Atlantic States Marine Fisheries Commission

Horseshoe Crab Management Board

August 2, 2016
2:00 – 3:30 p.m.
Alexandria, Virginia

Draft Agenda

The times listed are approximate; the order in which these items will be taken is subject to change; other items may be added as necessary.

1.	Welcome/Call to Order *(J. Gilmore)*	2:00 p.m.
2.	Board Consent • Approval of Agenda • Approval of Proceedings from May 2016	2:00 p.m.
3.	Public Comment	2:05 p.m.
4.	Review and Consider Recommendations from the Adaptive Resource Management (ARM) Subcommittee on Revisions to the ARM Framework (*J. Lyons*) **Action** • Technical Committee Report (*S. Doctor*) • Advisory Panel Report (*J. Cooper*)	2:15 p.m.
5.	Discuss Additional Bait Trials (*R. Ballou*) **Possible Action**	3:00 p.m.
6.	Other Business/Adjourn	3:30 p.m.

The meeting will be held at the Westin Alexandria; 400 Courthouse Square; Alexandria, VA; 703.253.8600

MEETING OVERVIEW

Horseshoe Crab Management Board Meeting
Tuesday May 3, 2016
2:00 p.m. – 3:30 p.m.
Alexandria, Virginia

Chair: Jim Gilmore (NY) Assumed Chairmanship: 10/14	Horseshoe Crab Technical Committee Chair: Steve Doctor (MD)	Law Enforcement Committee Representative: Doug Messeck (DE)
Vice Chair: Dr. Malcolm Rhodes (SC)	Horseshoe Crab Advisory Panel Chair: Dr. Jim Cooper (SC)	Previous Board Meeting: May 3, 2016
Shorebird Advisory Panel Chair: Dr. Sarah Karpanty (VA)	Delaware Bay Ecosystem Technical Committee Chair: Greg Breese (FWS)	
Voting Members: MA, RI, CT, NY, NJ, DE, MD, DC, PRFC, VA, NC, SC, GA, FL, NMFS, USFWS (16 votes)		

2. Board Consent

- Approval of Agenda
- Approval of Proceedings from May 2016 Board Meeting

3. Public Comment – At the beginning of the meeting public comment will be taken on items not on the agenda. Individuals that wish to speak at this time must sign-in at the beginning of the meeting. For agenda items that have already gone out for public hearing and/or have had a public comment period that has closed, the Board Chair may determine that additional public comment will not provide additional information. In this circumstance the Chair will not allow additional public comment on an issue. For agenda items that the public has not had a chance to provide input, the Board Chair may allow limited opportunity for comment. The Board Chair has the discretion to limit the number of speakers and/or the length of each comment.

4. Review and Consider Recommendations from the Adaptive Resource Management (ARM) Framework (2:15 – 3:00 p.m.) Action
Background • At the 2016 Winter Meeting, the Board supported moving forward with a short-term, partial review of the ARM Framework to be conducted by the ARM Subcommittee in consultation with the Horseshoe Crab Technical Committee subcommittee. • The ARM Subcommittee met twice a month from February through July 2016 to consider components of the ARM Framework to be updated. Areas of possible change in the ARM Framework include valuation of female horseshoe crabs, alternative harvest packages, abundance thresholds for allowing female horseshoe crab harvest, and the possibility of

including biomedical data in the ARM Framework moving forward (**Supplemental Materials**)

Presentations

- Recommendations on Revisions to the ARM Framework by J. Lyons
- Technical Committee Report by S. Doctor
- Advisory Panel Report by J. Cooper

Board actions for consideration at this meeting

- Consider approval of recommendations from the ARM Subcommittee to the ARM Framework
- Consider initiation of an addendum to address ARM Subcommittee recommendations

6. Discuss Additional Bait Trials (3:00 -3:30 p.m.) Possible Action

Background

- In February 2016, the Board was presented the results of the 2014 alternative horseshoe crab bait trials conducted in Connecticut and Rhode Island. Based on the results of the trials, the Board tasked staff with developing a cost comparison.
- In May 2016, the Board was presented considerations by the Artificial Bait Trials Working Group and Advisory Panel in conducting a cost comparison. Based on the Board discussion, the Board expressed interest in conducting additional bait trials in the future.
- In July 2016, the Board was presented a prospectus for considering conducting additional bait trials in fall 2016. (**Briefing Materials**)

Presentations

- Prospectus for continuing alternative bait trials by R. Ballou

Board actions for consideration at this meeting

- Consider tasking the Technical Committee with conducting additional alternative bait trials

7. Other Business/Adjourn

Commonwealth of Massachusetts
Division of Marine Fisheries
251 Causeway Street, Suite 400
Boston, Massachusetts 02114
(617)626-1520
fax (617)626-1509

David E. Pierce
Director

Charles D. Baker
Governor
Karyn E. Polito
Lieutenant Governor
Matthew A. Beaton
Secretary
George N. Peterson, Jr.
Commissioner
Mary-Lee King
Deputy Commissioner

MEMORANDUM

To: Robert Ballou, RI DEM
Kirby Rootes-Murdy, ASMFC Horseshoe Crab Plan Coordinator

From: Daniel McKiernan, Deputy Director and ASMFC Horseshoe Crab Board Member

Date: July 5, 2016

Subject: Continuing horseshoe crab alternative bait trials

The Massachusetts Division of Marine Fisheries (DMF) provides the following comments on the June 6 memorandum from Robert Ballou to the ASMFC Horseshoe Crab Management Board and Technical Committee. Staff of DMF's Invertebrate Fisheries Project, led by Chief Biologist Robert Glenn and including fisheries specialists Derek Perry (horseshoe crab biologist and ASMFC technical committee member) and Steve Wilcox (whelk biologist), have been investigating fishing and baiting practices over the past few years. Although DMF has been a proponent of pursuing alternative bait types to enhance horseshoe crab conservation—and have spoken on the record in support of alternative baits—we have practical concerns about the issues raised in the June 6 memo. Specifically, we are concerned that the use of "ecobait" may not be a viable alternative to current practices and bait types. Our concerns fall into four categories: efficacy, cost, product handling challenges, and potentially exaggerated conservation benefits.

1) **Efficacy.** The ecobait uses marine species that the fishery is currently using but appears to require 2–6 times the manufacturer-recommended amount of bait to fish properly.

Based on the results of a mail survey of commercial whelk pot fishermen conducted by DMF whelk biologist Steve Wilcox, Massachusetts whelk pot fishermen use an average of a ¼ of a horseshoe crab per trap. Based on conversations with Penny Howell of CT DEP, CT harvesters use a similar amount. The standard practice used to bait traps in MA and CT is not to solely use horseshoe crab as bait, but to use a bait medley usually consisting of horseshoe crab mixed with cheaper baits such as green crabs, mussels, or fish. The June 6 memo states a goal of determining a bait alternative to fisheries that use horseshoe crabs as their sole bait. Cases of traps being baited solely with horseshoe crab appears to be very rare in MA and possibly in other neighboring states. The artificial bait trials appear to be merely testing the bait that is similar to that already being used by the fishery, but in another form that is more expensive and logistically challenging to work with.

2) **Cost.** The ecobait may be more expensive than current baiting practices.

LaMonica gave an initial price of $50 per slab which was supposed to bait approximately 50 traps ($1/trap). If 2–6 times the recommended bait is needed to fish effectively, then it is $2–$6/trap (or $400–$1200/set of 200 traps). Based on a conference call with ASMFC staff, there is also some indication that the price per slab may increase to $65–75, making it even more cost prohibitive. More recent conversations between LaMonica and ASMFC staff indicate that LaMonica may sell the product for $40 a slab for the first six months, and then reevaluate the price. MA fishermen generally buy horseshoe crabs for $3.50–$4.00/crab. At a quarter of a crab per trap, that equals about $1/trap, or less. The horseshoe crab is then mixed with a variety of cheaper baits, such as the invasive green crab. It costs an estimated $1.25 to bait a whelk trap based on current practices.

3) **Handling.** Based on feedback from RI and CT, the ecobait has a short shelf life and does not last long in the water. Also, the company has been unable to deliver the bait to New Bedford which prevented MA from being able to participate in the bait study.

The alternative ecobait appears to be replicating a similar bait medley the commercial industry is currently using, but this form may be more difficult to handle. It is our understanding that the binding agent used should not be frozen and only has a shelf life of two weeks; the manufacturer recommends refrigerating the bait, which would be problematic for many fishermen without access to walk-in refrigerators. In certain areas with strong tidal current, the bait only lasted one night. Finally, while the manufacturer suggested that New Bedford is a convenient place for them to deliver bait to our state, we were frustrated because we were unable to secure a delivery.

4) **Conservation benefit.** The alternative bait does not substantially reduce the amount of horseshoe crabs used on a per trap basis, so we conclude the conservation benefit for horseshoe crabs is overestimated.

Each "piece" of artificial bait used in the trial contained approximately ⅛ of a female horseshoe crab. When you multiply these numbers by 2 or 6 (the amount of bait needed to actually get the pot to fish), the artificial bait used ¼ to ¾ of a horseshoe crab per pot to fish effectively. The artificial bait used more horseshoe crabs per pot than what is currently used in the whelk pot fishery, thus providing no conservation benefit.

We would be open to testing the efficacy of other alternative marine species as baits, but based on the trials that have already been done by CT and RI we intend to decline to participate in further testing. We suggest testing baits that do not use any horseshoe crab but use currently available and abundant baits such as green crabs, mussels, or byproducts from crab processing (e.g., Jonah, red crab) to see how critical horseshoe crabs are to catching whelk. We would also recommend testing baits made from post-processed horseshoe crab blood which is currently discarded by the biomedical industry.

cc: David E. Pierce, PhD, Director
Robert Glenn, Steve Wilcox, Derek Perry

Horseshoe Crab ARM Subcommittee Draft Recommendations of ARM Framework Review
July 2016

Executive Summary

Under the guidance of the ASMFC Horseshoe Crab Management Board (Board), the Adaptive Resource Management (ARM) Subcommittee undertook a review of the ARM Framework as outlined in Addendum VII to the Horseshoe Crab FMP. The ARM Framework allows for ecosystem considerations in annually setting horseshoe crab harvest specifications in the Delaware Bay Region. Over the last 8 months, the ARM Subcommittee considered, evaluated, and developed recommendations to the ARM Framework in three categories: 1) monitoring programs, 2) harvest rates and specifications, and 3) the ARM objective function. The ARM Subcommittee outlined the following recommendations:

- Continuation of the Virginia Tech University (VT) trawl survey to inform the population abundance estimate for Horseshoe Crabs in the ARM Framework.
  - o In the absence of the VT trawl survey, continue with the composite index developed by Sweka et al. in 2015
- Redouble efforts to conduct the annual red knot shorebird mark-recapture survey
- Adjust current harvest packages to account for biomedical bled mortality of female horseshoe crabs
- No adjustment to the order of red knot and horseshoe crabs in the objective statement
- Removal of duplicate sex ratio constraint on the utility function
- No adjustment to the (2x) multiplier of utility of female crab harvest in the reward function as it reflects the market value of male to female crabs (2:1 male to female)
- No adjustment to the current knife-edge utility function to a sloped function.

Background

In February 2016, the Board considered several aspects of the ARM Framework that could be reviewed in the interest of maintaining and improving the ARM Framework. Aspects of the framework that were considered for review included both long-term (1-2 year) and short-term (6-8 months) items. A long-term review would include five aspects of the framework: 1) ecological models, 2) ARM optimization and software platform, 3) monitoring programs, 4) harvest rates and specifications, and 5) ARM objective function; a short-term review would consider only items #3-5. The Board tasked the ARM subcommittee with a short-term review of the ARM framework- those review items have been renumbered in this report as 1) monitoring programs, 2) harvest rates and specifications, and 3) the ARM objective function).The ARM subcommittee met several times via conference call from February 2016 through July 2016 to evaluate these short-term review items and develop recommendations. Below is the summary of the ARM Subcommittee's evaluation, conclusions, and recommendations for each review item.

<u>Review Item #1</u>: *Evaluate the monitoring program; update and improve monitoring protocols as needed; use available data to assess quality and precision if possible and as needed.*

Evaluation:

A. Virginia Tech Bottom Trawl Survey

The Virginia Tech (VA Tech) bottom trawl survey was the primary horseshoe crab (HSC) monitoring effort conducted in the development and support of the Adaptive Resource Management (ARM) framework for the management of horseshoe crabs in the Delaware Bay region. Estimates of HSC abundance from this trawl survey in year *t* were used to inform harvest recommendations in year *t*+1 within the ARM framework. The VA Tech trawl survey was conducted from 2002 – 2012, but 2012 had reduced sampling effort due to funding limitations. The survey was not funded in 2013 – 2014, and was not carried out in 2015 due to timing of when grant funds were released.

Methods

From 2002 - 2010 the VA Tech trawl survey was conducted along the coastal Delaware Bay area from 39° 20’ N (Atlantic City, NJ) south to 37° 40’ N (slightly north of Wachapreague, VA) and was conducted in the fall of each year (October – November). The survey area was stratified according to distance from shore (0-3 nm and 3-12 nm) and by bottom topography (trough vs. non-trough). Sampling was conducted with a 16.8 m chartered commercial fishing vessel based out of Ocean City, MD. The trawl used a two-seam flounder trawl with a 18.3 m headrope and a 24.4 m footrope, rigged with a Texas Sweep of 13 mm link chain and a tickler chain. The net body consisted of 15.2 cm stretched mesh and the bag consisted of 14 cm stretched mesh. Individual tows were conducted with an approximate 15 minute bottom time. In 2011, the survey was expanded to areas inside of the lower Delaware Bay and this area was stratified by bottom topography alone (trough vs. non-trough). In 2012, funding was limited and the survey was reduced to the areas inside of the lower Delaware Bay and along the coast between 39° 10’ N and 38° 10’ N from shore out to 3 nm (Hallerman and Hata 2013). Captured HSC were measured for prosomal width, sexed, and maturity classified. Maturity classifications consisted of immature, newly mature (those that are capable of spawning but have not yet spawned) and mature (those that have previously spawned).

Stratum mean catch per 15 minute tow was calculated using two methods – assuming a normal distribution and a lognormal delta distribution. Stratum mean and variance estimates were then combined to estimate an overall stratified mean catch per tow. In addition to mean catch per tow, a population estimate was generated by first calculating the stratum mean density of HSC within the area sampled by the trawls and then expanding this density estimate to the total area of each stratum and summing across strata. Indices of abundance (catch per tow) and the population estimates were calculated individually for each sex. The population estimates for each sex were then used to inform ARM harvest recommendations.

Future Surveys

Funding for the VA Tech trawl survey was not available after the 2012 survey. ASMFC has secured funding for the 2016 season and is pursuing funding through NMFS to continue the survey beyond 2016. Staff at VA Tech are currently operating under the assumption that the survey will continue indefinitely (E. Hallerman, *personal communication*). The sampling plan for 2016 will be to conduct the survey as it was conducted in 2011 (the last year of full funding).

B. Index of Abundance from Other Trawl Surveys

With the lack of funding for the VA Tech trawl survey after 2012, the ARM workgroup began considering alternative methods to assess the abundance of horseshoe crabs in the Delaware Bay region. There have been several other trawl surveys in the Delaware Bay region that assess the abundance of horseshoe crabs including: the Delaware 30 foot trawl survey, the Delaware 16 food trawl survey, the New Jersey Delaware Bay trawl survey, the New Jersey Surf Clam dredge survey, and the Maryland Coastal Bays trawl survey (See ASMFC 2009a for descriptions of these trawl surveys). In 2015, the ARM workgroup developed a methodology using data from these surveys in lieu of the VA Tech trawl survey to produce estimates of abundance that could be used to make harvest recommendations for the 2016 season (ARM Workgroup 2015).

Methodology

The ARM workgroup decided that the final set of trawl surveys to be considered in this alternative abundance estimation methodology include the Delaware 30 foot trawl survey, the New Jersey Delaware bay trawl survey, and the New Jersey Ocean trawl survey. These surveys were selected because they had sex-specific abundance indices, had overlapping years of data with each other and with the VA Tech trawl survey, and they are expected to continue into the future. A linear mixed random effects model was used to generate annual composite indices of male and female abundance from 1998 – 2014. In this model, each individual survey within a year represented a random effect. The model was fit using the "lme" function from the package "nlme" in R 3.0.2 and was specified as a non-intercept model to allow for year-specific estimates of abundance rather than differences for each year from the intercept. Index values from each survey were ln + 0.01 transformed prior to model fitting and final yearly indices of abundance from the model were back-transformed.

Yearly composite indices of abundance were correlated with overlapping years of abundance estimates from the VA Tech trawl survey (2002 – 2011). Linear regression models then related the composite indices of abundance for each sex to the total abundance estimates from the VA Tech trawl survey. These regression parameters were then used to estimate the total abundance of each sex for the time period of 1998 – 2014. The resulting estimates in 2014 were 16.4 million males and 8.4 million females.

Future Surveys

It is anticipated that the three surveys used in the composite index of horseshoe crab abundance will continue into the future. The method of combining data from each of these surveys can continue into the future if the VA Tech trawl survey cannot continue indefinitely. Also, additional years in which the VA Tech trawl survey is conducted will add information to the calibration of the composite index when estimating total abundance.

Conclusions – Trawl Surveys

Future monitoring of the Delaware Bay horseshoe crab population is uncertain and ultimately depends upon funding – especially for the VA Tech trawl survey. At the time of the 2009 ASMFC stock assessment, the plan for horseshoe crab abundance estimation was to further advance a catch-survey model (Collie and Sissenwine 1983) based on data provided by the VA Tech trawl survey. This model simulates stock dynamics through time using two stages (pre-recruits and fully recruited crabs) and has minimal data requirements including: 1) annual indices of relative abundance for each stage; 2) relative selectivities of stages to the survey gear; 3) annual total harvest in number; and 4) an estimate of instantaneous natural mortality rate. Output from the model gives estimates of abundance and exploitation. This type of model is well suited for the assessment of horseshoe crabs because horseshoe crabs cannot be aged, but can be separated into pre-recruit versus fully recruited individuals. Preliminary use of the catch survey model was included as part of the 2009 stock assessment (ASMFC 2009a) and further development and use of this model was encouraged by the peer review panel, although more work is needed to identify appropriate gear selectivities for pre-recruits and fully recruited crabs.

Unfortunately, development of the catch-survey model was halted when funding for the VA Tech trawl survey ended. Other trawl surveys could not be adequate substitutes because they do not separate pre-recruits from fully recruited crabs. If the VA Tech trawl survey secures funding beyond 2016, the catch-survey model appears to be the most promising way to assess horseshoe crab abundance in the Delaware Bay region. However, it is uncertain if the catch-survey model can be run again once 2016 data is collected due to the several consecutive years of missing data when the VA Tech trawl survey was not funded, or if several additional years of data must first be been collected.

If the VA Tech trawl survey is not funded beyond 2016, a practical alternative is to continue to use the composite index of abundance based on data from other trawl surveys. The 2016 data collected from the VA Tech trawl survey can be added to the regression model which calibrates the composite index of abundance to total abundance. Although this methodology can continue into the future because the surveys on which it is based will likely continue, a major shortcoming is that this method assumes that the abundance estimates from the VA Tech trawl survey are unbiased and scaling of the composite index to total abundance would remain unchanged into the future. At this point we do not know how accurate total abundance estimates form the VA Tech trawl survey were and it is likely that they are underestimates because the efficiency of the trawl survey was not 100% as evidenced by the gear efficiency study conducted by Hallerman and Hata (2013) in 2011. This bias could compromise the ability to select optimal harvest packages in the ARM modeling framework because predictions for optimal harvest assume an accurate assessment of the state of horseshoe crabs and red knots at each time step. It is possible that estimates of total abundance from the composite index scaled to VA Tech trawl survey abundance estimates would be underestimates of horseshoe crab abundance, which we would expect to lead to recommending more conservative harvest packages than what would actually be necessary to sustain the horseshoe crab population and ensure enough resources are available to red knots. Further, if the composite index method is substituted for the VA Tech trawl survey long term, the Commission will need to coordinate with the U.S. Fish and Wildlife Service to determine if the ARM framework is still functioning as intended, and if further evaluation is needed in light of the federal listing of the red knot (*Calidris canutus rufa*) under the Endangered Species Act.

C. Mark-Recapture Approach to Horseshoe Crab Abundance Estimation

Mark-recapture efforts for horseshoe crabs have been ongoing for many years. The U.S. Fish and Wildlife Service (USFWS) has been administering a horseshoe crab tagging program since 1999 through its Maryland Fisheries Resource Office. Objectives of the program included the estimation of horseshoe crab movement and migration and to provide data necessary for estimation of survival and mortality. Horseshoe crabs are tagged along the Atlantic coast by natural resource agencies and other researchers for various purposes and the information associated with tagged crabs is maintained in a database by the USFWS. The USFWS also receives reports of tagged crabs that are recaptured in fisheries independent surveys, commercial harvests, and by sightings reported by the public including the volunteer-based spawning surveys.

Although the tagging program has relatively large spatial and temporal coverage, only two studies have used tagging data to estimate abundance of horseshoe crabs in the Delaware Bay region: Smith et al. (2006) and Merritt (2015).

Summary of Smith et al. (2006)

Smith et al. (2006) conducted an intensive tagging study in 2003 with the objective of estimating the spawning population size of horseshoe crabs in Delaware Bay. Prior to peak spawning in 2003, crabs were collected by trawling vessels and tagged throughout Delaware Bay. Recaptured tags came from the Delaware Bay spawning survey. Two estimation techniques were employed: Chapman's modification of the Petersen estimator and an extension of a likelihood estimator by Borchers et al. (2002). Smith et al. (2006) also conducted radio telemetry on horseshoe crabs to evaluate the assumption that tagging does not affect spawning behavior and used the results from the radio telemetry study to adjust population estimates.

Smith et al. (2006) tagged a total of 12,489 males and 5,054 females prior to the peak spawning period of 2003. During the spawning survey, 22,051 males and 6,675 females were counted and an additional 45 males and 3 females were tagged. Male abundance was estimated and then the ratio of males:females was used to estimate female abundance. These abundance estimates were adjusted based on radio telemetry data to account for tagging effects on crab behavior and the final estimates of abundance were 13,730,000 (8,780,000 – 19,400,000; 95% CI) males and 6,250,000 (4,000,000 – 8,840,000) females in 2003.

Summary of Merritt (2015)

Merritt (2015) explored another approach to the analysis of mark-recapture data in order to estimate abundance of horseshoe crabs in the Delaware Bay region. Merritt (2015) used a hierarchical modeling approach within a Bayesian framework which had a state-space model component to describe capture history data with a model for the unobservable or partially observable state process and a model for the observation process. The state process consisted of a model for occasion-specific spawning probabilities which allowed crabs to spawn at various times throughout the season, and when animals were not spawning, they were unavailable for detection. This modeling effort used data from 2003 and 2004 because these years coincided with large, known numbers of tagged crabs in the system from the work of Smith et al. (2006).

Results from this modeling effort gave estimates of abundance that overlapped mark-recapture estimates from Smith et al. (2006) and estimates based on expansion of the VA Tech trawl catches from Hata and Hallerman (2009). However, modeled estimates of the number of marked crabs in the population were less than the number known to be marked from Smith et al. (2006). Merritt (2015) also conducted simulations to evaluate the effects of increasing tagging and recapture effort on the precision and relative bias of population estimates. The simulations generated capture histories for known numbers of tagged individuals, with a known population size, detection probability, and probabilities of spawning. Simulated increases in effort were found to increase the precision of estimates but the relative bias of the estimates also increased. These results suggest that although this framework for estimating horseshoe crab abundance shows promise, more work is needed in the model structure and estimation techniques before a mark-recapture approach such as this can be used for management decision making in the Delaware Bay region.

Recommendations:

- The ARM subcommittee recommends continuation of the Virginia Tech Bottom Trawl Survey in future years since it supports the ARM model, provides substantial data to the assessment of horseshoe crabs, and ensures that the ARM framework will function as intended.
- Additionally, the subcommittee supports the recommendations from the 2009 Horseshoe Crab Stock Assessment to estimate the proportion of the Delaware Bay population that is available in time and space within the survey area and to continue the work to assess the selectivity of gear used in the survey.

D. Red Knot Population Monitoring

The evaluation of the Red Knot population monitoring included 1) documentation of the mark-resight study design and sampling plan used to estimate stopover population size each year, 2) discussion of the study design and sampling plan with the Delaware and New Jersey shorebird monitoring teams, and 3) a discussion of mark-resight population estimates and aerial survey population indices. Here we review how historic population indices from aerial surveys informed the development of the ARM framework, the transition to mark-resight approaches to estimate stopover population size, and assess the current mark-resight monitoring program.

Annual monitoring of the Red Knot stopover population size is an important part of the harvest decision making framework because female crab harvest recommendations depend in part on Red Knot population size. The primary approach to monitoring Red Knot stopover populations prior to, and during the development of, the ARM framework was aerial surveys; these surveys have been conducted in Delaware Bay each year since at least 1986. ARM recommendations for female crab harvest are informed by Red Knot population monitoring through a utility function that includes a utility threshold determined by Red Knot abundance (McGowan et al. 2009). When Red Knot populations are below the abundance threshold, utility of female crab harvest is set to zero, otherwise the utility of female crab harvest is set to unity, i.e., maximum utility. (There is another utility function for female crab harvest that sets utility to unity if the crab population is above a crab abundance threshold.) The Red Knot abundance threshold in the utility function was initially set at 45,000 knots in reference to historic aerial survey data from Delaware Bay (one half of historic peak counts in aerial surveys).

Mark-resight methods to monitor stopover populations were not available when ARM framework was under development and when the Red Knot abundance thresholds determined. However, during ARM development there was agreement within the Delaware Bay Ecosystem Technical Committee (DBETC) to pursue a mark-recapture/resight approach to population monitoring to replace the aerial survey. Mark-recapture/resight methods provide advantages over aerial surveys because they account for turnover in the population and probability of detection; of course, mark-resight population estimates are larger than peak counts from aerial surveys for these reasons.

Mark-resight methods for monitoring stopover populations were developed shortly after the ARM framework was complete. With the transition to mark-resight methods, the ARM Subcommittee agreed to adjust the utility threshold because the mark-resight estimates are larger than aerial survey indices for the reasons stated above. The subcommittee decide the adjustment to the Red Knot abundance threshold should be commensurate with the best available data on the ratio of mark-resight estimates and aerial survey peak counts. After discussing available data from 2011-2013, the ARM Subcommittee recommended in September 2013 to use the ratio of mark-resight and aerial survey indices from the years 2012-2013 to adjust the utility threshold. This recommendation was presented to the DBETC in October 2013 and subsequently approved by the Board.

In 2015, some members of the ARM Subcommittee and the TCs raised concerns about the higher than usual ratio of mark-resight estimate to aerial survey peak count; the mark-resight analysis suggested that more knots stopped in Delaware Bay in 2015 than in previous years, whereas the aerial survey indicated no change. In response, the ARM Subcommittee conducted additional analyses in 2015 to evaluate some possible causes for the higher-than-usual ratio in 2015, including the fact that the 2015 resighting effort was inadvertently skewed in time and space. The additional analyses evaluated some of the assumptions of the mark-resight model, and indicated that any bias in the 2015 mark-resight estimate from the resighting data being skewed in time and space would lead to under-estimating, not over-estimating, the stopover population size. There was no evaluation of the assumptions related to the aerial survey data that may have led to an underestimate.

To address any issues related to resighting data collection, details of the mark-resight study design and sampling plan were documented in 2016 (Appendix). The study design and sampling plan were reviewed by Red Knot monitoring teams from Delaware and New Jersey and discussed during a conference call in April 2016. No new protocols were implemented as a result of this review, but teams standardized their efforts to collect data in a way that is consistent with the mark-resight model of the data.

There continues to be disagreement among ARM Subcommittee members about the cause of discrepancy between aerial survey data and mark-resight estimates of stopover population size, especially in 2015. The mark-resight model estimates the number of birds that use the sampled beaches in Delaware Bay each year (i.e., the "stopover population size" or "superpopulation", N^*). This estimate accounts for turnover in the population during the migration season and probability of detection of marked birds during resighting surveys. Therefore, estimated superpopulation size will always be greater than counts ("snapshots") from an aerial survey on any given day. The primary reason for the discrepancy between the superpopulation estimate (N^*) and the peak count from aerial surveys (C) is population turnover.

The mark-resight model also produces time-specific population estimates (N_t) at 8-10 points during the season (depending on the amount of data available), and while not directly comparable to aerial surveys, it may be instructive to explore the discrepancy between these time-specific estimates and aerial surveys. The mark-resight data are aggregated before analysis into 3-day time periods, the length of time required to survey all beaches in the bay (Appendix). The time-specific estimates (N_t) therefore are for the number of knots in the bay during a 3-day period, whereas the aerial surveys are completed in one day and represent the number of birds present on the day of the survey. From 2011-2015 there were 1-3 aerial surveys each year. The difference (D) between peak mark-resight estimate (N_t) and peak aerial count (C) each year, expressed as a fraction of the time-specific mark-resight estimate (N_t), has ranged from 12% (2012) to 50% (2011) ($D = [\{N_t - C\}/N_t]*100$). The large discrepancy in 2011 may have been due to extenuating circumstances (observer illness during the survey); the second largest discrepancy was 36% (2015). The median discrepancy (D) during 2011-2015 was 25%.

The assumptions of the mark-resight method are described in detail in the Appendix. One set of assumptions is that the rates of arrival, stopover persistence, and resighting are the same for all marked and unmarked individuals. Heterogeneity in resighting probability can cause bias in parameter estimates (Appendix). The study design and sampling plan (Appendix) has many aspects that attempt to meet the assumption of homogeneity in resighting probability (e.g., even sampling of the study area). Effects of heterogeneity of stopover persistence on parameter estimates is not well known. Some heterogeneity of stopover persistence may occur from data aggregation into 3-day periods for analysis. The average stopover duration in Delaware Bay is much longer than three days, however, so heterogeneity in stopover persistence from data aggregation should be small. Heterogeneity in stopover persistence may also occur from population structure and stopover-age effects, where stopover age is the amount of time since arrival to the stopover. There is some evidence that age-related variation in persistence does not affect parameter estimates when the amount of variation is small to moderate. Nevertheless, effects of heterogeneity in rate parameters from stopover age and population structure require additional research. See the Appendix for a complete description of these and other assumptions of the mark-resight model.

The aerial surveys in Delaware Bay do not include corrections for bias of any sort. The surveyed area is not drawn from a sampling frame and the estimate is not extrapolated to any unsurveyed area. To the extent possible, observers attempt to be consistent in the methodology and timing to reduce errors of estimation. Nevertheless estimation errors may occur as a result of 1) imperfect detection of birds, 2) availability of birds, and 3) counting errors. Counting large flocks of birds from the air is a difficult task and imperfect detection may result from poor visibility, inclement weather, identification, bird behavior, etc. Surveys are generally conducted only in good weather conditions, but the Delaware Bay aerial survey protocol does not estimate probability of detection and it is difficult to assess the magnitude of detection errors, which result in the counts being too low by some unknown amount. Another error of estimation is related to "availability"; birds that are not in view of the aircraft are not available to be detected. The aerial survey covers most bay beaches used by knots but does not include the Atlantic coast of New Jersey (Niles et al. 2009), managed wetlands, and intertidal marshes; some birds use managed wetlands in Delaware (Niles et al. 2008) and marshes at high tide (Burger et al. 1997). Observers make efforts to cover as much suitable habitat as possible during the aerial survey and be consistent from year to year, but it is impossible to survey all habitats and it seems that some fraction of birds in the bay are not available to be counted. The aerial survey estimate may be biased low due to availability but it is difficult to determine the magnitude of this error. Counting error is another type of estimation error in the aerial survey. Counting errors may be over- or under-estimates but there is ample evidence in the literature that observers tend to under-estimate the size of large flocks of birds (Smith and Francis 2010). Smith and Francis (2010) conducted simulation experiments with experienced observers and concluded that counting errors may result in population estimates that are approximately 25% too low, and that the magnitude of under-counts increased with flock size. It is perhaps coincidence that the median discrepancy between aerial surveys and mark-resight estimates was 25%, but the implications of under-counting error should be acknowledged in an evaluation of aerial surveys and mark-resight estimates. When all sources of estimation error that are possible with aerial surveys – imperfect detection, availability bias, and counting error – are considered, almost all of which result in under-estimates, the discrepancy between aerial survey data and mark-resight estimates may not be difficult to reconcile.

Recommendations:

- At this time, mark-recapture is not a viable option for estimating horseshoe crab abundance within the ARM Framework and therefore it should not be incorporated into the model but it should continue to be developed for future consideration.
- The ARM subcommittee recommends continuation of the mark-resight methodology to estimate the Red Knot stopover population size. The continued methodology should

include the standardized resighting effort outlined in 2016 (Appendix A) in order to model abundance and turnover of birds as accurately as possible.

E. Incorporation of Biomedical Data into the ARM Framework

The ARM Subcommittee discussed the importance of capturing biomedical collection mortality data in the ARM Framework given its lack of inclusion in the initial set up of the ARM Framework through Addendum VII in 2012. In deliberating how best to incorporate this information, the ARM Subcommittee developed 5 options to took different approaches to either explicitly treating biomedical bled mortality as a model input or as a variable in adjusting the current harvest packages. Details on all of the options considered for inclusion in the ARM Framework are included in appendix B. Below is the ARM Subcommittee's recommended preferred option as well as the secondary option considered.

<u>*Preferred Option*</u>: *Adjust harvest packages to account for biomedical mortality of females.*

Mortality associated with biomedical activities due to capture, handling, or post-bleeding stress is considered to be a form of harvest, and thus is incorporated into the harvest quota. In this option, the allocation of the harvest quota among biomedical and bait sources of mortality is left to the Board to consider. The set of harvest packages will be adjusted in recognition that biomedical activities cause mortality of females in the Delaware Bay population.

Adjustment of packages will occur during the 'setup phase' and not during the 'iterative phase'. As such, the packages will be adjusted only during double loop review, which occurs about every 4 to 6 years. The allocation will use the most recent X year moving average of female mortality in Delaware Bay crabs due to biomedical activities. A moving average will be used to adhere to the confidentiality requirements. The number of years in the moving average (X) is proposed to be X=3 so that the average can be responsive to recent trends. All of the harvest packages will be adjusted by including the most recent moving average. The female quota for packages that had been previously male only (Packages 2 and 3) would be designated for biomedical activity only.

The optimization of the ARM decision model will be conducted as before except that the optimization will use the adjusted packages. After a harvest package is selected in a given year, the harvest quota will be allocated among the biomedical and bait sources of mortality. Allocation of harvest will proceed as follows: 1) the up-to-date moving average of mortality of Delaware Bay crabs due to biomedical activities will be subtracted from the quota and 2) the remainder will be allocated for bait harvest. Note that the female quota for Packages 2 and 3 are stipulated for biomedical activity only; thus, there would be no allocation of females for bait under Packages 2 and 3. Current methods would be used to allocate bait harvest among states.

In this option, harvest regardless of source will be accounted for properly in accordance with the ARM Framework. Allocation of bait industry harvest among states would use current methodology. The Management Board would not set a limit on the number of horseshoe crabs that can be killed on an annual basis by the biomedical industry as long as mortality from biomedical activities alone does not exceed the total sex-specific harvest quota. Data confidentiality will be adhered to by using a moving average.

For example, in this option (Table 1), harvest package 3 of 500,000 male crabs only would become 464,000 male crabs only for bait harvest and 36,000 males plus 18,000 females for biomedical harvest. See table below for changes in the current harvest packages under this option with a theoretical biomedical harvest.

Table 1. Comparison of Current Harvest Packages to modified Harvest Packages under the Preferred Option

Current Harvest Packages			Preferred Option Harvest Packages			
Harvest Package	Bait Harvest		Bait Harvest		Biomedical Mortality	
	Males	Females	Males	Females	Males	Females
1	0	0	0	0	36,000	18,000
2	250,000	0	214,000	0	36,000	18,000
3	500,000	0	464,000	0	36,000	18,000
4	280,000	140,000	244,000	122,000	36,000	18,000
5	420,000	210,000	384,000	192,000	36,000	18,000

Secondary Option: Account for biomedical harvest in the population dynamics equations of the ARM framework

One approach to addressing the biomedical industry's take would be to incorporate it into the population dynamics equations for adult crabs as an additional mortality factor. Currently the predicted future abundance of adults is a function of current abundance of juveniles that transition directly to breeding adults (skipping the primiparous stage), plus the number of primaparus individuals that survive the year and become adults, plus the number of current adults that survive the year with the number harvested for bait explicitly subtracted. Abundance projections are calculated for each sex separately:

$$N^{af}_{t+1} = (((N^{j}_{t} \times T^{ja}_{t}) + (N^{p}_{t} \times S^{p}_{t})) \times p) + (N^{af}_{t} – H^{f}_{t}) \times S^{af}_{t}$$

$$N^{am}_{t+1} = (((N^{j}_{t} \times T^{ja}_{t}) + (N^{p}_{t} \times S^{p}_{t})) \times (1\text{-}p)) + (N^{am}_{t} – H^{m}_{t}) \times S^{am}_{t}$$

To incorporate biomedical take (bleeding induced mortality), an additional mortality could be added to account for the bled crabs die:

$$N^{af}_{t+1} = (((N^{j}_{t} \times T^{ja}_{t}) + (N^{p}_{t} \times S^{p}_{t})) \times p) + ((N^{af}_{t} – H^{f}_{t}) – (P_{b} \times N^{af}_{t} \times M_{b})) \times S^{af}_{t}$$

$$N^{am}_{t+1} = (((N^{j}_{t} \times T^{ja}_{t}) + (N^{p}_{t} \times S^{p}_{t})) \times (1\text{-}p)) + ((N^{am}_{t} – H^{m}_{t} – (P_{b} \times N^{amf}_{t} \times M_{b}))) \times S^{am}_{t}$$

Where P_b is the proportion of the population bled and M_b is the mortality rate for bled crabs. This approach would assume that the P_b and M_b are more or less constant overtime and equivalent for both sexes. If data were available, the model could be made sex specific, relaxing the sex equivalency assumption.

Recommendations:

- The ARM subcommittee recommends the preferred option to account for biomedical bled mortality in the annual harvest specifications and modifies current harvest packages.
- As a secondary option, the ARM Subcommittee outlined an approach for incorporating biomedical bled mortality in the ARM Framework without modifications to the harvest packages

Review Item #2: *Harvest rates and specifications: evaluate the harvest of the Delaware Bay states relative to the quotas, as well as the harvest packages, e.g. 500K individual (400K males, 100K females) etc. The ARM subcommittee agreed that harvest and harvest rates should be reconsidered relative to the harvest packages outlined in Addendum VII.*

The ARM Subcommittee considered a suite of alternative harvest packages (see appendix C) to address interest from the Board in allowing female horseshoe crab harvest for the bait industry. In developing different harvest packages, the ARM Subcommittee determined that currently set thresholds for horseshoe crab abundance and the red knot stopover population dictate which harvest packages are selected. In finding that the current thresholds should not be adjusted or changed, the ARM Subcommittee recommended not to include alternative harvest packages in the ARM Framework. A detail summary of the evaluation and consideration of these alternative harvest packages is included in Appendix C.

Recommendation:

- The ARM Subcommittee does not recommend adding new harvest packages to the ARM Framework.

Review Item #3: Revisit objective function: assess the structure of the objective function, with questions such as: Are the thresholds set at the correct level? Is a threshold approach still the most appropriate?

Evaluation:

A. Discussion of Changing the Order of Red Knots and Horseshoe Crabs in the Objective Statement

The current objective statement that describes the management goals of the ARM Framework is as follows:

Manage harvest of horseshoe crabs in the Delaware Bay to maximize harvest but also to maintain ecosystem integrity and provide adequate stopover habitat for migrating shorebirds.

The group discussed switching the order of red knots and horseshoe crabs in the objective statement. A switch would imply the decision problem was one of red knot recovery and not horseshoe crab management. Given that the ASMFC management board is the decision maker and only has jurisdiction over horseshoe crab harvest, this change was not appropriate. Red knot recovery decisions are best handled with the recovery plan being developed for this sub-species by the USFWS. The original statement was carefully worded through collaborative efforts of the Horseshoe Crab and Shorebird Technical Committees and the group felt that editing this statement was beyond the scope of a short term review and unnecessary at this time.

Recommendation:

- Changing the order of red knots and horseshoe crabs in the objective statement is not recommended as it implies that the problem is one of red knot recovery rather than horseshoe crab management.

B. Discussion of Reward and Utility Functions

The group evaluated the removal of sex ratio constraint on utility of male crab harvest and the removal of the (2×) multiplier on utility of female crab harvest in the total reward function used for optimization. This was initially put in the model to reflect that the market values females twice as much as it does males.

Recommendations:

- Because the (2x) multiplier of utility of female crab harvest in the reward function reflects the market value of female crabs over males, it is recommended that this be left in the model.

C. Discussion of Utility Function for Female Horseshoe Crab Harvest (knife-edge vs sloped)

The group discussed the recommendation from the 2009 peer review of the ARM framework to evaluate how the knife-edge utility function for female crab harvest affects results compared to a sloped function. Dave Smith provided the group with summary comments on the results similar analysis he had completed on this topic, highlighting that little to no difference is seen between the two approaches. Given that there is little difference between the a more sloped function vs knife-edge, and no biological or ecological reasoning for changing the current knife-edge approach, the group was in agreement with maintaining the current knife-edge form for the utility function.

Recommendations:

- No change from current knife-edge utility function to a sloped function.

D. Discussion of Horseshoe Crab Sex Ratio Constraint on Utility of Male Horseshoe Crab Harvest

The sex ratio of horseshoe crabs was originally incorporated in two places with the ARM: 1) within the population dynamics model for horseshoe crab; and 2) within the utility function for when male harvest of horseshoe crabs would have value. If the observed sex ratio became skewed toward females due to excessive harvest of male crabs, the productivity of females would become compromised as there would not be enough males to fertilize all the eggs of the female crabs. This effect is accounted for within the horseshoe crab population dynamics model and if the sex ratio were skewed to such a degree that the population would experience a decline, the optimization would suggest more restricted harvest of male crabs or a complete moratorium on both sexes. Thus, inclusion of the sex ratio constraint in the utility function appears redundant and model system states were conducted to evaluate which supported this notion. There was little difference in recommended harvest packages with or without the sex ratio constraint in the utility function.

Recommendations:

- The ARM Subcommittee is recommending the removal of the sex ratio constraint from the utility function because it is conceptually redundant with aspects of the crab population dynamics model.

Literature Cited

Atlantic States Marine Fisheries Commission (ASMFC). 2009a. Horseshoe Crab Stock Assessment for Peer Review, Stock Assessment Report No. 09-02 (Supplement A) of the Atlantic States Marine Fisheries Commission. Washington D.C. 122pp.

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

Borchers, D. L., S. T. Buckland, and W. Zucchini. 2002. Estimating animal abundance: closed populations (Vol. 13). Springer Science & Business Media.

Burger, J., L. Niles, and K. E. Clark. 1997. Importance of beach, mudflat, and marsh habitats to migrant shorebirds on Delaware Bay. Biological Conservation 79:283-292.

Collie, J. S., and M.P. Sissenwine. 1983. Estimating population size from relative abundance data measured with error. Canadian Journal of Fisheries and Aquatic Sciences, 40(11): 1871-1879.

Hata, D., and E. Hallerman, E. 2009. Evaluation of the coastal horseshoe crab trawl survey for estimating juvenile recruitment and mortality: Supplemental report to the Atlantic States Marine Fisheries Commission Horseshoe Crab Technical Committee. Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA.

McGowan, et al. 2009. A Framework for Adaptive Management of Horseshoe Crab Harvest in the Delaware Bay Constrained by Red Knot Conservation. Stock Assessment Report No. 09-02 (Supplement B). Atlantic States Marine Fisheries Commission.

Merritt, E. M. 2015. Evaluating Methods for Estimating Delaware Bay Limulus polyphemus Abundance (Doctoral dissertation, Auburn University).

Niles et al. 2008. Studies in Avian Biology No. 36.

Niles et al. 2009. Bioscience.

Smith, D.R., Millard, M.J. and Eyler, S., 2006. Abundance of adult horseshoe crabs (Limulus polylphemus) in Delaware Bay estimated from a bay-wide mark-recapture study. Fishery Bulletin, 104(3): 456-464.

Smith, P and C. Francis 2010. Environment Canada's Monitoring of Red Knots in South America. Report to the Environment Canada Avian Monitoring Review.

Appendix. A

Study Design Guidelines for Mark-resight Investigations of Red Knots in Delaware Bay

J. Lyons (jelyons@usgs.gov)

4/25/2016

Introduction

Mark-recapture/resight data from migration areas can be used to estimate passage population size and parameters related to migration ecology (Nichols 1996). The Jolly-Seber mark-recapture model for open populations (Jolly 1965, Seber 1965) is appropriate for migration studies because a stopover area can be viewed as an open, "flow-through" system. Estimation often focuses on the total number of individuals going through the system in a relatively short period of time.

When used at migration areas, the Jolly-Seber (JS) model has time-specific (i.e., specific to sampling occasion) parameters representing 1) probability of arrival to the study area, 2) probability of stopover persistence, 3) probability of being sighted during a sampling occasion, and 4) overall passage population size ("superpopulation"). Stopover persistence is the probability that a bird present in the study area at sample time t is present in the study area at time $t + 1$ (the "survival" parameter in other applications of the JS model).

At Delaware Bay, our application of the JS model relies on two types of data: repeated observations of individually marked birds ("resights"), and counts of marked and unmarked birds ("marked ratio samples"; Fig. 1). Resighting data are collected nearly every day during migration. Because it is not possible to sample the entire study area every day, the data are aggregated for analysis into 3-day periods, the time necessary to sample all parts of the study area. The 3-day periods become the "sampling occasions" in the mark-resight analysis.

The resightings of individually marked (flagged) birds are used to create encounter histories describing when individuals were observed within the season. From these encounter histories we can estimate the total number of flagged birds (detected and not detected) using the study area (M^*). The counts of marked and unmarked birds are used to estimate the proportion (π) of the population that is individually marked (flagged). Finally, the estimated number of flagged birds is adjusted upward using the estimated marked proportion, resulting in an estimate of total passage population size or superpopulation ($N^* = M^*/\pi$; Fig. 1; see Lyons et al. 2016).

At Delaware Bay, the main objective of the analysis is to estimate passage population size each year, a key parameter in the Delaware Bay adaptive management program for horseshoe crab harvest. To do this we analyze the data with a single site, single season (year) framework. In this single-season analysis, the parameters of the model – and model assumptions – are interpreted slightly differently than if the same data were used in a multi-season (year) analysis to estimate apparent annual survival or other parameters (e.g., McGowan et al. 2011).

Here we 1) review assumptions of the JS model in the context of a single-season investigation of migration, 2) review important study design considerations when estimating population size, and 3) recommend sampling plans to collect data in a way that is consistent with the model and assumptions.

Model Assumptions

To improve study designs and sampling plans for mark-resight investigations at migration areas, it is important to understand the assumptions of the JS model, and the direction of any bias that may result from violations of assumptions. In some cases, we can modify the study design and sampling plan to minimize violations of model assumptions, and in other cases we can modify the model to adequately reflect the data and relax model assumptions (i.e., accommodate sources of variation in the data).

Homogeneity of rate parameters.—One assumption of the JS model is homogeneity of rate parameters for all marked and unmarked individuals. The rate parameters of the JS model are probability of arrival to the stopover, probability of stopover persistence, and probability of resighting. The assumption of homogeneity of rates implies that the same rate parameters govern the arrival, persistence, and resighting of all marked and unmarked individuals.

As noted above, the estimation of M^* is based on the resightings of marked birds encountered at each sampling occasion. Observations of unmarked birds are not used in this part of the inference process. Heterogeneity in resighting probability, in which different marked birds present during the sampling occasions have different probabilities of being resighted, can cause bias in parameter estimates (Williams et al. 2002). "Trap response" refers to the situation in which a bird's previous detection history (usually whether it has been seen before or not) influences its subsequent probability of being resighted. If birds exhibit a "trap-happy" response, in which previously detected birds are resighted repeatedly, marked population size estimates will be negatively biased; if birds exhibit a "trap-shy" response, marked population size estimates will be positively biased (Williams et al. 2002). Trap response may seem unlikely in a mark-resight study because animals are not physically captured. However, uneven sampling of the study area may result in a form of heterogeneity and/or trap response of resighting probability. For example, if certain sites in the study area are visited more often than others, the same birds may be resighted in a pattern that mimics either heterogeneity or a trap-happy response. Finally, the legibility of the alphanumeric code may be a function of how much ink remains in the engraving. Ink is lost from the engraved leg flags over time (years). Flags that were applied many years ago may not be as legible or readable as flags applied in recent years, creating heterogeneity in resighting probability. If marks become completely illegible, those birds should be treated as unmarked. Birds with illegible flags do not appear in the resighting statistics, and they should be counted as unmarked when tallying the counts of marked and unmarked birds for estimation of π.

The above assumptions about detection probability apply to resightings of individual marked birds. The special counts used to estimate marked to unmarked ratios, π, are typically different than the surveys used to obtain detection histories of marked birds. These counts do not require individual identification information for marked birds and usually entail special counts during surveys designed to record marked bird identifications. Estimation of π requires the assumption that marked and unmarked birds have equal probabilities of being detected in these special counts. Trap response would occur if marked birds showed different detection probabilities than unmarked, but this sort of response seems unlikely in such counts. Finally, we note that detection probabilities for marked birds in the two types of surveys, those used to estimate marked to unmarked ratios, and those used to estimate M^*, need not be the same.

Effects of heterogeneity in stopover persistence on estimates of persistence and population size have not been thoroughly investigated (Williams et al. 2002). Heterogeneity in stopover persistence may result from population structure (e.g., different stopover dynamics for age classes or migratory subpopulations), and stopover-age effects, where stopover-age is measured by length of time at the stopover. In a simulation study of age-related variation in survival probability, Manly (1970) found that the JS model could be reliably used when there is small to moderate variation in survival (persistence) probability.

Some amount of heterogeneity in stopover persistence may result from aggregating data into sampling occasions for analysis, e.g., the 3-day sampling occasions used in Delaware Bay. For example, individual birds observed on day 3 of the sampling occasion may have a greater probability of remaining until the next sampling occasion than birds observed on day 1. However, because the average stopover duration of knots in Delaware Bay is much greater than 3 days, heterogeneity in stopover persistence resulting from data aggregation should be small. Hargrove and Borland (1994) found that effects aggregating data for sampling occasions did not produce bias in population parameters when survival is high within the pooled periods.

Effects of heterogeneity of rate parameters resulting from age and population structure require additional research. We plan to explore models that accommodate age-related variation in stopover persistence as part of the ongoing review of monitoring data for the Adaptive Resource Management Working Group for Delaware Bay. In addition, it may be possible to model stopover persistence as a function of boreal-wintering area of marked birds using observations away from Delaware Bay.

Marks are not lost or overlooked, and are recorded correctly.—Birds are marked with a leg flag (Clark et al. 2005), which is attached using epoxy and is not expected to fall off over time. Furthermore, loss of flags is not expected to impact population size estimates because the JS model currently implemented at Delaware Bay is a single-season model (i.e., loss of flags during the approximately 15-day stopover may be minimal).

Incorrect recording of alphanumeric combinations, however, may impact parameter estimates. Using the centralized database of capture and banding data (bandedbirds.org), alphanumeric combinations that have not been deployed in the field are removed before analysis. Some errors of recording are thus handled as part of data management. However, it is not possible to identify instances in which alphanumeric codes are incorrectly recorded as codes that actually have been deployed (i.e. "false-positives"). The rate of false positive identifications and impacts on parameter estimates requires additional research.

A form of "flag loss" may result as the ink in engraved leg flags is lost over time or the alphanumeric code otherwise becomes unreadable; this type of flag loss may be an important consideration of multi-year studies of annual survival and other parameters, but is not expected to impact passage population size estimates in single-season investigations if such flags are properly treated in analysis. Either birds with such flags should be counted as “unmarked” in the surveys for marked to unmarked ratios, or if this is too difficult (requires too much extra time), then the ratio of unreadable to readable flags in the detection history sampling can be used to adjust the marked to unmarked ratio.

Sampling is instantaneous.—This assumption is related to the assumption of homogeneous survival (persistence) probability. Strictly speaking, the assumption of instantaneous sampling is rarely met in practice. The interval between sampling occasions is typically long relative to the duration of the sampling occasion, however. In a simulation study of sampling occasions created from pooling data, Hargrove and Borland (1994) found that estimates of population sizes were acceptable because bias was small.

Permanent emigration.—Emigration from the study area is expected to be permanent. Temporary emigration will not bias estimates of passage population size if it is a completely random process (Kendall et al. 1997). That is, birds not available for detection (temporary emigrants) at one sampling occasion are no more or less likely to be available for detection at the next sampling occasion than birds that are currently available.

Independence of fates with respect to rate parameters.—This assumption may be violated if birds migrate in pairs, family groups, or other associations that remove independence of fates with respect to arrival, persistence, and resighting. We are not aware of any evidence that shorebirds migrate in groups that would result in a violation of this assumption. If this assumption is violated, variance estimates will be negatively biased resulting in confidence intervals that do not accurately reflect uncertainty in parameter estimates, but such a violation will not create bias in population estimates. Variance estimates can be adjusted with quasi-likelihood methods to accurately reflect uncertainty in parameter estimates.

Marked ratio data are representative of the population.—Scan samples of flocks of birds are used to estimate the proportion of the population with marks; in each scan sample, the observer records the number of marked birds and the number of birds checked for marks. Care should be taken to insure that the samples are representative of the flocks under study and the population as a whole. A field protocol (see appendix) has been developed to randomly select birds to be scanned and avoid bias in the data collection. Sampling throughout the season is also important to maintain a representative sample. Because birds marked with color band combinations (whether individually- or batch-marked) are not included in the data used to create encounter histories and estimate the size of the flagged population, we recommend that birds with color band combinations are not counted as “marked” during scan samples; these birds should be counted among those checked for marks but not included in the tally of marked (i.e., flagged) birds.

Study Design Considerations

When designing a mark-resight study for estimating abundance at a migration area, it is important to define the geographic boundary of the study area and the beginning and end of migration (i.e., define spatial and temporal extent of the open population).

Spatial sampling

The study area can be considered a collection of sites (beaches, shoreline segments, etc.). To reduce heterogeneity in rate parameters, it is essential that the sites are sampled at each sampling occasion. In some migration studies, each day of the migration is a sampling occasion, and resighting observations are made throughout the study area each day. When it is not possible to sample all sites in the study area in one day – when the study area is too large to sample entirely in one day, for example – it becomes necessary to change the sampling occasion from one day to a period that allows all sites to be sampled. If 3 days are required to complete a circuit of all sites, for example, then a 3-day period becomes the "sampling occasion", and all data for the 3 days are aggregated. Multiple observations of the same individual bird are lumped into one observation (detected) for the 3- day period. To facilitate even sampling of all sites, it will be helpful to define site boundaries on a map or via written description. This way observers will know the area to be sampled on each visit.

> <u>Study design recommendation: Define the geographic boundaries of all sites to be sampled.</u>

Temporal sampling

There are two temporal aspects to consider for an effective study design to estimate population size. First, resighting surveys should be conducted at all sites during each sampling occasion (e.g., 3-day period). If it is not feasible to sample all sites every 3 days, the sampling occasion could be changed to include however many days are required, given logistical constraints, to complete a circuit of the sites. Second, sampling should begin when the first birds arrive and continue until the last birds depart the study area. If resighting surveys do not begin until after birds have arrived in the study area, the stopover population size estimate will not include any birds that arrived and left before sampling began.

> <u>Study design recommendation: Begin sampling when birds arrive and continue sampling occasions until birds depart the area.</u>

> <u>Study design recommendation: Complete a circuit of sites in the study area to collect resighting data at each sampling occasion (e.g., 3-day period).</u>

Marked Ratio Data

We use a scan sampling protocol to estimate the proportion of the population with marks (see Appendix). Lyons et al. (2016) used a simulation study to investigate sample size requirements and the impact on bias and precision from factors related to data collection protocols and characteristics of the population under study. The two factors related to data collection protocols were 1) number of birds per scan sample, and 2) number of scans per day; the two factors related to the population under study were 1) stopover population size, and 2) true proportion marked. Simulation results suggested that the bias of estimates was low in all scenarios and that precision was greatest when 5-10 scan samples per day were collected and each scan sample included 50 or more birds checked for marks.

These simulation results should be interpreted with caution however (Lyons et al. 2016) because the simulation investigated only situations with constant probability of arrival to the stopover area and constant probability of stopover persistence. In Delaware Bay, we have used a model with time-dependent probability of arrival and time-dependent stopover persistence as the most biologically plausible model. In this more general model with time-dependent parameters, larger sample sizes may be required.

Therefore, we suggest that field crews attempt to collect 10 scan samples per day and attempt to count 50 birds in each scan sample. If the birds fly off before 50 birds are checked, the ratio data can still be used; simply record the number of marked birds and the number checked for marks, as usual.

Scan samples of this size usually requires less than 2 minutes to complete. This sampling thus devotes approximately 3% of every hour of field time to scan samples and 97% to collecting repeated observations of marked individual birds. Scan samples can be conducted at the beginning of each resighting session and once per hour thereafter. In the case of small flocks (small enough to check every bird relatively quickly), it is not necessary to repeat scan samples once per hour. We also recommend that observers do not count birds with color band combinations as marked birds (only leg-flagged birds) when counting marked and unmarked birds.

> <u>Study design recommendation: A marked ratio scan sample should be collected at the beginning of each resighting session and once per hour during the session.</u>

Field and Logistical Constraints

Much of the data for mark-resight investigations in Delaware Bay are collected by volunteers. The same field crews also conduct capture and marking operations, ground and aerial surveys, and other research and monitoring activities. All field operations are subject to constraints of weather and logistics. These operations require substantial investments of time and energy.

The mark-resight study design recommendations provided here are merely suggestions and can be modified to make the data collection more feasible while maintaining data integrity. The principal investigator of the mark-resight study should periodically visit field operations to discuss implementation of the study design and any challenges to the data collection.

Acknowledgments

J. Nichols provided comments on a draft version and helpful discussions about mark-resight methods. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

Clark, N.A., S. Gillings, A.J. Baker, P.M. González, and R. Porter. 2005. The production and use of permanently inscribed leg flags for waders. Wader Study Group Bull. 108: 38–41.

Hargrove, J.W. and C.H. Borland. 1994. Pooled population parameter estimates from mark-recapture data. Biometrics 50:1129-1141.

Jolly, G.M. 1965. Explicit estimates from capture-recapture data with both death and immigration–stochastic model. Biometrika 52:225–247.

Kendall, W.L., J.D. Nichols, and J.E. Hines.1997. Estimating temporary emigration using capture-recapture data and Pollock's robust design. Ecology **78**, 563-578.

Lyons, J.E., W.L. Kendall, J.A. Royle, S.J. Converse, B.A. Andres, and J.B. Buchanan. 2016. Population size and stopover duration estimation using mark–resight data and Bayesian analysis of a superpopulation model. Biometrics 72:262-271.

Manly, B.F.J. 1970. A simulation study of animal population estimation using the capture-recapture method. Journal of Applied Ecology 7:13-39.

McGowan, C.P., Hines, J.E., Nichols, J.D., Lyons, J.E., Smith, D.R., Kalasz, K. S., et al. (2011). Demographic consequences of migratory stopover: linking red knot survival to horseshoe crab spawning and abundance. Ecosphere 2, article 69.

Nichols, J.D. 1996. Sources of variation in migratory movements of animal populations: Statistical inference and a selective review of empirical results for birds. Pages 147-197 in O.E. Rhodes, Jr., R.K. Chesser, and M.H. Smith (eds.), *Population Dynamics in Ecological Space and Time*. Chicago, Illinois: University of Chicago Press.

Seber, G.A.F. 1965. A note on the multiple-recapture census. Biometrika 52:249–259.

Williams, B.K., Nichols, J.D., and Conroy, M.J. (2002). *Analysis and Management of Animal Populations*. San Diego, California: Academic Press.

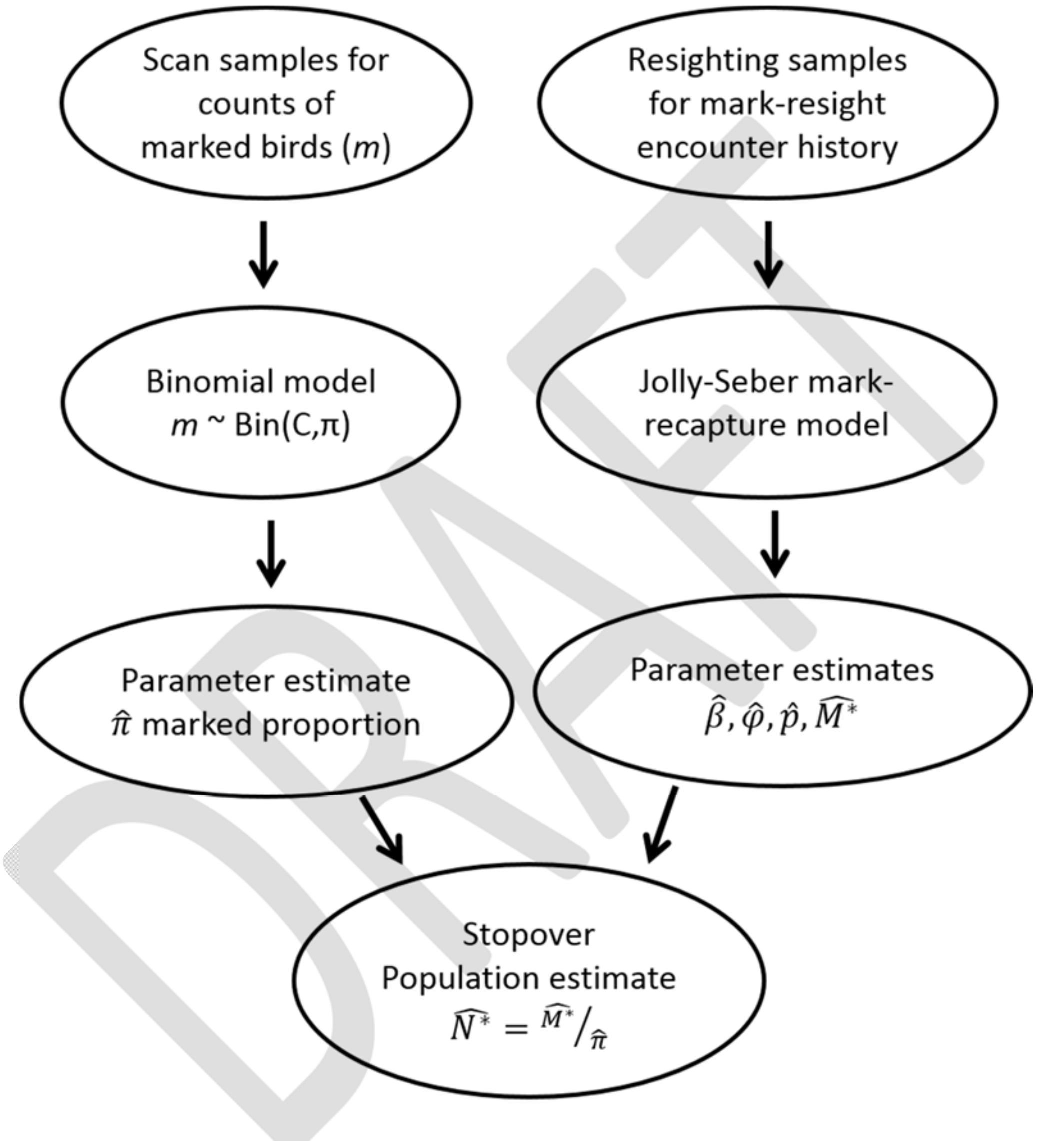

Figure 1. Flow chart for data collection and parameter estimation using mark-resight data to estimate stopover population size at migration areas. From Lyons et al. (2016).

Table 1. Dates for mark-resight sampling occasions in Delaware Bay.

Sample	Dates
1	<10 May
2	11-13 May
3	14-16 May
4	17-19 May
5	20-22 May
6	23-25 May
7	26-28 May
8	29-31 May
9	1-3 June

Appendix A.1

A Field Protocol to Estimate Marked Proportion in Mark-resight Studies

We use a scan sampling protocol (Martin and Bateson 1986) to record the ratio of marked to unmarked birds in all areas that are searched for flagged birds, with certain precautions to avoid bias in the scan samples.

For large flocks (e.g. >100 birds):

1. Determine the general area in front of the observer that is visually accessible (i.e. the area within which the birds can be viewed well enough to determine whether birds are marked or not). This is the "scan area" in front of the observer.
2. Visually divide the scan area into four equal segments and number them from one to four, e.g. left to right.
3. Using a table of random numbers between 1 and 4 (see below), randomly select a segment of the scan area.
4. Without looking through the scope, which might bias scan results if the observer begins the scan with a conspicuous (i.e. marked) bird, aim the scope at the selected segment.
5. Looking through the scope and beginning with a bird at the edge of the field of view, scan birds in the flock, and 1) tally the number of marked birds, and 2) tally the number of birds checked for marks. When a predetermined number of birds has been checked for marks, say 50 birds, record the number of birds with alphanumeric flag codes and the number of birds checked for flags. A hand-held tally counter may be helpful here.
6. If the flock flies off before the scan sample is complete (e.g., before you check 50 birds), the data are still useful. Record the number marked and the number checked, as usual.
7. Only those birds whose legs are visible are counted as checked for marks. In some cases, certain individual birds cannot be checked for marks (e.g., when roosting on one leg, with only one leg visible). If it is not possible to clearly determine whether or not a bird has an alphanumeric flag, the bird is not tallied in the total number checked for birds.
8. Only those birds with legible alphanumeric flags should be counted as marked birds.
    a. Birds that are marked with a combination of color bands only, without an alphanumeric flag, are not tallied as "marked" birds. Birds with color band combinations only are not counted as marked birds in this protocol because many color band combinations are not unique to the individual bird and therefore will not be part of the analysis using the resighting data; even birds that are marked with a unique combination of color bands are not included in the analysis with alphanumeric codes.
    b. Similarly, engraved flags that are illegible because they have lost ink (or are otherwise unreadable) should not be counted as marked; they should be counted as unmarked.

For small flocks (i.e., when it is possible to quickly check every bird present in the scan area):

1. Scan the entire flock for marks and recorded the number of birds checked for flags and the number of marked birds.
2. In the case of a small flock, it is unlikely that the observer will require more than one hour to record alphanumeric flags of individual marked birds, but in the event that the resighting session is longer than one hour, it is not necessary to conduct more than one scan-sample of the same small flock.

Random numbers table. Cut on dotted line and place in field notebook.

Random numbers table for use in the field to select birds for scan samples.

1	1	3	4	3	3	2	2	3	4
4	1	2	1	1	1	1	3	4	1
3	2	1	1	3	4	4	3	3	2
2	3	4	4	3	1	1	1	4	4
3	1	3	2	2	1	4	3	2	4
3	2	3	2	1	4	2	1	3	1
4	2	1	3	3	4	2	2	3	4
4	4	1	2	1	2	3	3	1	1
3	1	1	1	1	1	1	1	4	1
1	1	4	1	2	3	4	2	4	4
4	2	3	2	2	2	4	4	3	3
1	2	2	4	4	4	1	3	3	2
3	4	3	3	2	3	2	2	3	3
3	2	2	3	2	1	4	1	1	1
2	1	1	1	1	3	1	2	2	1
3	4	2	4	4	4	1	4	4	4
4	2	2	4	4	3	2	1	1	3
2	3	1	4	3	1	2	2	4	2
4	2	3	3	3	1	1	4	1	3

Appendix B.

Incorporation of Biomedical Data into the ARM Framework Options

Option 1: Include biomedical in the harvest allocation of horseshoe crabs within the Delaware Bay region (apportion biomedical mortality within existing harvest packages).

This option requires the Horseshoe Crab Management Board to specify a limit on the mortality of Delaware Bay origin crabs attributable to biomedical industry as a byproduct of the bleeding process. This level could be chosen based on historical numbers (e.g. average number over some number of years) bled by the biomedical industry and the estimated total mortality from the bleeding process using an assumed mortality rate (e.g. 15% of bled crabs die). Alternatively, this limit could be equivalent to some proportion of the total Delaware Bay origin harvest as recommended by the ARM. Regardless of how the limit is chosen, this limit would then be subtracted proportionately from the allowable sex-specific bait harvest of horseshoe crabs recommended by the ARM Framework.

As an example, assume the Management Board decides to allow the biomedical industry 20% of the harvest recommended by the ARM Framework. If the ARM Framework specified an allowable harvest of 500,000 males and 0 females (harvest package #3), the total mortality attributed to the biomedical industry could not exceed 100,000 male crabs (females would not be permitted). Assuming a 15% mortality rate for bled crabs, the biomedical industry should bleed and release no more than 666,667 male crabs. As another example with the same 20% biomedical allowance, if the ARM Framework specified an allowable harvest of 280,000 males and 140,000 females (harvest package #4), the total mortality attributable to the biomedical industry could not exceed 56,000 males and 28,000 females. Again, with a 15% mortality rate for bled crabs, the biomedical industry should bleed and release no more than 373,333 male crabs and 186,667 female crabs.

The bait industry would receive the remainder of the ARM recommended harvest. In the examples above, the bait industry would receive 400,000 male crabs under harvest package #3 and 224,000 males and 112,000 females under package #4. This remaining allowable harvest could then be allocated among the four Delaware Bay region states in the same manner as is currently being done under Addendum VII of the horseshoe crab fishery management plan.

Advantages of this option:

- Explicitly accounts for the mortality attributable to the biomedical industry.
- The most straight forward option for precise implementation of ARM Framework recommendations for the total allowable mortality of horseshoe crabs by the two stakeholder groups exploiting the resource.
- Allocates bait industry harvest among states according to the same methodology that is currently being used.

Disadvantages of this option:

- Requires the Management Board to set some limit on the number of horseshoe crabs that can be killed on an annual basis by the biomedical industry. This is likely to be a contentious decision, in part due to implications for human health.
- Data confidentiality may be violated. Because there is only one biomedical company in the New England Region and only one company in the Southeast Region of horseshoe crab management, either of these companies will be able to determine what the other company bled because they could subtract their number of bled crabs and the allowable number of bled crabs from the

Delaware Bay Region from the coast wide total to determine what the other company bled. However, there would still be some uncertainty in what the other company bled because it would not be known if the companies in the Delaware Bay region reached their catch limit within a year.

- There is concern that when the ARM Framework recommends 0 female harvest that the biomedical companies would end up handling and sorting more total crabs in order to fill their needs through the bleeding of only male crabs. This could result in greater overall crab mortality, exceedance of the allowable biomedical harvest set by the board, and further reductions in the allowable bait harvest in future years.

Option 2: Account for biomedical harvest in the population dynamics equations of the ARM framework

One approach to addressing the biomedical industry's take would be to incorporate it into the population dynamics equations for adult crabs as an additional mortality factor. Currently the predicted future abundance of adults is a function of current abundance of juveniles that transition directly to breeding adults (skipping the primiparous stage), plus the number of primaparus individuals that survive the year and become adults, plus the number of current adults that survive the year with the number harvested for bait explicitly subtracted. Abundance projections are calculated for each sex separately:

$$N^{af}_{t+1} = (((N^{j}_{t} \times T^{ja}_{t}) + (N^{p}_{t} \times S^{p}_{t})) \times p) + (N^{af}_{t} - H^{f}_{t}) \times S^{af}_{t}$$

$$N^{am}_{t+1} = (((N^{j}_{t} \times T^{ja}_{t}) + (N^{p}_{t} \times S^{p}_{t})) \times (1-p)) + (N^{am}_{t} - H^{m}_{t}) \times S^{am}_{t}$$

To incorporate biomedical take (bleeding induced mortality), an additional mortality could be added to account for the bled crabs die:

$$N^{af}_{t+1} = (((N^{j}_{t} \times T^{ja}_{t}) + (N^{p}_{t} \times S^{p}_{t})) \times p) + ((N^{af}_{t} - H^{f}_{t}) - (P_{b} \times N^{af}_{t} \times M_{b})) \times S^{af}_{t}$$

$$N^{am}_{t+1} = (((N^{j}_{t} \times T^{ja}_{t}) + (N^{p}_{t} \times S^{p}_{t})) \times (1-p)) + ((N^{am}_{t} - H^{m}_{t} - (P_{b} \times N^{amf}_{t} \times M_{b}))) \times S^{am}_{t}$$

Where P_b is the proportion of the population bled and M_b is the mortality rate for bled crabs. This approach would assume that the P_b and M_b are more or less constant overtime and equivalent for both sexes. If data were available, the model could be made sex specific, relaxing the sex equivalency assumption.

Option 3: Adjust harvest packages to add biomedical to the existing bait allocations

Harvest packages could be adjusted to specify allotments to bait harvest and biomedical mortality. New harvest packages would be established that explicitly detail how many male and female crabs could be collected to bait (100% mortality) and how many collected for bleeding (15% mortality). To do this, an estimation of the mean collection rates by the biomedical industry from the last 5 years could be added as allowance to the existing harvest packages. For example: if mean collection rates for the biomedical industry were 100,000 females and 200,000 males the five current harvest packages would be:

$N_{hscf,i} + 100{,}000 \times M_b$ and $N_{hscm,i} + 200{,}000 \times M_b$

Where i indicates the specific harvest package. So harvest package 3, current 500,000 male only would be come 530,000 males and 15,000 females. Presumably these levels of take were already occurring in the DE Bay population and, while neither knots nor HSC have reached threshold levels to trigger female horseshoe crab harvest, both populations are exhibiting growing or stable populations.

Option 4: *Adjust harvest packages to account for biomedical mortality of females.*

Option 4 combines elements of Options 1 and 3 (above). As in both Options 1 and 3, mortality associated with biomedical activities due to capture, handling, or post-bleeding stress is considered to be a form of harvest, and thus is incorporated into the harvest quota. In Option 4, the allocation of the harvest quota among biomedical and bait sources of mortality is left to the Board to consider; this is a difference from Option 1. In Option 4, the set of harvest packages will be adjusted in recognition that biomedical activities cause mortality of females in the Delaware Bay population. However, in contrast to Option 3, the existing packages will be modified only for female quota and male quotas will be left in place.

Adjustment of packages will occur during the 'setup phase' and not during the 'iterative phase'. In other words, the packages will be adjusted only during double loop review, which occurs about every 4 to 6 years. The allocation will use the most recent X year moving average of female mortality in Delaware Bay crabs due to biomedical activities. A moving average will be used to adhere to the confidentiality requirements. The number of years in the moving average (X) is proposed to be X=3 so that the average can be responsive to recent trends. Packages 2 and 3 will be adjusted by including the most recent moving average. The male quota for all packages, the female quota for Packages 4 and 5, and the Package 1 (moratorium) for both species will not be adjusted. The female quota for packages that had been previously male only (Packages 2 and 3) would be designated for biomedical activity only.

The optimization of the ARM decision model will be conducted as before except that the optimization will use the adjusted packages. After a harvest package is selected in a given year, the harvest quota will be allocated among the biomedical and bait sources of mortality. Allocation of harvest will proceed as follows: 1) the up-to-date moving average of mortality of Delaware Bay crabs due to biomedical activities will be subtracted from the quota and 2) the remainder will be allocated for bait harvest. Note that the female quota for Packages 2 and 3 are stipulated for biomedical activity only; thus, there would be no allocation of females for bait under Packages 2 and 3. Current methods would be used to allocate bait harvest among states.

In this option, harvest regardless of source will be accounted for properly in accordance with the ARM Framework. Allocation of bait industry harvest among states would use current methodology. The Management Board will not be required to set a limit on the number of horseshoe crabs that can be killed on an annual basis by the biomedical industry as long as mortality from biomedical activities alone does not exceed the total sex-specific harvest quota. Data confidentiality will be adhered to by using a moving average.

Option 5: Reduce bait harvests to account for biomedical mortality within existing harvest packages using the 2:1 male to female offset

Under this option, biomedical harvest would not be capped, but bait harvests would be reduced to account for biomedical mortality. Using the sample numbers from Option 3, suppose the 3-year running average of biomedical mortality in the DE Bay region is 30,000 males and 15,000 females. Here's how that would affect bait harvests under each harvest package:

Package 1: Full bait moratorium on both sexes

Package 2: 250,000 males – 30,000 biomedical males – 30,000 due to biomedical females (2:1 offset) = 190,000 males and 0 females

Package 3: 500,000 males - 30,000 biomedical males – 30,000 due to biomedical females (2:1 offset) = 440,000 males and 0 females

Package 4: 280,000 males – 30,000 biomedical males and 140,000 females – 15,000 biomedical females = 250,000 males and 125,000 females

Package 5: 420,000 males – 30,000 biomedical males and 210,000 females – 15,000 biomedical females = 390,000 males and 195,000 females

Current methods would be used to allocate bait harvest among states.

Appendix C.

Development and Evaluation of New Harvest Packages allowing Bait Female Horseshoe Crab Harvest.

Evaluation:

In recent years, the ARM harvest package #3 (500,000 males harvest, no female harvest) has been selected, while there has been a combined quota of 661,000 crabs for the Delaware Bay States available under the ASMFC Horseshoe Crab FMP. Four alternative harvest packages were developed under the following conditions: 1) stressed population, 2) recovering population, 3) recovered population, and 4) recovered population; all set to harvest levels up to 661,000 crabs.

Alternative harvest package 1: Stressed Population

Understanding that a moratorium of harvest for a stressed population would have significant impact on the industry, the harvest mortality under alternative option #1 is set at a low level for each of the Delaware Bay States on male crabs.

Alternative package 1. Stressed Population

	Delaware Bay Origin HSC Quota		Total Quota	
State	**Male**	**Female**	**Male**	**Female**
Delaware	100,000	0		0
New Jersey	100,000	0		0
Maryland	150,000	0		0
Virginia	60,000	0		0

Alternative harvest package 2: Recovering Population

For option #2 (recovering population), female harvest is allowed but limited to predominately non-DE Bay female crabs and at a small harvest level. The proposal allows harvest of 1/3 of the non-DE Bay origin horseshoe crabs in Maryland and Virginia. The reduced female harvest is allowed by not allowing the harvest of females before July 1st and after July 1st they are not allowed to be harvested on spawning beaches in the Delaware Bay region.

Alternative package 2. Recovering Population

	Delaware Bay Origin HSC Quota		Total Quota	
State	**Male**	**Female**	**Male**	**Female**
Delaware	162,136	0	162,136	0
New Jersey	162,136	0	162,136	0
Maryland	141,112	0	197,996	28,442
Virginia	34,615	0	67,775	6,778

Alternative harvest package 3: Recovered Population (10% female harvest allowed)

Under Option #3, with a recovered population, 10% of the female population can be harvested but with the same season and location restrictions as Option #2. Under this option, Delaware and New Jersey would be allowed to harvest female horseshoe crabs, while Maryland and Virginia would as well, but at a reduced level than in option 2.

Alternative package 3. Recovered Population (10% female harvest allowed)

10% Female harvest	**Present Harvest Quota**		**Proposed Harvest Quota**	
State	**Male**	**Female**	**Male**	**Female**
Delaware	162,136	0	145,923	16,213
New Jersey	162,136	0	145,923	16,213
Maryland	255,980	0	230,382	25,598
Virginia	81,331	0	73,198	8,133

Alternative harvest package 4: Recovered Population (20% female harvest allowed)

Under Option #4, with a recovered population, 20% of the female population can be harvested but with the same season and location restrictions as Options #2 and #3.

Option 4. Recovered Population. 20% female harvest allowed.

20% Female harvest	**Present Harvest Quota**		**Proposed Harvest Quota**	
State	**Male**	**Female**	**Male**	**Female**
Delaware	162,136	0	129,709	32,427
New Jersey	162,136	0	129,709	32,427
Maryland	255,980	0	204,784	51,196
Virginia	81,331	0	65,070	16,261

The group discussed whether these options would require knowing if the population is stressed or recovering, and if so, how that status is determined since those qualifiers are not currently used in the ARM Framework. There is currently an assumption in the objective function of the ARM Framework that there is value for every additional male horseshoe crab harvested when it actually drives the market price down and there is no additional value. The group was in agreement that addressing the economic value of male crabs in the ARM Framework should be done and that current harvest package options of full moratorium and male only harvest should remain and be considered with alternative harvest packages.

The group reviewed the alternative harvest packages and noted that adding additional harvest packages or switching/replacing current harvest package options with new ones would not necessarily result in different harvest packages being selected. The reason for little change in the selection of harvest packages is due to the current threshold levels for female crab abundance and red knot abundance, not the diversity of harvest packages.

Proposed addition to option selected under Subsection E ("Incorporation of Biomedical Data into the ARM Framework") of the *Horseshoe Crab ARM Subcommittee Draft Recommendations of ARM Framework Review*

BACKGROUND

The 1998 Fishery Management Plan (FMP) states, "*Because both the number of horseshoe crabs captured per year and the reported mortality are low, the horseshoe crab fishery for biomedical use is not subject to the potential limitations contained in Section 4.2.1 and 4.2.2., subject to the following restrictions. States must issue a special permit, or other specific authorization, for harvests for biomedical purposes. Horseshoe crabs taken for biomedical purposes shall be returned to the same state or federal waters from which they were collected. If horseshoe crab mortality associated with collecting, shipping, handling, or use by the biomedical industry exceeds 57,500 horseshoe crabs per year, the Commission would reevaluate potential restrictions on horseshoe crab harvest by the biomedical industry.*"

Based on data in the annual FMP reviews, the 57,500-crab threshold has been exceeded each year since 2007, and the estimated contribution of biomedical collection to coastwide total (biomedical plus bait) mortality rose from about 6 percent in 2004 to about 12 percent in 2014. According to the FMP reviews, mortality from the biomedical harvests to date hit a high of 90,440 crabs in 2012, an increase of nearly 100 percent since reporting began in 2004. Further, these data are based on a mortality rate of 15 percent of the total biomedical harvest. As cited in the 2012 FMP review, the Technical Committee (TC) recommends using a range of values (5 to 30 percent) for estimating mortality, in order to include the known variances in conditions and situations that can occur over the geographical and temporal range of collecting and bleeding the horseshoe crabs.

In 2011, the TC and industry members developed Biomedical Best Management Practices (BMPs) in a document entitled "Horseshoe Crab Biomedical Ad-Hoc Working Group Report, October 3, 2011." The industry has voluntarily adopted these BMPs.

CONCLUSIONS AND RECOMMENDATIONS

Given the consistent exceedances of the mortality threshold, steady increases in biomedical harvest levels since reporting began, and uncertainty around the actual percent of biomedical crabs that die, action should be taken consistent with the FMP. The ARM Subcommittee recommend the following actions.

1. Incorporate biomedical mortality into the Adaptive Resource Management (ARM) process and methods that are used to set harvest quotas in the Delaware Bay Region.

2. Require each company to submit confidential data on its own levels of mortality at each stage (capture, transport, holding, bleeding, and condition at release).

3. Require each company to submit an annual report regarding its specific measures, practices, and safeguards to implement the 2011 Biomedical handling BMPs, and documentation that crabs are being returned to the same waters from which they were collected.

4. Urge the industry to fund additional research regarding post-release mortality rates and sublethal effects that could affect populations.

5. Periodically revisit the Biomedical handling BMPs and update as appropriate, informed by current data and research.