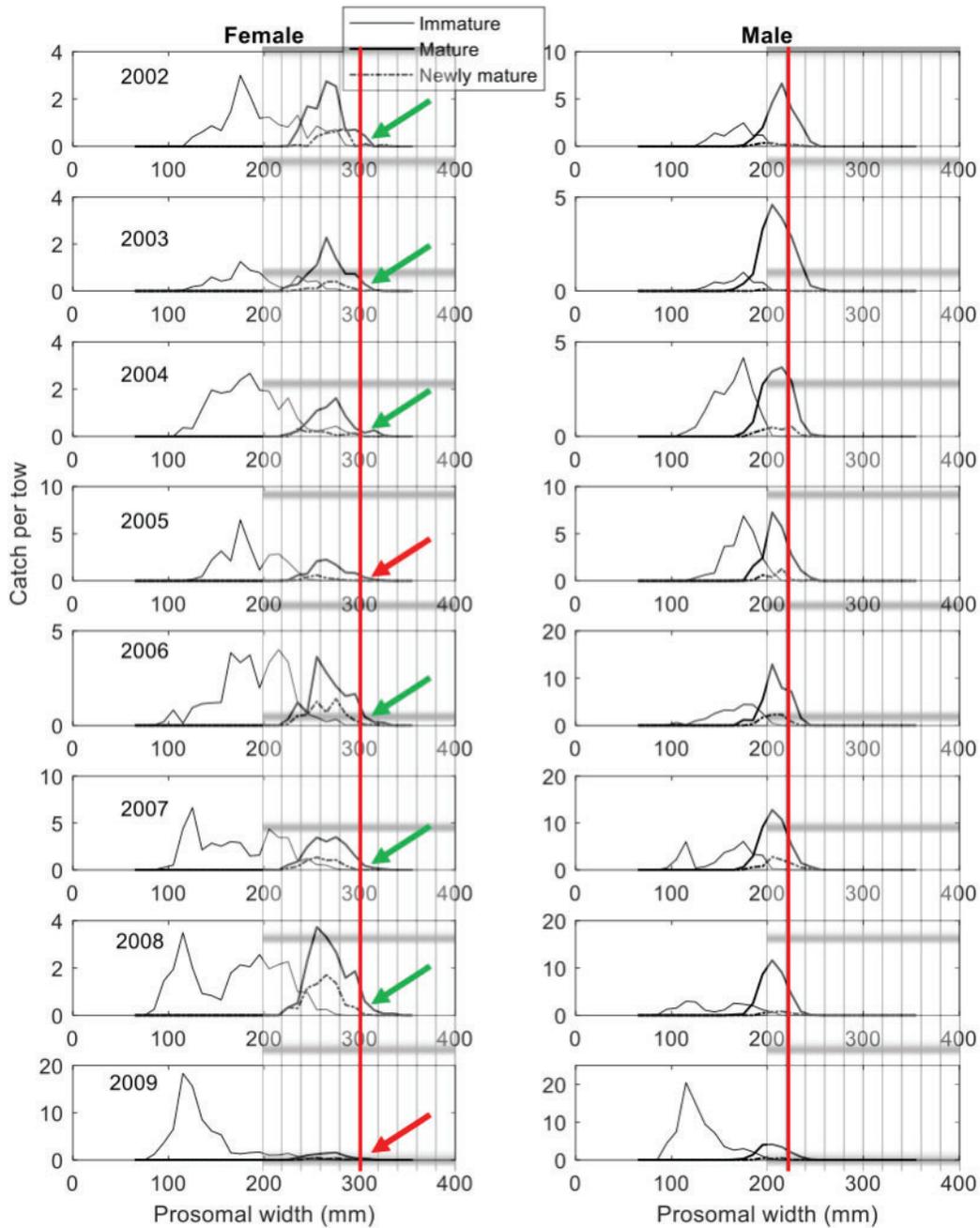


Figure 10: Size frequencies of mature female and male horseshoe crabs over 2002 to 2009 from the VT survey in the coastal Delaware Bay area (Hallerman and Jiao, 2021). Vertical red lines and grid cells were added for reference. Green arrows indicate years when mature females larger than 300 mm prosomal width were apparent, and red arrows when not.

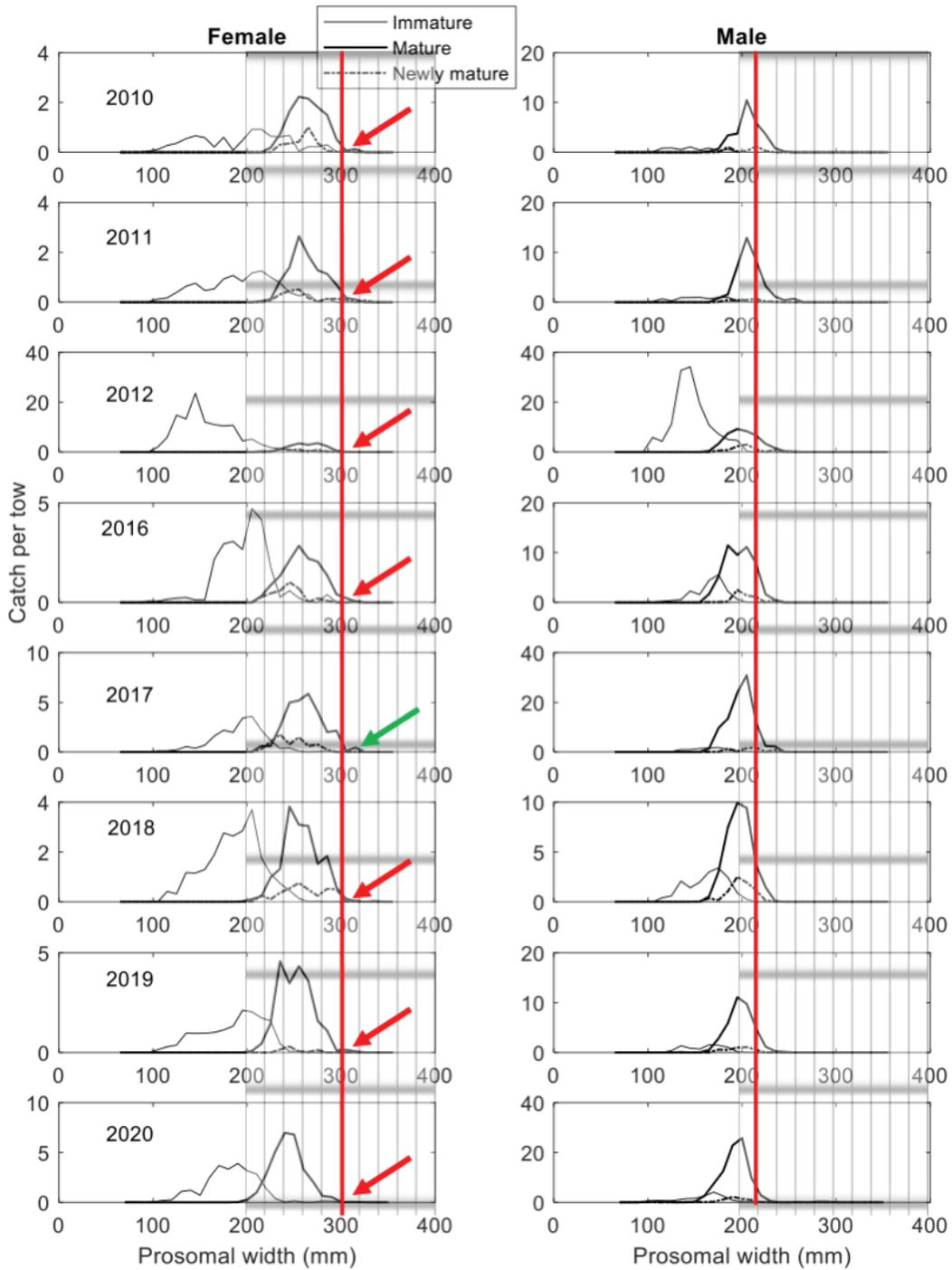


Figure 11: Size frequencies of mature female and male horseshoe crabs over 2010 to 2020, with gap years from 2013 to 2015, from the VT survey in the coastal Delaware Bay area (Hallerman and Jiao, 2021). Vertical red lines and grid cells were added for reference. Green arrows indicate years when mature females larger than 300 mm prosomal width were apparent, and red arrows when not.

6 Acknowledgements

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8 Qualifications & Credentials

The qualifications, experience and scientific recognition that allow me to provide an informed, expert opinion on this matter are described below. My academic and professional credentials include: Professor (2000-present), Associate Professor (1993-2000), and Assistant Professor (1986-1993) of Marine Science, Virginia Institute of Marine Science, William & Mary, Department of Fisheries Science; Senior Postdoctoral Fellow, Smithsonian Institution (1997-1999); Postdoctoral Fellow, U.S. National Research Council (1985-1986); Adjunct Professor, Anne Arundel Community College (1984-1985); Postdoctoral Fellow, Smithsonian Institution (1984-1985); and Assistant Professor, Florida A & M University (1981-1984; while Ph.D. student at FSU). I received my Ph.D. from Florida State University in 1984 (major: Biological Science; minor: Statistics).

My scientific expertise and research specialties include Marine Conservation Ecology, Fisheries Management, Mathematical Biology, Ecological Statistics, and Ecology and Management of Crustaceans and Molluscs. Over the span of my career, I have 121 publications in peer-reviewed scientific journals, numerous technical reports, and 80 research grants totaling over \$20 million from agencies including the National Science Foundation, National Oceanic and Atmospheric Administration, U.S. Army Corps of Engineers, National Undersea Research Program, Department of Defense, and various others.

I have 45 years of experience with eastern oyster, blue crab, Caribbean spiny lobster, queen conch, Nassau grouper and various marine bivalves; 36 years experience as the Commonwealth of Virginia's expert on blue crab ecology and fishery management; provision of formal opinions to Virginia Marine Resources Commission, Chesapeake Bay Commission, Chesapeake Bay Stock Assessment Committee, and Chesapeake Bay Program Fisheries Goal Implementation Team; 18 years experience as scientific advisor on oyster restoration to U.S. Army Corps of Engineers, NOAA Chesapeake Bay Office, and Chesapeake Bay Program Fisheries Goal Implementation Team; 33 years as Chief Scientist of the Blue Crab Winter Dredge Survey; Co-Principal Investigator of the Blue Crab Stock Assessment in Chesapeake Bay; and member of technical teams for Gulf of Mexico and Chesapeake Bay oyster and blue crab stock assessment, conservation and restoration.

Scientific honors, recognition and awards include: (i) Coastal America Partnership Award from the Executive Office of the President of the U.S., (ii) Kavli Fellowship from U.S. National Academy of Sciences, (iii) Aldo Leopold Leadership Fellow Award, (iv) Outstanding Faculty Award for Advisory Service, Virginia Institute of Marine Science, and (v) Outstanding Faculty Award for Research, Virginia Institute of Marine Science.