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Working towards healthy, self-sustaining populations for all Atlantic coast fish species or successful restoration well in progress by the year 2015

Terms of Reference Report for the Stock Assessment of Atlantic Coast Horseshoe Crab: A Proposed Framework

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The Atlantic States Marine Fisheries Commission thanks all of the individuals who contributed to this review of the ASMFC Horseshoe Crab Technical Committee's report "Stock Assessment of Atlantic Coast Horseshoe Crabs: A Proposed Framework". The Commission extends its appreciation to members of the Peer Review Panel that reviewed the framework and developed this report: Dr. Ruth Carmichael (University of Maine at Machias), Mr. Joe Grist (ASMFC), Dr. Robert Muller (Florida Fish and Wildlife Conservation Commission) and Mr. Rich Wong (Delaware Department of Natural Resources). The Commission appreciates their efforts evaluating the proposed stock assessment methodologies and in developing this Panel Report.

The Commission also thanks David Smith, Mike Millard, and Stew Michels of the ASMFC Horseshoe Crab Stock Assessment Subcommittee for their presentation of the Framework and for answering questions regarding the past and current efforts to conduct horseshoe crab stock assessments. Other members of the Horseshoe Crab Stock Assessment Subcommittee who contributed to the development of the Framework include Jim Berkson, Jeff Brust, and Tom O'Connell.

The Commission also thanks ASMFC staff members Brad Spear and Patrick Kilduff for coordinating the peer review and assisting with the preparation of this report.

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Terms of Reference Report for the Stock Assessment Framework of Atlantic Coast Horseshoe Crabs

The Panel noted and commended the work done in the last five years to implement improved fishery dependent and independent data collection programs.

The Panel determined that any stock assessment modeling approach will have limited ability to estimate population dynamics, stock biomass, and total and fishing mortality rates on any scale given the limited data available for horseshoe crabs. In this sense, adequacy of model function cannot be separated from quality of data available for the assessment. The most notable data deficiencies for the horseshoe crab stock assessment are the lack of accurate historical landings and fishery dependent size-sampling, the limited time series of a high quality index of horseshoe crab abundance, and that the majority of fishery independent data come from the Delaware Bay area. Due to their variability, some of these indices have very limited power to detect significant declines overtime. The previous horseshoe crab stock assessment was limited to trend analyses of multiple state and federal surveys and lacked a quantitative approach to estimating stock size, total mortality, and fishing mortality rate.

Terms of Reference

1. Evaluate adequacy of the proposed models, as well as current assessment work, for estimating population dynamics, stock biomass, and total and fishing mortality rates for horseshoe crabs as a coastwide stock.

The proposed framework for the stock assessment of Atlantic coast horseshoe crabs by the Horseshoe Crab Stock Assessment Subcommittee recommended a catch-survey method (CSA) as the population model for evaluation of management methods.

The Panel agreed that this model is capable of providing estimates of population dynamics, total and fishing mortality rates, and stock biomass when the proper data are available. Landings by stage and an adequate index time series are currently inadequate for use in a CSA model. The Panel agreed that the CSA approach is one of several desirable models that should be explored for long-term horseshoe crab population assessment planning. In the mean time, the Panel recommended that current trend, power, and meta analyses be continued until data are available for more advanced population analyses, with management following the precautionary approach.

The SAC framework also recommended that if the appropriate data were available, a surplus production model could be reserved as a potentially useful secondary 'check'.

The Panel recommended developing the surplus production model and a modified DeLury model (Rosenberg et al. 1990, Basson et al. 1996) as interim models until better data become available. The modified DeLury method (as opposed to surplus production model) is beneficial because it uses landings and surveys in numbers rather than biomass (Muller et al. 2002).

$$N_{t+1} = R_t / Z_t + (N_t - R_t / Z_t)\exp(-Z_t)$$

N_{t+1} is the number of fish at time $t+1$, R_t is the number of fish entering the exploited portion of the population at time t, Z_t is the total instantaneous mortality rate at time t, and N_t is the number of fish in the population at time t. This equation for the number of fish at time $t+1$ assumes continuous recruitment during time t, which implies that crabs of a given size may represent many ages. The predicted catch for a given sector or time is:

$$C_t = q \cdot E_t \cdot Nbar_t$$
$$Nbar_t = (R_t + (N_t - R_t / Z_t) * (1 - \exp(-Z_t) / Z_t)$$

$Nbar_t$ is the average number in the population at time, t. The model easily accommodates tuning indices. Horseshoe crab landings reported in numbers, although problematic, currently are available and expected to improve through time, while landings in biomass (weight) are not directly reported. Reported estimates of landed biomass are typically made by multiplying numbers of individuals landed by an assumed average weight per individual. Such conversions, however, have not been scientifically validated or calibrated, making landings in numbers rather than biomass more reliable inputs for models. The panel recognizes that the difficulties with landings data apply to all available fisheries models.

All proposed modeling methods include the assumptions that no significant immigration and emigration from the population occur during the fishing season, and catchability can be estimated.

Based on the increasing availability of data on juvenile and sub-adult size classes (Carmichael et al. 2003, Botton 2003), the Panel also recommended the exploration of modified age-structured models, referred to by the Panel as a 'stage'-structured models. A stage-structured model could be developed for juvenile, sub-adult, and adult life-history stages, with the strong recommendation for the development of a YOY abundance index, fishery specific size and weight catch data, and expansion of tagging projects for estimations of fishing and natural mortality.

2. Evaluate adequacy of the fishery-dependent, fishery-independent, and life history data currently being collected for use in the current assessment work and the proposed assessment.

Dependable fishery landings data and directed fishery independent surveys are limited to the last three to five years. Both the brief time series of high quality data and the less informative data from finfish surveys limit the successful application of quantitative stock assessment models to yield defensible estimates of stock size and mortality rates. At a minimum, the Panel recommended continuing to collect the current data (fishery dependent and independent) and to begin collecting landings by life stage (juvenile, sub-adult, and adult). These data are essential to implement the CSA model suggested in the framework, as well as, the stage-structured model.

Fishery Dependent

The Panel noted that all proposed models require fishery landings data, but landings data are limited because coastwide mandatory reporting of horseshoe crab landings was not put into effect until 1998 by the Interstate Fishery Management Plan for Horseshoe Crab (FMP). The FMP required states to collect and report all horseshoe crab harvest by numbers, pounds, sex, and harvest method. The Panel strongly recommended improved characterization of the commercial catch and landings by fishery (bait, biomedical, and scientific) and by life stage. The Panel also recommended commercial reporting to include location, depth, biological information (length, weight, sex and maturity stage), and measures of effort for each fishery, if possible. The Panel noted that the composition (magnitude and selectivity by size and sex) of the harvest varies among the biomedical and bait fisheries, and these differences underscore the need for improved characterization of landings. The scientific fishery takes small males, the biomedical fishery takes large animals of both sexes, and the bait fishery preferentially harvests large females (Rutecki et al. 2004).

The Panel noted that several horseshoe crab tagging programs exist along the Atlantic Coast, and they recommended that all tagging data be aggregated into a common database. This capability would provide additional data to refine estimates of population size, fishing morality rates, and other models. Information from tagging data may be limited by the loss of tags during molting. PIT tags may be a viable method to less obtrusively and permanently mark horseshoe crabs. The Panel noted that there might be enough support in the biomedical fishery and via port samplers or spawning surveys to scan catch and spawning beaches for tags. In addition, PIT tags would provide information on age-structure and growth rates of the stock.

The Panel identified caveats regarding releasing tagged animals in a different area after being harvested for bleeding for the biomedical fishery. If PIT tags were used, then the age-growth information would be valid. The Panel notes that if crabs were captured in one locale and returned to another it would alter the number of crabs at large at a given time, which would invalidate the mortality and population estimates. However, if the release locations were known, then the models could account for the shifts.

Fishery Independent

The current horseshoe crab stock assessment is based on trend and power analyses of several state and federal fishery independent surveys. Given this type of analysis, a generalized linear model might better relate the diverse surveys across regions, habitats, gears, etc. Currently, the best fishery independent data available for horseshoe crab stock assessment are from the Virginia Tech Offshore Trawl Survey and the Delaware Beach Spawning Survey. If coastwide assessment is the goal, then it is essential to expand the scope of these surveys to encompass the full range of horseshoe crabs on the Atlantic Coast.

Fishery independent surveys should identify juveniles, sub-adults, and adult horseshoe crabs and record the usual suite of environmental observations, so that standardized indices could be developed by stage with environmental covariates.

Life History

Stock identification

While the long-term goal is to develop a coastwide stock assessment, the Panel thinks it is necessary to move ahead by developing models using information from the Mid-Atlantic sub-stock, while additional data are collected in other areas. Genetic stock structure (King et al. 2003) and historical landings (D. Smith pers. comm) support that this approach is a reasonable stratification of data based on population size, genetic structure, and harvest pressures. The Panel strongly recommended expansion of the genetic stock identification work conducted by King et al. (2003) to further refine the stock structure of Atlantic Coast horseshoe crabs, particularly in northern and southern-most locations near the limits of crab distribution.

Natural mortality

Data currently are available regarding 1) numbers of individuals of different size classes from hatchling to adult stages, 2) total mortality and recruitment of different age classes, and 3) magnitude and fishery-specific selectivity of harvest from only one embayment, Pleasant Bay, on Cape Cod (Carmichael et al. 2003, Rutecki et al. 2004). Hence, the panel recommended that these data be combined to provide a test case from which to make initial estimates of natural mortality by applying standard methods. The Panel also recommended repeating this study in Pleasant Bay and conducting similar studies in other areas to evaluate the consistency of harvest mortality rates.

Reproductive biology (& life stage identification)

In the formation of population benchmarks, the Panel recommended that the Horseshoe Crab Technical Committee utilize the most recent information on fecundity, which indicate that larger females carry more eggs, lay more eggs and make more trips to the beach to spawn in a season (Brockman, pers. comm, and Webber, pers. comm.).

The Panel recognized that there are shed exoskeletons with mating scars, therefore, females continue to molt after sexual maturity or the presence of mating scars is not necessarily indicative of maturity. Until this dilemma is resolved, there is uncertainty in the discrimination between sub-adult and adult stages that may introduce bias into the CSA analysis.

Length & Weight

Although there is historical information on the length-weight relationship for horseshoe crabs, the Panel recommended collecting weight information in addition to prosomal width, stratified by season and location, and based on a standard protocol for weight measurements (i.e., a defined wet weight). It would also be very useful to have this type of sampling program repeated in Pleasant Bay and also conducted in other areas to see how consistent are the harvest mortality rates.

3. Develop recommendations for improving assessment methodology and data collection.

Model Recommendations

The Collie-Sissenwine model was proposed by the Horseshoe Crab Technical Committee as the long-term approach to the coastwide stock assessment of horseshoe crabs.

The Panel agreed that the CSA model is one of several desirable models that should be explored for horseshoe crab population assessments. Until the data time series is of sufficient length to run a CSA or other stage-structured models (i.e., a modified statistical catch-at-age model), the Panel recommended exploration of a surplus production model and a modified DeLury model (Rosenberg et al. 1990, Basson et al. 1996) with existing data as interim assessment models. The Panel also recommended continuing the exploration of stage-structured models. As described above for estimating natural mortality, a pilot stage-based model could be tested using data available from Pleasant Bay, Massachusetts to refine the stage-structured model in development by John Sweka, Mike Millard, and Dave Smith.

The Panel recommended that current trend, power, and meta analyses be continued with management following the precautionary principle until data are available for more advanced population analyses.

Proposing biological reference points for the horseshoe crab resource is a challenge, because setting reference points implies that attributes of a healthy, sustainable population are known and that assessments can compare the condition of the exploited population to that healthy stock level. When what constitutes a healthy stock is unknown, a variety of proxies is used in place. Most of the benchmarks assume a constancy in nature and that the fishery is responsible for most of the dynamics in the population. The sustainable measures imply knowledge of the relationship between spawning stock size and subsequent recruitment. A possibility for horseshoe crabs would be to monitor sub-adult densities to ensure adequate recruitment. At the minimum, growth rates and maturity schedules are needed to develop basic F-based biological reference points.

Data Recommendations

As stated above, development of a quantitative horseshoe crab assessment is limited by the quantity and quality of available fishery-dependent, fishery-independent, and life-history data. The Panel strongly recommended that measures be taken to improve characterization of landings and bycatch in the commercial fisheries (bait, biomedical, and scientific) by life stage. Other important fishery data include prosomal widths, weights, effort, and, if possible, environmental variables, such as, location and depth.

There are several independent tagging programs for horseshoe crabs on the Atlantic Coast. Recognizing the potential benefits of coastwide coordination of these programs, the Panel recommended improved coordination of these programs and that all tagging data be aggregated into a common database. Analyses of tagging data might provide estimates of mortality rates and population abundance in addition to migrations/movements and growth rate information.

The Panel suggested investigating PIT tags as a viable method to permanently mark horseshoe crabs and noted that there might be a sufficient infrastructure within the biomedical fishery and via port samplers or spawning surveys to scan catch and spawning aggregates for tags. Estimates from tagging data could be used to compare relative estimates to absolute estimates of population size, migration, and individual growth rates (if PIT tags are used).

The horseshoe crab directed fishery independent surveys – the offshore trawl survey and the Delaware Bay spawning stock survey – are the most powerful fishery independent surveys for detecting trends in horseshoe crab abundance. If coastwide assessment is the goal, then it will be important to expand the scope of these surveys to encompass the full range of horseshoe crabs on the Atlantic Coast. Fishery independent surveys should also identify juvenile, sub-adult, and adult horseshoe crabs. When creating standardized indices for these surveys, include environmental covariates that explain a significant portion of the index's variability. Potential environmental covariates include water and air temperature, wind speed, wave height, precipitation, cloud cover, and recent storm events.

The Panel also recommended the creation of a directed inshore survey. An inshore survey could have greater importance beyond the core area covered by the offshore trawl survey, because these populations may remain loyal to inshore embayments and even over winter in shallow waters, rather than returning offshore after spawning (O'Connell et al. 2003, Carmichael et al. 2004, and B. Barlow pers. comm.).

The Panel recommended using spawning population census information from 'small' beaches as a means to ground-truth the sub-sampling methods used to develop indices from the Delaware Bay spawning survey (for example, by comparing the Delaware Bay spawning index method side-by-side with a "total" count of spawning crabs from smaller more isolated embayments to test accuracy, precision, and calibration to "population" scale). The Panel also suggests refining spawning survey methods by conducting investigations on the timing of peak spawning activity (e.g. Is there an increase in spawning activity one-hour after for the tide goes out?) and by employing consistent measurements of environmental conditions (tide stage, wind direction, water temperature, and air temperature).

The Panel recommended continuing the genetic stock identification work conducted by King et al. (2003) to further refine the stock structure of Atlantic Coast horseshoe crabs, particularly for southern and northern-most regions.

The Panel further recommended better characterization of the abundance and size structure of juvenile populations coastwide. The Panel suggested that juveniles, which have readily and more clearly distinguishable size and age classes (and hence life stages), have the potential to be indicators of recruitment to adulthood (Carmichael et al. 2003).

Horseshoe crabs inhabit a wide range of habitats throughout their life history and their geographic range. The Panel recommended characterizing essential horseshoe crab habitats and evaluating potential variations in essential habitats in different regions of its distribution.

The Panel recommends using data from Pleasant Bay, Massachusetts to provide a test case from which to make initial estimates of natural mortality by applying standard methods. The Panel also recommended repeating the Pleasant Bay study and conducting similar studies in other areas to evaluate the consistency of harvest mortality rates.

The Panel recommended that the Horseshoe Crab Technical Committee utilize the most recent fecundity studies, which indicate that larger females carry more eggs, lay more eggs and make more trips to the shore to spawn in a season in the formulation of population benchmarks (Brockman, pers. comm, and Webber, pers. comm.).

The Panel recommended quantitatively assessing the frequency and directionality of possible misidentification of life stages for all relevant models.

The Panel recommended collecting weight and prosomal width data stratified by season and location based on a standard protocol for weight measurements. A standard protocol should be adhered to throughout the collection process

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