

**Center for Independent Expert Peer Review of 2026 Stock Assessment of Blue
Crab in Chesapeake Bay**

April 13 - 15, 2026

Annapolis, MD

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May 2026

Executive Summary

The NOAA Chesapeake Bay Office requested an independent peer review for the 2025 “Benchmark Quantitative Fishery Stock Assessment for Blue Crab in the Chesapeake Bay”. The purpose of the updated stock assessment was to provide a critical science product at a time of partnership-wide strategic planning for the Chesapeake Bay Program and to inform science-based management of the Chesapeake Bay blue crab fishery.

Three CIE reviewers undertook the review, and Dan Hennen was the chairperson of the review. The review process was professionally handled and all aspects of the review process went smoothly. The reviewers prepared a combined summary report and their individual reports. This review addresses each of the following 10 Terms of Reference:

TOR 1: Does the assessment critically review and estimate life history parameters and vital rates of blue crab in the Chesapeake Bay that are relevant to the stock assessment? In particular, does the assessment evaluate the extent and scale of interannual variation in life history parameters and vital rates of blue crab in the Chesapeake Bay?

The assessment team reviewed extensive literature on blue crab life history in Chesapeake Bay and updated analyses on growth, mortality, recruitment size, and female maturity. Research highlighted seasonal patterns in female maturation and recommended tracking pre-pubertal females and continued monitoring of the operational sex ratio (OSR). While some life history variability (e.g., overwinter mortality) was studied, spatial and annual variation in growth and maturity remains underexplored. Natural mortality—significantly influenced by cannibalism—may vary with population density and warrants further testing. Understanding environmental drivers of recruitment is critical, particularly given recent recruitment declines despite high mature female abundance, and integrating these factors could improve insight into the stock–recruitment–environment relationship. Based on the information provided, TOR 1 was partially met. Recommendations are:

- A re-assessment of the growth model is required with consideration of spatial variation in growth.
- To reflect the impact of cannibalism on natural mortality, an assessment of a density-dependent natural mortality rate should be undertaken which could be examined in the sex and length-structured stock assessment model (SLAM) as a sensitivity test.
- With the greater protection provided to mature females and males being below the reference point, research needs to make sure that there are sufficient males to mate females. Therefore, it is important to monitor the OSR.

- The feasibility of all blue crab surveys recording information on pre-pubertal females should be assessed.
- An assessment should be undertaken as to whether information on pre-pubertal female abundance could be incorporated in SLAM as this would provide an indication of female maturity a year ahead.
- The timing of recruitment and its effect on the size distribution of recruits should be monitored as this is probably sensitive to temperature changes. The annual variation in size distribution should be reflected in the SLAM which currently assumes a fixed size distribution in February.
- Zoea and megalopae were available from monthly zooplankton monitoring during 1979 – 1998. These data have the potential to provide valuable insight into the recruitment process. Consideration should be given to repeat the sampling of zoea and megalopae for comparison with the historic data.

TOR2: Does the assessment describe and quantify patterns in fishery-independent surveys to develop indices of abundance and characterize the size composition of the population?

The stock assessment is strengthened by extensive fishery-independent survey data, with eight surveys evaluated and five providing detailed size and sex composition suitable for inclusion in SLAM, including new additions such as the ChesMMAP and SERC trawl surveys. These surveys span long time periods, broad spatial coverage across Maryland and Virginia waters, and most months of the year, using seasonally appropriate gear, allowing robust estimation of population structure. Standardized abundance indices were developed using advanced statistical approaches with calibration across vessels and regions and quantified uncertainty. Environmental effects like winter temperature on mortality were incorporated. However, weaknesses remain such as insufficient evaluation of environmental influences on survey results. Gaps exist in understanding age-0 crab dynamics, particularly as surveys do not sample shallow habitats where most juveniles occur, and in assessing consistency among overlapping surveys. Based on information provided, TOR 2 was partially met. Recommendations are:

- Some surveys (winter dredge survey (WDS) and trawl) are catching age-0 crabs so survey estimates of the annual trends of this year class should be produced and compared to each other and to the model recruitment estimates produced by SLAM.
- An assessment is required to see if the age-0 blue crabs' abundance from the WDS survey area (and other surveys) are representative of the recruitment that is occurring mainly in shallower water.
- Sponge CPUE should be examined to see if they can be used to estimate an egg production index.
- Spike in recruitment in 2012 did not translate into above-average abundance of 1+. Can the fishery-independent surveys be used to assess where/when the bottleneck occurred?

- Crab information should be recorded in Maryland seine surveys and the Virginia seine surveys could provide valuable information on the age-0 crab abundance in shallow water.
- The potential environmental effects on survey abundance estimates need to be thoroughly assessed.

TOR 3: Does the assessment describe and quantify patterns in catch, effort, and CPUE?

The assessment benefits from comprehensive monthly catch and effort data across Maryland, Virginia, and the Potomac River, supported by mandatory reporting that has improved data quality and enabled analysis of multiple fleets and gear types. Adjustments were made to account for recreational harvest and dead discards, though incidental mortality of crabs returned alive remains unquantified, contributing to uncertainty alongside the recreational estimates. Biological data on sex and size composition are reasonably robust for some fisheries drawing on the Maryland Sentinel Fishery Monitoring Program, but remain limited for others, particularly the Virginia pot fishery. Concerns remain about potential inaccuracies in self-reported catch data and the lack of quantified validation error rates. Commercial fishing effort metrics were deemed unreliable for direct use in SLAM, though better characterization of effort—especially in dominant pot fisheries—would improve interpretation of fishing mortality and overall stock dynamics. Based on the information provided, TOR 3 was met. Recommendations are;

- There is some level of validation of harvest reports but the error rate is not recorded. It is important to have some validation of the commercial landings with a recording of the error rate and the nature of the error found.
- An assessment of the fishing effort in the pot fisheries, which take most of the catch, would be valuable information to understand the trends in fishing effort and help interpret model estimates of fishing mortality. This would also enable an examination of the catch-effort relationship to see what impact the changes in fishing effort have on catch.
- The estimates of sex ratios and size composition for the Virginia catch data are only based on monitoring that occurred in 2016/17. More regular monitoring of the sex and length composition of the Virginia data is required if this information is to be used in SLAM.

TOR 4: Does the assessment evaluate the feasibility of, and if possible, implement blue crab stock assessment models that operate on sub-annual time steps and/or at spatial resolutions lower than that of the entire Chesapeake Bay to better represent population dynamics?

SLAM represents a major advancement, integrating sex- and length-structured dynamics with monthly resolution and incorporating recruitment, growth, mortality processes, multiple survey datasets, and fishery selectivity changes over time. It fits a wide range of data inputs reasonably well, prioritizes broad-scale surveys like the WDS, captures sex-specific fishing mortality trends reflecting management actions, and produces a potentially valuable recruitment index, while demonstrating overall stability through diagnostic testing. However, several limitations remain, particularly around growth, recruitment timing and size structure, and uncertainties about how

well estimated recruitment reflects true abundance given gaps in shallow-water sampling. Additional issues include inconsistent selectivity and catchability patterns, residual biases and survey conflicts likely linked to spatial heterogeneity, challenges fitting a single Bay-wide model to regionally distinct populations, and limited treatment of environmental drivers. Based on the information provided, TOR 4 was partially met. Recommendations are:

- An initial two-state model covering Maryland and Virginia could be a first step in developing a spatial model as there is survey data for the two states, the catch data are recorded by state and there are clear life history differences in the spatial distribution of spawning and recruitment.
- An assessment to see how the estimated survey and model recruitment indices reflect the following year's abundance of the survey age-1 crab and/or the subsequent commercial landings would provide some confidence in the recruitment estimate.
- Recruitment was presented as a pulse in the winter and initial size distribution was assumed to be constant over time. There is variability in the timing of recruitment within the Bay and this spatial and temporal variation in recruitment should be reflected in the model.
- The development of an egg production index may better reflect the larval release than the use of mature female abundance.
- Historically there have been declines in recruitment when the abundance of mature females has been low and there is some evidence that overfishing has occurred. There is also evidence that environmental conditions are affecting the recruitment. Therefore, an assessment of the stock-recruitment-environment relationship should be undertaken when the study of the environmental effects on recruitment is completed.

TOR 5: Does the assessment characterize uncertainty in assessment estimates (mortality and abundance)?

SLAM incorporates uncertainty through standard errors, confidence intervals, and estimates of variability in survey inputs, recreational harvest, and discards, with most parameters estimated at relatively high precision (CV < 30%). Sensitivity analyses on key inputs such as growth, natural mortality, and survey selectivity showed that overall trends in abundance and fishing mortality are generally robust to many assumptions, supporting confidence in the model's core outputs. However, important gaps remain, including a lack of evaluation of long-term changes in life history parameters like growth and recruitment, and limited integration of environmental drivers beyond winter temperature effects on mortality. While the model is relatively insensitive to natural mortality and selectivity assumptions, it is highly sensitive to growth parameter choices, highlighting growth as a key source of uncertainty that requires further investigation. Based on the information provided, TOR 5 was partially met.

TOR 6: Does the assessment update the sex-specific catch survey models used in the 2011 benchmark stock assessment with relevant new data? Does the assessment characterize major changes in assumptions between the 2011 assessment model and the 2023 model?

The updated stock assessment builds on the 2011 benchmark by incorporating new data and revising key assumptions, including improved estimates of recreational catch, discard mortality, and commercial landings based on mandatory reporting since 1994, as well as introducing sex- and length-specific catch and survey data. Fishery-independent surveys were expanded with the addition of ChesMMA and SERC and analyzed using updated model-based standardization methods. While overall abundance trends remain broadly consistent between the 2011 and 2023 models, the new assessment estimates higher abundance levels, largely due to revised assumptions about WDS selectivity for recruits. Attempts to update the original 2011 model led to instability in stock–recruitment parameter estimates, prompting the development of a more stable STAN-based version for comparison between the two assessments. Based on the information provided, TOR 6 was met.

TOR 7: Does the assessment recommend appropriate biological reference points for management? Does the assessment evaluate stock status relative to recommended reference points?

The assessment uses a spawning potential ratio (SPR) framework to define biological reference points, with F40% serving as the threshold for fishing mortality and corresponding abundance benchmarks based on equilibrium conditions under median recruitment, while more precautionary targets are set at 75% of these thresholds. Recruitment reference points, based on a 3-year running average relative to the historical 25th percentile, provide an early warning system for low recruitment periods—critical given the stock’s reliance on a single annual cohort of females for reproduction. Current estimates indicate that fishing mortality for both sexes is below target levels, though overfishing occurred in some past years; mature female abundance is slightly above target, while male abundance has remained below threshold since 2020, and recent recruitment has fallen below the recommended threshold. Concerns remain about reliance on long-term median recruitment for setting abundance benchmarks in a changing climate, suggesting more precautionary, recent-period estimates may be appropriate. There is also a need to better validate recruitment indices and their relationship to future stock levels before they are used confidently to trigger management actions. Based on the information provided, TOR 7 was partially met. Recommendations are:

- The survey and the model estimates of recruitment need to be thoroughly assessed so that researchers and managers have sufficient confidence in the recruitment index to warrant management action.
- Consideration should be given to using the median recruitment over the last decade to determine reference points, especially if this is lower than the long-term median recruitment. This would represent a precautionary approach.

TOR 8: Does the assessment identify relevant ecosystem and climate influences (such as habitat, environmental drivers, prey availability, and predation/cannibalism) on the population dynamics and fisheries and explore other analyses that support the assessment?

The assessment includes valuable analyses of ecosystem and climate influences, highlighting issues such as predation by blue catfish, temperature effects on growth and overwinter mortality (OWM), and the roles of hypoxia and spatial temperature

variation. Evidence suggests blue catfish may have reduced recruitment by around 8%, with potential for increasing impact as their range expands, while OWM varies widely (1–13%) depending on winter severity and is higher for larger crabs, highlighting the importance of continued climate monitoring. Studies indicate that warming winters could shorten their duration and increase crab survival, with broader environmental datasets showing rising temperature across habitats. However, gaps remain in fully understanding climate impacts, including limited exploration of additional environmental drivers (e.g., nutrient declines), unresolved dynamics in temperature-dependent growth, and unclear biological explanations for size-related differences in OWM. While progress has been made, a more comprehensive integration of environmental change and climate projections is needed to better understand and predict blue crab population dynamics. Based on the information provided, TOR 8 was partially met. Recommendations are:

- The spread of catfish in the Bay is continuing so its effect could increase over time which highlights the importance of continued monitoring of the catfish and its effect on crabs.
- OWM warrants continued monitoring of the winters as changes in temperature, winter severity, and rainfall could have a marked effect on crab survival. Therefore, it is important to assess the historic trend in winter temperatures and other relevant environmental variables and assess climate projections of future trends in environmental conditions.
- The environmental conditions could drive many of the life history behaviours of blue crab and therefore it is important to understand what are the key changes that are occurring in Chesapeake Bay, how could they be affecting the life history of blue crab stocks (such as spawning, recruitment, mortality, growth) and what are the climate projections for the key environmental variables. This information could inform the level of risk attached to blue crabs due to climate change.
- The effect of the decline in nutrient load in Chesapeake Bay on the recruitment abundance should be further explored.

TOR 9: Does the assessment report on the status of research recommendations from the most recent benchmark assessment? Does the assessment identify and prioritize research recommendations for future work?

The stock assessment demonstrated substantial progress in addressing prior research recommendations, including integrating reference points and stock status estimation within the model, improving model performance through sex-specific growth and maturation, expanding and standardizing survey inputs, incorporating monthly seasonality, and using new data sources such as tagging studies to quantify recreational harvest and updated biological research on mortality, reproduction, and ecosystem interactions like blue catfish predation. The assessment also clearly identified future research priorities, including improving shallow-water sampling, recruitment understanding, spatial modelling, environmental drivers, and harvest data validation, with key gaps noted in growth, mortality and survey selectivity. Other limitations include the lack oceanographic drivers of recruitment (pending separate research), unsuccessful attempts to implement a spatially explicit model despite evident regional differences, and insufficient understanding of spatial-temporal recruitment patterns. Prioritization of research recommendations has been the

responsibility of the Chesapeake Bay Stock Assessment Committee (CBSAC), and many members of the assessment team also serve on the CBSAC. Based on the information provided, TOR 9 was met.

TOR 10: Based on your full review, is the 2025 Blue Crab Stock Assessment adequate for informing management decisions?

This assessment of the 2025 Chesapeake Bay Blue Crab Stock Assessment represents a large step forward from the last assessment. The assessment met or partially met all the ToR and represents the best available tool for management decisions.

Background

The NOAA Chesapeake Bay Office requested an independent peer review for the 2025 “Benchmark Quantitative Fishery Stock Assessment for Blue Crab in the Chesapeake Bay”. The purpose of the updated stock assessment is to provide a critical science product at a time of partnership-wide strategic planning for the Chesapeake Bay Program and to inform science-based management of the Chesapeake Bay blue crab fishery.

In the Chesapeake Bay, the blue crab (*Callinectes sapidus*) supports economically and culturally important commercial fisheries. Diverse gears are used to harvest blue crabs regionally and seasonally, and many of these were developed in response to spatiotemporal variability in the presence of specific life stages. The previous benchmark blue crab stock assessment for the Chesapeake Bay was completed in 2011 (Miller et al. 2011). Previous assessments were conducted by Miller et al. (2005) and Rugolo et al. (1997).

Review Process

Three CIE reviewers (Appendix 3) were selected to undertake the review, and Dan Hennen was the chairperson of the review panel. The review process consisted of:

- A stock assessment report, 13 working papers, R code for the Assessment model and several background papers were provided to the reviewers more than two weeks before the review meeting.
- Reviewers were asked to provide some preliminary key issues identified in the stock assessment before the meeting so that the assessment team could take them into account in their presentations to the meeting.
- Prior to the panel review meeting there was a testing of the online reviewer computer equipment to ensure the meeting went smoothly as two of the review panel members attended online from Australia.
- The panel review meeting occurred at Annapolis during 13-15 April 2026 and the assessment team members presented their work on all of the terms of reference.
- Presentations made at the meeting were made available to the panel.
- A number of requests for further information and analyses were raised by the panel during the meeting and the assessment team addressed these issues during the meeting.
- At the end of the panel review meeting, the panel chair and the three reviewers met to summarise the key findings of the panel for each TOR and to discuss the process of producing a panel summary report.
- The key findings were presented to the panel review meeting in a plenary session on 15 April.

- The reviewers then contributed to the panel summary report and wrote their individual reviewer's reports.

The NOAA fisheries review process was professionally handled, the assessment team were professional in their presentations and provided all the information requested by the review panel. All aspects of the review process went smoothly.

Summary of Findings

TOR 1: Does the assessment critically review and estimate life history parameters and vital rates of blue crab in the Chesapeake Bay that are relevant to the stock assessment? In particular, does the assessment evaluate the extent and scale of interannual variation in life history parameters and vital rates of blue crab in the Chesapeake Bay?

Strength:

- The Assessment Team undertook a very thorough review of the extensive literature that exists on the life history of blue crabs in Chesapeake Bay.
- The genetic status of the blue crabs in Chesapeake relative to crabs in other regions was well studied. The evidence supported the assumption that the blue crab population in Chesapeake Bay comprised a unit stock for assessment purposes.
- The current assessment conducted new analyses to estimate length-weight relationships, natural mortality, overwinter mortality (OWM), size at recruitment and female maturity and growth.
- Ogburn et al. (2026) used data from a long-term (2004-2023), monthly trawl survey of blue crabs in the Rhode River, Maryland to evaluate 1) the timing of the molt to maturity, 2) the growth increment at the molt to maturity, and 3) variability in the operational sex ratio (OSR). The proportion of females maturing varied among months with the abundance of pre-pubertal females peaking in August. It would be useful if other blue crab surveys also began identifying pre-pubertal females to understand the spatial and temporal variation in female maturation and growth. Information on pre-pubertal female abundance could also be considered for incorporation in the sex- and length-structured stock assessment model (SLAM) and this could provide an indication of female maturity abundance a year ahead as the annual survival of mature females is estimated to be about 10% (Lipcius et al. 2026a).
- There has been increased protection of mature females since the management changes after 2008 and the mature female abundance has increased, however the male abundance has declined. The current status of the OSR is estimated to be satisfactory (Ogburn et al. 2026) but it is important that the OSR is

continued to be monitored especially as the male abundance has been below the reference level for the last four years.

- The mean annual survival rate of mature female crabs was 0.10 ± 0.01 (yr^{-1} ; mean \pm SE), and the mean recovery rates were 0.22 ± 0.01 during 2002-2008 and 0.08 ± 0.004 during 2009-2017 (Lipcius et al. 2026a). The decline in recovery rate reflected a decrease in fishing effort and supported the decrease in fishing mortality on mature females estimated by SLAM.

Weakness:

- Interannual variation in life history parameters has been assessed for some life history parameters (e.g., overwinter mortality) but the interannual and spatial variation in some life history rates (e.g., growth, maturity) were not fully explored.
- Several approaches were tried to estimate growth including temperature-dependent growth and the von Bertalanffy growth model but the Gompertz model was finally selected with a variable monthly b parameter as it fitted the size distribution of the survey crab length data best. However further assessment of the growth model is required with consideration of spatial variation in growth as there is a north-south gradient in growth rate.
- The stock assessment report states that 'observed variability in winter temperatures could vary the timing of recruitment to the fishery by up to 10%' which would affect the size distribution of the recruits in the model. It is important to continue monitoring the timing of recruitment as this is probably sensitive to temperature which is influenced by climate change. SLAM currently assumes a fixed size distribution placed in the model in February.
- About a third of the crab mortality is believed to be due to cannibalism. As there are large variations in annual abundance, there could be marked variations in annual natural mortality due to a density-dependent mortality rate. This should be assessed and examined in the SLAM as a sensitivity test.
- Colton et al. (2014) found evidence of recruitment synchrony over time from New York to Florida, which could be caused by interchange of larvae or a common response to large-scale environmental drivers. Modeling by Garvine et al. (1997) indicated that some larvae return to Delaware Bay using upwelling-favorable wind events. The environmental drivers affecting recruitment are being examined in a separate study and were not reported at this review. Understanding the drivers of recruitment variation (egg production and environmental conditions) has become especially important with the recent recruitment decline at a time when the mature female abundance is above the target level. Historically there have been declines in recruitment when the abundance of mature females have been low and there is some evidence that overfishing has occurred. The environmental assessment on recruitment combined with the information available on mature female abundance should enable an assessment of the stock-recruitment-environmental relationship.

Conclusion

The assessment reviewed extensive literature on blue crab life history in Chesapeake Bay and confirmed the population functions as a single stock, while introducing updated analyses on growth, mortality, recruitment size, and female maturity. Research highlighted seasonal patterns in female maturation and recommended tracking pre-pubertal females, recommended that continued monitoring of the OSR was important. While some life history variability (e.g., overwinter mortality) has been studied, spatial and annual variation in growth and maturity remains underexplored. Natural mortality—significantly influenced by cannibalism—may vary with population density and warrants further testing. Finally, understanding environmental drivers of recruitment is critical, particularly given recent recruitment declines despite high female abundance, and integrating these factors could improve insight into the stock–recruitment–environment relationship. Based on the information provided on the life history review, TOR 1 was partially met.

Recommendations:

- A re-assessment of the growth model is required with consideration of spatial variation in growth.
- To reflect the impact of cannibalism on natural mortality, an assessment of a density-dependent natural mortality rate should be undertaken which could be examined in the SLAM as a sensitivity test.
- Management policies focused on conserving female crabs. There have been a number of studies that indicate that mating success is high (Schneider et al. 2024a). With the greater protection provided to mature females and males being currently below the reference point, research needs to make sure that there are sufficient males to mate females. The current status of the OSR is estimated to be satisfactory but it is important that the OSR continues to be monitored.
- The feasibility of all blue crab surveys recording information on pre-pubertal females should be assessed.
- An assessment should be undertaken as to whether information on pre-pubertal female abundance could be incorporated in SLAM as this would provide an indication of female maturity a year ahead as the survival of mature females is estimated to be about 10%.
- The timing of recruitment and its effect on the size distribution of recruits should be monitored as this is probably sensitive to temperature changes. The annual variation in size distribution should be reflected in the SLAM, which currently assumes a fixed size distribution placed in the model in February.
- Zoea and megalopae were available from the Chesapeake Bay Program's monthly zooplankton monitoring program from 1979 – 1998. These data have the potential to provide valuable insight into the recruitment process.

Consideration should be given to repeat the sampling of these zoea and megalopae data for comparison with the historic data.

TOR 2: *Does the assessment describe and quantify patterns in fishery-independent surveys to develop indices of abundance and characterize the size composition of the population?*

Strength:

- Eight fishery-independent surveys were evaluated and five surveys had sufficient size and sex composition data for use in the SLAM. The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAAP) bottom trawl survey and the Smithsonian Environmental Research Center bottom trawl survey (SERC Trawl) of the Rhode River and adjacent upper Chesapeake Bay had sufficient information to be added to the stock assessment model for the first time.
- The availability of many fishery-independent surveys over long periods and covering most months and many of the areas inhabited by the blue crabs is one of the major strengths of the stock assessment.
- Many of the surveys were conducted over multiple months with different gears that were suitable for the crab behaviour at time of the year, such as dredge survey in winter and trawl surveys in the warmer months of the year when crabs were more active. This provided information for nearly all months of the year on the sex and size composition.
- There was also significant spatial variation of the surveys over the Maryland and Virginia components of the stock with the winter dredge survey (WDS) providing the largest spatial coverage of blue crab stock.
- Model-based indices were developed for the five surveys with sufficient length- and sex-specific data.
- Spatio-temporal models were used to standardize abundance indices for surveys with designs that used random sampling (Winter dredge survey (WDS), Virginia Institute of Marine Science (VIMS) Trawl Survey, Chesapeake Bay Multispecies Monitoring and Assessment Program [ChesMMAAP]). However, length compositions were not standardized between surveys.
- Generalized additive models were used for surveys with fixed-site designs (Maryland Trawl Survey including the SERC Trawl Survey, and PEARL Pot Survey).
- Survey indices were calculated to represent the population in specific months.
- Fishery-independent surveys over an extended period can be affected by changes in vessel and gear which requires some calibration and this has been undertaken. There has also been calibration for vessels operating in different regions such as the Maryland and Virginia trawl surveys.
- Confidence limits on survey indices have been determined.
- Warming temperatures in winter resulted in lower winter mortality which resulted in higher abundance in the WDS so that this temperature effect is considered in the SLAM.

Weakness:

- Maryland and Virginia operate a seine survey designed to monitor the status of young-of-the-year striped bass. The VIMS Seine Survey began enumerating blue crabs by sex and measuring individuals in 2015 but the length of the time series was too short to include in the current assessment but should be suitable for future assessments. The crab abundance information should also be recorded in the Maryland seine surveys as both these surveys could provide valuable information on the age-0 crab catch in shallow water.
- Fishery-independent trawl surveys can be affected by the environmental conditions at the time of the surveys. The potential environmental effects on surveys have not been thoroughly assessed.
- Some surveys (WDS and trawl) are catching age-0 crabs, and it would be interesting to see the annual trends of this year class for those surveys and see how they compare to each other and to the model recruitment index produced by SLAM. For example, the length frequencies for the MD trawl show a clear signal of age-0 crabs in May (particularly for males) and for the VIMS trawl a signal for age-0 crabs in April/May each year (Drzewicki and Wilberg 2026).
- The WDS does not sample all habitats where age-0 blue crabs can be found in the winter because it has a minimum sampling depth of 1.5 m, and shallower habitats have smaller blue crabs, on average. About 90% of the recruits have been estimated to occur in the shallow water (Ralph and Lipcius 2014). An assessment is required to see if the age-0 blue crab abundance from the WDS survey area (and other surveys) are representative of the recruitment that is occurring mainly in shallower water.
- To evaluate among-survey coherence, a comparison was made between each pair of surveys that occurred within a given month. For example, in February, the WDS and VIMS Trawl surveys were compared for all years where both surveys occurred. When comparing surveys, it would be useful to also compare the surveys for the area of the surveys which overlapped.

Conclusion:

The stock assessment is strengthened by extensive fishery-independent survey data, with eight surveys evaluated and five providing detailed size and sex composition suitable for inclusion in the SLAM, including new additions such as the ChesMMAP and SERC trawl surveys. These surveys span long time periods, broad spatial coverage across Maryland and Virginia waters of Chesapeake Bay, and most months of the year, using seasonally appropriate gear, allowing robust estimation of population structure. Standardized abundance indices were developed using advanced statistical approaches with calibration across vessels and regions and quantified uncertainty, while some environmental effects like winter temperature on mortality were incorporated. However, weaknesses remain such as insufficient evaluation of environmental influences on survey results. Additionally, gaps exist in understanding age-0 crab dynamics, particularly as key surveys do not sample shallow habitats where most juveniles occur, and in assessing consistency among

overlapping surveys. Based on the information provided on the fishing-independent surveys, TOR 2 was partially met.

Recommendation:

- Some surveys (WDS and trawl) are catching age-0 crabs so survey estimates of the annual trends of this year class should be produced and compared to each other and to the model recruitment estimates produced by SLAM.
- An assessment is required to see if the age-0 blue crab abundance from the WDS survey area (and other surveys) are representative of the recruitment that is occurring mainly in shallower water.
- Sponge CPUE data should be examined to see if they can be used to estimate an egg production index for blue crab.
- The spike in recruitment in 2012 did not translate into above-average abundance of 1+. Can the fishery-independent surveys be used to assess where/when the bottleneck occurred?
- The crab abundance information should be monitored in the Maryland seine surveys as both the Virginia and Maryland seine surveys could provide valuable information on the age-0 crab abundance in shallow water.
- The potential environmental effects on survey abundance estimates need to be thoroughly assessed.

TOR 3: Does the assessment describe and quantify patterns in catch, effort, and CPUE?

Strength:

- Monthly catch and effort were available for each management jurisdiction (Maryland, Virginia, and the Potomac River) for all commercial fishers during 1994-2023. There has been mandatory reporting of commercial landings available since 1994 for all jurisdictions which should result in improved catch data in this assessment.
- Catches were examined for six fleets using eight gear types: Maryland Pot, Maryland Trotline, Virginia Pot, Virginia Dredge, Potomac River, and peeler. The fleets have different selectivity and monthly patterns of harvest.
- An assessment was made to account for recreational harvest and dead discards of blue crabs in the commercial fishery. For example, since the last assessment, a tagging study by Semmler et al. (2021) estimated the recreational harvest of male blue crabs in Maryland.
- The dead discards are based on the number of dead crabs recorded in pots. However, there is no accounting for incidental mortality of undersize and other crabs returned to the sea alive.
- The sex ratios and size compositions of the catch for each fleet were estimated from commercial monitoring and relevant survey data. The data on proportions-at-length and sex of the fishery catch in Maryland, the Potomac River, and the Bay-wide peeler/soft shell fishery from the Maryland Sentinel Fishery Monitoring Program were used. Through this program, biological data were collected from commercially caught blue crabs by state biologists and

commercial fishers starting in 2002 (Fegley et al. 2006). However, the estimates of sex ratios and size composition for the Virginia catch data are only based on monitoring that occurred in 2016/17.

- Estimates of uncertainty in the catch estimates were mainly associated with the estimates of dead discards and recreational harvest.
- The analysis of 50+ years of data from the PEARL Pot Survey suggested a significant decline in average size for both males and females within the survey area with much of the decline in male CW occurring prior to 1990. This appears to have stabilised during the period of assessment 1994-2023. The long-term assessment of mean size trends can be an important indicator of fishing effort, so it is important that this continues to be monitored.
- Harvest controls in the form of daily bushel limits were instituted in the 2010s and are now in place throughout Chesapeake Bay. Some fishers (~25% in Virginia) are recording daily catches at the bushel limits.

Weakness:

- While catch reporting is mandatory, there is evidence that there may be some invalid reporting by some fishers. There is some validation of harvest reports, but the error rate was not recorded. It is important to have some validation of the commercial landings with a recording of the error rate and the nature of the errors found.
- Commercial fishing effort (and hence catch per unit effort, CPUE) was evaluated but was not considered sufficiently reliable to be considered in SLAM. The availability of fishery-independent surveys provides more reliable estimates of abundance trends than would be provided by commercial CPUE. However, understanding the trends in fishing effort, particularly in the pot fisheries which take most of the catch (e.g., 80-97% of annual harvest in Virginia), would be valuable information to understand the trends in fishing effort and help interpret model estimates of fishing mortality. Information on the number of trips per year was presented at the review but additional assessment of traps used would be useful.
- The length compositions for the Virginia pot fishery were based on data from a buyer sampling program that occurred in 2016-2017. More regular monitoring of the sex and length composition of the Virginia landings data are required if this information is to be used in the SLAM.

Conclusion:

The assessment benefits from comprehensive monthly catch and effort data (1994–2023) across Maryland, Virginia, and the Potomac River, supported by mandatory reporting that has improved data quality and enabled analysis of multiple fleets and gear types in Chesapeake Bay. Adjustments were made to account for recreational harvest and dead discards, though incidental mortality of crabs returned alive remains unquantified, contributing to uncertainty alongside recreational estimates. Biological data on sex and size composition are reasonably robust for some fisheries—drawing on programs like the Maryland Sentinel Fishery Monitoring Program—but remain limited for others, particularly the Virginia pot fishery, highlighting the need for more consistent monitoring. Concerns remain about

potential inaccuracies in self-reported catch data and the lack of quantified validation error rates. Additionally, commercial fishing effort metrics (e.g., CPUE) were deemed unreliable for direct use in the stock assessment model, though better characterization of effort—especially in dominant pot fisheries—would improve interpretation of fishing mortality and overall stock dynamics. Based on the information provided on the catch and effort, TOR 3 was met.

Recommendation:

- There is some level of validation of harvest reports, but the error rate is not recorded. It is important to have some validation of the commercial landings with a recording of the error rate and the nature of the errors found.
- An assessment of the fishing effort in the pot fisheries, which take most of the catch (e.g., 80-97% of annual harvest in Virginia), would be valuable information to understand the trends in fishing effort and help interpret model estimates of fishing mortality. This would also enable an examination of the catch-effort relationship to see what impact the changes in fishing effort have on catch.
- The estimates of sex ratios and size composition for the Virginia catch data are only based on monitoring that occurred in 2016/17. More regular monitoring of the sex and length composition of the Virginia data is required if this information is to be used in the SLAM.

TOR 4: Does the assessment evaluate the feasibility of, and if possible, implement blue crab stock assessment models that operate on sub-annual time steps and/or at spatial resolutions lower than that of the entire Chesapeake Bay to better represent population dynamics?

Strength:

- A bespoke sex- and length-structured stock assessment model (SLAM) was developed for Chesapeake Bay blue crabs that includes recruitment, growth, and fishing and natural mortality.
- The model operates on a monthly time step for the period 1994-2023 which represents an improvement on the annual assessment conducted previously. Consideration could be given to combining the winter months (December–March), as there is no growth, no reproduction, and no commercial fishing. Pooling these months into a single time step would reduce model complexity.
- Fishery selectivity was used to account for changes in minimum size limit regulations, which have occurred over years and months across fleets.
- The SLAM was fitted to sex-specific fishery catch, sex-specific fishery proportions at length, sex-aggregated survey indices of abundance, and survey proportions at sex and length.
- The model included survey indices from the WDS, VIMS Trawl Survey, Maryland Trawl Survey, ChesMMAP, and the PEARL Pot Survey.
- Fitting WDS was prioritized because it covered the largest spatial extent of the blue crab distribution in Chesapeake Bay and the model was able to fit the survey indices and sex- and length-composition data relatively well without substantial sex-specific residual patterns.

- There is evidence that natural mortality is higher for smaller blue crabs compared to larger blue crabs (Bromilow and Lipcius 2017) and length-based estimates of M were developed using information from Bromilow and Lipcius (2017).
- Estimated sex-specific fishing mortality rates were obtained and the trends differed by sex with female fishing mortality rates being lower than those for males by the mid-2000s which reflected the change in regulations to conserve more females.
- The model produced a recruitment abundance index based on the survey input of age-0 crabs. If this index is shown to be a reliable indicator of actual recruitment that is occurring in the Bay, then it will be a valuable for fisheries researchers and managers.
- Model stability was tested using jitter analyses. This was done to ensure that the model converged on the same objective function value and that a better solution (i.e., lower objective function value) was not found.
- A simulation self-test of the model and some retrospective analyses were provided during the workshop at the request of the panel. The self-test showed some small bias and there was some small retrospective bias.
- The base model had 2,639 estimated parameters. It appeared to converge on a unique solution with a maximum gradient component of 0.054 (associated with the logit of the proportion male for recruits), and all except one other parameter had first partial derivatives < 0.001 . No parameters were estimated to be on their upper or lower bounds.

Weakness:

- There were significant issues determining the best way to fit growth in the model. Growth was applied using a Gompertz growth model which allowed for variable monthly growth and a modification for female maturation growth was used.
- Each month was assigned b growth parameters for the Gompertz model that were constant over time and the same for both sexes. The values for b were determined by iteratively adjusting the parameters until the model could match changes in the first mode of the length distribution in the WDS, the Maryland Trawl Survey, and the VIMS Trawl survey. The biological reasons why the b parameters are higher for April and August compared to the other months should be provided to support the choice of the b parameters.
- Temperature-dependent growth function was attempted but it could not match the observed monthly changes in the length composition because temperature-dependent models consistently underestimated growth in the spring and overestimated growth in the summer and fall.
- Seitz et al. (2005) quantified juvenile (25-52 mm CW) blue crab growth across upriver and downriver areas and between vegetated and unvegetated habitats within a Chesapeake Bay sub-estuary. Is the variation in growth between the different regions of the Bay large enough to cause issues with fitting one growth model to the whole Bay?
- Recruitment was presented as a pulse in the winter and initial size distribution were assumed to be constant over time. It is not clear whether this

adequately represents the spatial and temporal variation in recruitment that is happening in the Bay.

- It is not clear how well the estimated recruitment time series reflects the actual recruitment abundance. The shallow water (<1.5 m) area is not covered by the WDS and about 90% of the recruits have been estimated to occur in the shallow water (Ralph and Lipcius 2014).
- While the survey abundance estimates were standardized, the size distributions were not standardized between surveys.
- There are unusual selectivity patterns in May and June compared to the other months. Are there biological reasons for these patterns?
- Are there biological reasons for catchability in April to be much high than other months?
- There are large fluctuations of fishing mortality for males, but it is not clear what is driving this variation.
- The SLAM was able to fit the catch time series better than the 2011 model, however it had some sex-specific residual patterns which probably reflects the spatial differences in the crab stock between different locations where the six fleets operated.
- In jitter runs, the parameters associated with PEARL catchability and ChesMMAP selectivity were the most problematic to estimate and likely contributed to model instability. Is the PEARL pot survey data an issue because it is spatially limited and doesn't generally reflect what is happening over the whole Bay?
- Residuals in the catch had very clear temporal or cyclical patterns that differed by fleet and sex. For most fleets, male and mature female residuals had opposing patterns. Males often had negative residuals (indicating overestimation) while mature females usually had positive residuals (indicating underestimation), on average.
- Misfits in certain months highlighted some data conflicts between the MD and VIMS trawl surveys. This provides another example that Bay-wide model cannot cope with the spatial differences between data from Maryland and Virginia.
- The model represented the whole Chesapeake Bay which is probably contributing to many of the model fitting issues outlined in the Report. An initial two-state model covering Maryland and Virginia could be a first step in developing a spatial model as there are survey data for the two states, the catch data are recorded by state and there are clear life history differences in the spatial distribution of spawning and recruitment.
- The current evidence suggests that females inseminated in upper Bay sub-estuaries produce their first broods the year following mating, while females inseminated in the lower Bay may reproduce the same year as they mated or the following year (Turner et al. 2003). This spatial variation in the timing of spawning for crabs in different areas could affect the estimate of egg production.
- Environmental effects on the parameter estimates in the model and on the recruitment abundance were not thoroughly assessed. Understanding the environmental effects on the crab stock becomes even more important with the potential climate change effects that may be happening on winter severity, water temperature, rainfall, etc.

- Abundance of mature females was lower in the first half of the time series and increased after additional restrictions on fishing for females were implemented in 2008. Did the lower abundance of mature females prior to 2008 contribute to the low recruitment over 1998-2007? An assessment of the stock-recruitment-environment relationship would be useful to answer this question and others on understanding recruitment variability.

Conclusion:

The SLAM represented a major advancement, integrating sex- and length-structured dynamics with monthly resolution and incorporating recruitment, growth, and mortality processes, multiple survey datasets, and fishery selectivity changes over time. It fits a wide range of data inputs reasonably well, prioritizes broad-scale surveys like the WDS, captures sex-specific fishing mortality trends reflecting management actions, and produces a potentially valuable recruitment index, while demonstrating overall stability through diagnostic testing. However, several limitations remain, particularly around growth modelling, simplified assumptions about recruitment timing and size structure, and uncertainties about how well estimated recruitment reflects true abundance given gaps in shallow-water sampling. Additional issues include inconsistent selectivity and catchability patterns, residual biases and survey conflicts likely linked to spatial heterogeneity, challenges fitting a single Bay-wide model to regionally distinct populations, and limited treatment of environmental drivers. An assessment of the stock-recruitment-environment relationship would be an important addition to the stock assessment. Based on the information provided on the stock assessment model, TOR 4 was partially met.

Recommendation:

- An initial two-state model covering Maryland and Virginia could be a first step in developing a spatial model as there is survey data for the two states, the catch data are recorded by state and there are clear life history differences in the spatial distribution of spawning and recruitment.
- An assessment to see how the estimated survey and model recruitment reflects the following year's abundance of the survey age-1 crab and/or the subsequent commercial landings would provide some confidence in the recruitment estimate.
- Recruitment was presented as a pulse in the winter and with an initial size distribution assumed to be constant over time. There is variability in the timing of recruitment within the Bay and this spatial and temporal variation in recruitment should be reflected in the model.
- The development of an egg production index may better reflect the larval release than the use of mature female abundance.
- There have been declines in recruitment when the abundance of mature females has been low and there is some evidence that overfishing has occurred. However, there is also evidence that environmental conditions are affecting the recruitment, and these effects are generally most prevalent during the larval phase of crab stocks. Therefore, an assessment of the stock-recruitment-environment relationship would be a valuable addition to the stock assessment. There are survey and model estimates of mature female biomass available, survey and model estimates of recruitment and there is

currently a study occurring on how environmental variables may be affecting blue crab recruitment.

TOR 5: *Does the assessment characterize uncertainty in assessment estimates (mortality and abundance)?*

Strength:

- Uncertainty was assessed in SLAM using asymptotic standard errors and 95% confidence intervals of survey data inputs as well as uncertainty associated with the recreational and discards component of the catch data
- Most parameters and model quantities were estimated with relatively high precision (coefficient of variation < 30%).
- Sensitivity analyses were conducted on key parameters such as growth, natural mortality, and WDS selectivity parameters.
- Sensitivity analyses indicated that trends in estimated fishing mortality rates and abundance were not sensitive to alternative values for fixed parameters.

Weakness:

- There were no assessments to see if there were long-term trends in life history parameters such as growth and recruitment and no environmental drivers were explicitly considered. However, the effect of changes in winter severity on the overwinter mortality was accounted for by the winter dredge survey.
- While estimated abundance and fishing mortality rates were relatively insensitive to alternative values of natural mortality and WDS selectivity parameters, they were highly sensitive to alternative growth parameters.

Conclusion:

The SLAM assessment incorporates uncertainty through standard errors, confidence intervals, and estimates of variability in survey inputs, recreational harvest, and discards, with most parameters estimated at relatively high precision (CV < 30%). Sensitivity analyses on key inputs such as growth, natural mortality, and survey selectivity showed that overall trends in abundance and fishing mortality are generally robust to many assumptions, supporting confidence in the model's core outputs. However, important gaps remain, including a lack of evaluation of long-term changes in life history parameters like growth and recruitment, and limited integration of environmental drivers beyond winter temperature effects on mortality. While the model is relatively insensitive to natural mortality and selectivity assumptions, it is highly sensitive to growth parameter choices, highlighting growth as a key source of uncertainty that requires further investigation. Based on the information provided on the uncertainty in the assessment, the TOR 5 was partially met.

TOR 6: *Does the assessment update the sex-specific catch survey models used in the 2011 benchmark stock assessment with relevant new data? Does the*

assessment characterize major changes in assumptions between the 2011 assessment model and the 2023 model?

Strength:

- The current assessment updated the sex-specific catch survey models used in the 2011 benchmark stock assessment with relevant new data. The current assessment calculated catch and survey indices of abundance differently than was done in 2011.
- The assessment characterized the major changes in assumptions between the 2011 assessment model and the 2023 model. These included revised estimates of recreational catch, estimates of discard mortality, commercial landings based on mandatory reporting data since 1994, and catch and survey data being sex and length specific.
- Fishery-independent survey data were implemented differently between the two assessments with additional surveys (ChesMMAP and SERC) being included in the new assessment and a different model-based standardization approach adopted.
- The trends in estimated abundance were similar between the 2011 and 2023 models, but the estimated abundance was higher in the new model mainly due to the alternative assumptions of WDS selectivity of recruits.
- Updating the 2011 model resulted in instability of the stock-recruitment parameter estimates and a STAN-based version of the model was developed that converged reliably and used for comparing the 2011 and 2023 model.

Weakness:

- No specific weaknesses identified.

Conclusion:

The updated stock assessment builds on the 2011 benchmark by incorporating new data and revising key assumptions, including improved estimates of recreational catch, discard mortality, and commercial landings based on mandatory reporting since 1994, as well as introducing sex- and length-specific catch and survey data. Fishery-independent surveys were expanded with the addition of ChesMMAP and SERC and analyzed using updated model-based standardization methods. While overall abundance trends remain broadly consistent between the 2011 and 2023 models, the newer assessment estimated higher abundance levels, largely due to revised assumptions about winter dredge survey selectivity for recruits. Attempts to update the original 2011 model led to instability in stock–recruitment parameter estimates, prompting the development of a more stable STAN-based version for comparison between the two assessments. Based on the information provided on the update of the 2011 benchmark stock assessment and characterization of the major changes in assumptions, TOR 6 was met.

TOR 7: Does the assessment recommend appropriate biological reference points for management? Does the assessment evaluate stock status relative to recommended reference points?

Strength:

- A spawning potential ratio approach (SPR) was used for calculating bay-wide biological reference points.
- Threshold and target reference points for male and mature female abundance and fishing mortality rates. $F_{40\%}$ was selected as the basis for the threshold reference points, where $F_{40\%}$ represents the fishing mortality rate that would be expected to reduce the lifetime reproductive potential to 40% of the unfished level.
- Abundance threshold reference points represent the expected equilibrium abundance under median recruitment and the threshold fishing mortality rate reference points.
- Sex-specific target fishing mortality rates were calculated as 75% of the threshold values, and target abundances were calculated assuming median recruitment and the target fishing mortality rates.
- Bay-wide recruitment reference points were developed to indicate extended periods of low recruitment that may require management action. The lower threshold recruitment reference point was defined as the 3-yr running average recruitment compared to the 25th percentile of estimated recruitment during 1994-2023. The use of a 3-yr running average is generally appropriate as there can be marked variability in recruitment due to environmental variability.
- The monitoring of recruitment relative to their reference points can be an important indicator for fisheries managers as recruitment overfishing typically occurs when there is a low recruitment period and fishing continues as normal which then drives the spawning stock to unacceptable levels.
- At the start of the spawning season, females with eggs are mostly primiparous, producing their first egg mass (Schneider et al. 2024a). These findings support a reliance on one annual cohort of female blue crabs for reproduction each year. The reliance of the stock on one annual cohort for reproduction makes it even more important to have an early indication of low recruitment.
- Male and female fishing mortality rates in the most recent year were below the threshold and target fishing mortality rate reference points indicating that overfishing was not occurring now, but overfishing was estimated to have occurred in some previous years.
- Mature female abundance was estimated to be slightly above the recommended target in 2023, but the male abundance has been below the threshold since 2020.
- Three-year average recruitment was below the recommended threshold for 2022 and 2023, but it was above the threshold for all previous years.

Weakness:

- Median abundance was used in the calculation of abundance reference points. However, this may not be appropriate if there are extended periods of low recruitment that can occur under climate change. Consideration should be given to using the median recruitment over a recent period, such as the last decade, particularly if the recruitment in the latter period is lower than the

long-term median recruitment. This would represent a precautionary approach to management.

- Recruitment reference points have the potential to allow proactive management during times when recruitment is lower than expected because there is some lead time between when recruitment is observed in the Chesapeake Bay Blue Crab Winter Dredge Survey (WDS) and the time when those recruits would begin to enter the hardshell fisheries (autumn of that year). However, the survey and the model estimates of recruitment need to be thoroughly assessed so that researchers and managers have sufficient confidence in the recruitment index to warrant management action. An assessment of the relationship between recruitment age-0 abundance and the following year's abundance of age-1 crabs in the survey or commercial catches in the following year or two would provide some evidence as to reliability of the recruitment time series.

Conclusion:

The assessment uses a spawning potential ratio (SPR) framework to define biological reference points, with F40% serving as the threshold for fishing mortality and corresponding abundance benchmarks based on equilibrium conditions under median recruitment, while more precautionary targets are set at 75% of these thresholds. Recruitment reference points, based on a 3-year running average relative to the historical 25th percentile, provide an early warning system for low recruitment periods—critical given the stock's reliance on a single annual cohort of females for reproduction. Current estimates indicate that fishing mortality for both sexes is below target levels, though overfishing occurred in some past years; mature female abundance is slightly above target, while male abundance has remained below threshold since 2020, and recent recruitment has fallen below the recommended threshold. However, concerns remain about reliance on long-term median recruitment for setting abundance benchmarks in a changing climate, suggesting more precautionary, recent-period estimates may be appropriate. There is also a need to better validate recruitment indices and their relationship to future stock levels before they are used confidently to trigger management actions. Based on the information provided on the biological reference points and evaluation of stock status, TOR 7 was partially met.

Recommendation:

- The survey and the model estimates of recruitment need to be thoroughly assessed so that researchers and managers have sufficient confidence in the recruitment index to warrant management action.
- In assessing reference points consideration should be given to using the median recruitment over the last decade if this is lower than the long-term median recruitment. This would represent a precautionary approach to management.

TOR 8: Does the assessment identify relevant ecosystem and climate influences (such as habitat, environmental drivers, prey availability, and predation/cannibalism) on the population dynamics and fisheries and explore other analyses that support the assessment?

Strength:

- Some assessments were presented on potential ecosystem and climate effects on blue crabs. They included the effects of blue catfish (*Ictalurus furcatus*), effects of temperature on blue crab growth and overwinter mortality, effects of hypoxia and spatial temperature patterns in Chesapeake Bay.
- The estimated effect of blue catfish on blue crab recruitment increased over time and may have caused recruitment to be about 8% lower than it would have been in the absence of blue catfish. The spread of catfish in the Bay is continuing so its effect could increase over time which highlights the importance of continued monitoring of the catfish and its effect on crabs.
- Overwinter mortality (OWM) was estimated by length and sex for Maryland and Virginia separately (and then combined) using data on dead crabs observed in the WDS. OWM was higher for larger blue crabs and varied substantially over time (1-13% bay-wide) and it was higher in years with severe winters. This warrants the continued monitoring of the winters as changes in temperature, winter severity, and rainfall could have a marked effect on crab survival.
- Brylawski and Miller (2006) conducted laboratory experiments that demonstrated that observed variability in winter temperatures could vary the timing of recruitment to the fishery by up to 10%. Glandon et al. (2019b) estimated that future winters could be up to 50% shorter and blue crab overwinter survival could increase by approximately 20%. Therefore, it is important to assess the historic trend in winter temperatures in Chesapeake Bay and the climate projections of future trends in temperature.
- Liang (2026) assessed the long-term, fixed-station seasonal monitoring conducted by the Chesapeake Bay Program which provides a spatially balanced representation of the Bay and estuary. These monitoring data were used to synthesize the environmental data collected during the blue crab surveys. To understand the variability of temperature and the changing environmental suitability of the blue crab population, a spatiotemporal synthesis of the survey environmental samples with data from the long-term fixed survey was developed. The study showed a positive trend for temperature for each habitat.

Weakness:

- While a number of important ecosystem and climate issues were examined under the TOR 8, there are many other climate-related issues that could have been assessed. The environmental conditions could drive many of the life history behaviours of blue crab and therefore it is important to understand what are the key changes that are occurring in Chesapeake Bay (e.g., as per Liang 2026), how could they be affecting the blue crab stocks and what are the climate projections for the key environmental variables.
- The decline in nutrient load in Chesapeake Bay was identified as a possible factor in the decline in recruitment and this should be further explored.
- Temperature-dependent growth models were examined but apparent periods of high growth in the spring and late summer that were evident in the Maryland and VIMS trawl surveys could not be described by these growth

models. Could there be lag effects on the effect of temperature on growth or could the rate of change in temperature (e.g., from winter to spring) be influencing growth? There are spatial temperature variations in the Bay that could also be affecting the temperature-growth model.

- Smaller crabs experienced lower rates of OWM when compared with larger crabs for males, immature and mature females. However, it was not clear if there is a biological explanation for the variation of OWM with size and maturity.

Conclusion:

The assessment includes valuable analyses of ecosystem and climate influences, highlighting factors such as predation by blue catfish, temperature effects on growth and overwinter mortality, and the roles of hypoxia and spatial temperature variation. Evidence suggests blue catfish may have reduced recruitment by around 8%, with potential for increasing impact as their range expands, while overwinter mortality varies widely (1–13%) depending on winter severity and is higher for larger crabs, highlighting the importance of continued climate monitoring. Studies indicate that warming winters could shorten their duration and increase crab survival, with broader environmental datasets showing rising temperature across habitats. However, gaps remain in fully understanding climate impacts, including limited exploration of additional environmental drivers (e.g., nutrient declines), unresolved dynamics in temperature-dependent growth, and unclear biological explanations for size-related differences in overwinter mortality. Overall, while progress has been made, a more comprehensive integration of environmental change and climate projections is needed to better understand and predict blue crab population dynamics. Based on the information provided on the ecosystem and climate influences, TOR 8 was partially met.

Recommendation:

- The spread of catfish in the Bay is continuing so its effect could increase over time which highlights the importance of continued monitoring of the catfish and its effect on crabs.
- OWM warrants continued monitoring of the winters as changes in temperature, winter severity, and rainfall could have a marked effect on crab survival. Therefore, it is important to assess the historic trend in winter temperatures and other relevant environmental variables in Chesapeake Bay and assess climate projections of future trends in environmental conditions.
- The environmental conditions could drive many of the life history behaviours of blue crab and therefore it is important to understand what are the key changes that are occurring in Chesapeake Bay, how could they be affecting the life history of blue crab stocks (such as spawning, recruitment, mortality, growth) and what are the climate projections for the key environmental variables. This information could inform the level of risk attached to blue crabs due to climate change.
- The effect of the decline in nutrient load in Chesapeake Bay on the recruitment abundance should be further explored.

TOR 9: *Does the assessment report on the status of research recommendations from the most recent benchmark assessment? Does the assessment identify and prioritize research recommendations for future work?*

Strength:

- The stock assessment report outlined the detailed work undertaken to address the previous research recommendations. This included (a) an integrated estimation of reference points and stock status; (b) using sex-specific growth and maturation improved the model's ability to match the sex ratio in catches and the winter dredge survey; (c) included additional surveys in the assessment such as ChesMMAAP and standardization of surveys using VAST and GAMS; (d) used a monthly time step to seasonality; (e) used the SERC tagging study in Maryland to quantify recreational harvest; (f) used additional data collection in the WDS to allow comparisons between the vessels; (g) used additional biological work on size-specific natural mortality for small blue crabs, changes over time in M for mature females and overwinter mortality; (h) reproductive studies and pre-pubertal crabs; and (i) ecosystem effects such as blue catfish interactions;.
- Recommendations have been made for future research to address knowledge gaps that were identified in this assessment. These included shallow water dredge survey, examine recruitment patterns, recording of pre-pubertal females, port sampling of catch, validation of harvest, development of a spatial model, examine stock-recruitment relationship, temperature growth model, environmental effects on recruitment, effect of cannibalism, and consideration of plankton surveys.
- The key data gaps identified were blue crab growth, drivers of recruitment, recreational harvest and bycatch mortality, spatial differences in survey trends and size distributions, natural mortality, and the WDS catchability and selectivity.

Weakness:

- The current assessment did not focus on potential oceanographic drivers of blue crab recruitment because an ongoing parallel study was investigating that topic. Environmental effects during the larval phase are often the key drivers of recruitment (especially as the mature female abundance is within historic range) so it will be interesting to see the outcome of this study.
- The current assessment attempted a spatial stock assessment model for blue crabs in Chesapeake Bay with 8 regions but was not successful. Some of the differences observed in current model are believed to be due to spatial recruitment and growth differences
- Given most of the recruitment comes from outside the Bay, it is important to assess what the key differences in spatial-temporal variation in recruitment between Maryland and Virginia, for example, and how they have changed over time. Analysis of age-0 crab abundance in the surveys would provide valuable information on spatial and temporal patterns of recruitment.

Conclusion:

The stock assessment demonstrates substantial progress in addressing prior research recommendations, including integrating reference points and stock status estimation within the model, improving model performance through sex-specific growth and maturation, expanding and standardizing survey inputs, incorporating monthly seasonality, and using new data sources such as tagging studies to quantify recreational harvest and updated biological research on mortality, reproduction, and ecosystem interactions like blue catfish predation. The assessment also clearly identified future research priorities, including improving shallow-water sampling, recruitment understanding, spatial modelling, environmental drivers, and harvest data validation, with key gaps noted in growth, recruitment processes, mortality, and survey selectivity. However, limitations remain, particularly the lack of oceanographic drivers of recruitment (pending separate research), unsuccessful attempts to implement a spatially explicit model despite evident regional differences, and insufficient understanding of spatial-temporal recruitment patterns. Prioritization of research recommendations has been the responsibility of the Chesapeake Bay Stock Assessment Committee (CBSAC), and many members of the assessment team also serve on the CBSAC. Based on the information provided on the previous research recommendations and identifying research recommendations, TOR 9 was met.

TOR 10: Based on your full review, is the 2025 Blue Crab Stock Assessment adequate for informing management decisions?

This assessment of the 2025 Chesapeake Bay Blue Crab Stock Assessment represents a large step forward from the last assessment. The assessment met or partially met all the TORs and represents the best available tool for management decisions.

Appendices

Appendix 1: *Bibliography of materials provided for review and references*

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Appendix 2: Performance Work Statement (PWS)

**National Oceanic and Atmospheric Administration (NOAA)
NOAA Fisheries
Office of Science & Technology
Center for Independent Experts (CIE)
External Independent Peer Review
Benchmark Quantitative Fishery Stock Assessment for Blue Crab in the
Chesapeake Bay (2023-2025)**

Background

The NOAA Fisheries is mandated by the Magnuson-Stevens Fishery Conservation and Management Act, Endangered Species Act, and Marine Mammal Protection Act to conserve, protect, and manage our nation's marine living resources based upon the best scientific information available (BSIA). NOAA Fisheries science products, including scientific advice, are often controversial and may require timely scientific peer reviews that are strictly independent of all outside influences. A formal external process for independent expert reviews of the agency's scientific products and programs ensures their credibility. Therefore, external scientific peer reviews have been and continue to be essential to strengthening scientific quality assurance for fishery conservation and management actions.

Scientific peer review is defined as the organized review process where one or more qualified experts review scientific information to ensure quality and credibility. These expert(s) must conduct their peer review impartially, objectively, and without conflicts of interest. Each reviewer must also be independent from the development of the science, without influence from any position that the agency or constituent groups may have. Furthermore, the Office of Management and Budget (OMB), authorized by the Information Quality Act, requires all federal agencies to conduct peer reviews of highly influential and controversial science before dissemination, and that peer reviewers must be deemed qualified based on the OMB Peer Review Bulletin standards¹.

Scope

The NOAA Chesapeake Bay Office requests an independent peer review for the 2025 "Benchmark Quantitative Fishery Stock Assessment for Blue Crab in the Chesapeake Bay" (blue crab stock assessment). This updated stock assessment will provide a critical science product at a time of partnership-wide strategic planning for the Chesapeake Bay Program and to inform science-based management of the Chesapeake Bay blue crab fishery.

In the Chesapeake Bay, the blue crab (*Callinectes sapidus*) supports economically and culturally important commercial fisheries. Diverse gears are used to harvest blue

¹ https://www.whitehouse.gov/wp-content/uploads/legacy_drupal_files/omb/memoranda/2005/m05-03.pdf

crabs regionally and seasonally, and many of these were developed in response to spatiotemporal variability in the presence of specific life stages. The previous benchmark blue crab stock assessment for the Chesapeake Bay was completed in 2011, and developed female biological reference points based on maximum sustainable yield (MSY). Following the 2011 assessment, management measures were implemented to reach the reference points and target exploitation rate for adult female crabs. Despite management successfully achieving the reference points and target exploitation rates, the population has not responded as anticipated in recent years. Specifically, recruitment has been lower than expected in the most recent decade. Improved understanding of continued low recruitment has been increasingly called for, and a new benchmark stock assessment was requested to reevaluate reference points for sustainable management. Potential causes of low recruitment include increased predation of juvenile blue crabs by finfish predators, changes in the ocean habitat and currents for larval blue crabs, reduced numbers of female spawners due to spring fishing for female blue crabs, and sperm limitation caused by too few adult male blue crabs.

Requirements

NOAA Fisheries requires **three (3)** reviewers to conduct an impartial and independent peer review in accordance with the Performance Work Statement (PWS), OMB guidelines, and the CIE Terms of Reference (ToRs) for reviewers listed below. The CIE reviewers shall have excellent communication skills in addition to working knowledge in fisheries stock assessment and modeling, statistics, fisheries science, and marine biology sufficient to complete the primary task of providing peer-review advice in compliance with the ToRs for the blue crab stock assessment. Preferably, reviewers will have specific expertise in crustacean fisheries. Additionally, the Chair, who is in addition to two CIE reviewers, will also be participating in this review and will be provided by the NOAA Chesapeake Bay Office. The Chair's participation (e.g., labor and travel) is not covered under this contract.

Terms of Reference for CIE Reviewers:

Each CIE reviewer shall complete the following tasks in accordance with the PWS and Schedule of Milestones and Deliverables herein.

- 1. Pre-review Background Documents:** A minimum of two weeks before the peer review, the NOAA Fisheries Project Contact will send by electronic mail or make available at an FTP site to the CIE reviewers all necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NOAA Fisheries Project Contract will consult with the Contractor on where to send the documents. The CIE reviewers shall read all documents in preparation for the peer review
- 2. Virtual Conferencing Test:** Additionally, one or two weeks prior to the peer review, the CIE reviewers will participate in a test to confirm that they have the necessary technical (hardware, software, etc.) capabilities to participate in the virtual panel in advance of the review meeting. This review's NOAA Fisheries Project Contact will provide the information for the arrangements for this test. The NOAA Fisheries Project Contact is responsible for facility arrangement

(e.g., video or teleconference arrangements). This virtual conferencing test will also serve as a check in on the panel review agenda, ensure reviewers have all necessary materials and address clarifying questions.

- 3. Attend and Participate in the Virtual Panel Review Meeting:** Each CIE reviewer shall conduct the independent peer review in accordance with the PWS and CIE ToRs for reviewers, and shall not serve in any other role unless, specified herein. Modifications to the PWS and the CIE ToRs for reviewers cannot be made during the peer review, and any PWS or CIE ToRs modifications prior to the peer review shall be approved by the Contracting Officer’s Representative (COR) and the CIE contractor. Each reviewer shall actively participate in a professional and respectful manner as a member of the review panel’s meeting. And their peer review tasks shall be focused on the CIE ToRs as specified herein.

- 4. Contract Deliverables – Independent CIE Peer Review Reports:** Reviewers are not required to reach a consensus. Each CIE reviewer shall complete the independent peer review according to required format and content as described in **Annex 1**. Each CIE reviewer shall complete the independent peer review addressing each of the questions in **Annex 2**. A draft agenda is provided in **Annex 3**. Each CIE reviewer will deliver their reports according to the specified milestone dates. Each reviewer shall assist the Chair of the meeting with contributions to the summary report.

Place of Performance

The place of performance shall be online.

Period of Performance

Each reviewer’s duties shall not exceed 14 days to complete all required tasks.

Schedule of Milestones and Deliverables: The contractor shall complete the tasks and deliverables in accordance with the following schedule:

Within two weeks of award	Contractor selects and confirms reviewers
Two weeks prior to review	Contractor provides the pre-review documents to the reviewers
April 13-16, 2026	Panel review meeting
Within two weeks after review	Reviewers submit draft peer-review reports to the contractor for quality assurance and review
Within three weeks of receiving draft reports	Contractor submits final reports to the Government

*The Chair's Summary Report will not be submitted to, reviewed, or approved by the Contractor.

Applicable Performance Standards

The acceptance of the contract deliverables shall be based on three performance standards:

(1) The reports shall be completed in accordance with the required formatting and content (2) The reports shall address each of the questions under the CIE ToR for reviewers as specified (3) The reports shall be delivered as specified in the schedule of milestones and deliverables.

Confidentiality and Data Privacy

This contract may require that services contractors have access to Privacy Information. Service contractors are responsible for maintaining the confidentiality of all subjects and materials and may be required to sign and adhere to a Non-disclosure Agreement (NDA).

Travel

Travel is not expected or authorized for this review.

NOAA Fisheries Project Contact:

Bruce Vogt
Ecosystem Science and Synthesis Manager
NOAA Chesapeake Bay Office
200 Harry S Truman Parkway, Annapolis, MD 21401
bruce.vogt@noaa.gov

Annex 1: Peer Review Report Requirements

1. The report must be prefaced with an Executive Summary providing a concise summary of the findings and recommendations and specify whether the stock assessment science reviewed is adequate for use in management.

2. The report must contain a background section, description of the individual reviewers' roles in the review activities, and a summary of findings for each question under the ToRs (*strengths and weaknesses, conclusions and recommendations for changes or improvements*).

a. Reviewers must describe in their own words the review activities completed during the panel review meeting, including a brief summary of findings, of the science, conclusions, and recommendations.

b. Reviewers should discuss their independent views on each ToR even if these were consistent with those of other panelists, but especially where there were divergent views.

c. Reviewers should elaborate on any points raised in the summary report they believe might require further clarification.

d. Reviewers shall provide a critique of the NOAA Fisheries review process, including suggestions for improvements of both process and products.

e. The report shall be a stand-alone document for others to understand the weaknesses and strengths of the science reviewed, regardless of whether or not they read the summary report. The report shall represent the peer review of each question under the ToR section, and shall not simply repeat the contents of the summary report.

3. The report shall include the following appendices:

Appendix 1: Bibliography of materials provided for review

Appendix 2: A copy of this Performance Work Statement

Appendix 3: Panel membership or other pertinent information from the panel review meeting.

Annex 2: Terms of Reference for the Peer Review

Benchmark Quantitative Fishery Stock Assessment for Blue Crab in the Chesapeake Bay (2023-2025)

CIE reviewers are contracted to complete their independent peer review based on the ToRs. Therefore, the CIE-NOAA Fisheries review and approval process is based on whether the CIE independent reports addressed each of the ToRs. The specific responsibilities of the CIE review are to provide detailed written responses to the questions below as part of their review. Responses to each of these questions should include strengths and weaknesses, conclusions and recommendations for changes or improvements.

- *Does the assessment critically review and estimate life history parameters and vital rates of blue crab in the Chesapeake Bay that are relevant to the stock assessment? In particular, does the assessment evaluate the extent and scale of interannual variation in life history parameters and vital rates of blue crab in the Chesapeake Bay?*
- *Does the assessment describe and quantify patterns in fishery-independent surveys to develop indices of abundance and characterize the size composition of the population?*
- *Does the assessment describe and quantify patterns in catch, effort, and CPUE?*
- *Does the assessment evaluate the feasibility of, and if possible, implement blue crab stock assessment models that operate on sub-annual time steps and/or at spatial resolutions lower than that of the entire Chesapeake Bay to better represent population dynamics?*
- *Does the assessment characterize uncertainty in assessment estimates (mortality and abundance)?*
- *Does the assessment update the sex-specific catch survey models used in the 2011 benchmark stock assessment with relevant new data? Does the assessment characterize major changes in assumptions between the 2011 assessment model and the 2023 model?*
- *Does the assessment recommend appropriate biological reference points for management? Does the assessment evaluate stock status relative to recommended reference points?*
- *Does the assessment identify relevant ecosystem and climate influences (such as habitat, environmental drivers, prey availability, and*

predation/cannibalism) on the population dynamics and fisheries and explore other analyses that support the assessment?

- *Does the assessment report on the status of research recommendations from the most recent benchmark assessment? Does the assessment identify and prioritize research recommendations for future work?*
- *Based on your full review, is the 2025 Blue Crab Stock Assessment adequate for informing management decisions?*

Annex 3: Tentative Agenda

Chesapeake Bay Blue Crab Stock Assessment Review

Annapolis, MD

April 13-16, 2026

This meeting is open to the public

Point of contact: Bruce Vogt
Ecosystem Science and Synthesis Manager
NOAA Chesapeake Bay Office
200 Harry S Truman Parkway, Annapolis, MD 21401
bruce.vogt@noaa.gov

Appendix 3: Panel membership or other pertinent information from the panel review meeting.

The review panel members were:

- Nick Caputi from the Western Australian Department of Primary Industries and Regional Development, Australia (CIE),
- Yong Chen from State University of New York at Stony Brook (CIE),
- Simon de Lestang from the Western Australian Department of Primary Industries and Regional Development, Australia (CIE), and
- Dan Hennen from the National Marine Fisheries Service (Panel chair).

Nick Caputi and Simon de Lestang attended the meeting online from Australia. The attendees over the three-day panel meeting were:

Day 1:

Dan Hennen (NOAA), Michael Wilberg (UMCES CBL), Bruce Vogt (NOAA), Christina Garvey (CRC), Nick Staten (CRC), Madison Sholes (UMCES CBL), Dong Liang (UMCES CBL), Gina Ralph (VIMS), Gabrielle Salula (VIMS), Rom Lipcius (VIMS), Carrie Kennedy (MDNR), Maya Drzewicki (UMCES CBL), Yong Chen (Stony Brook University/CFE), Ingrid Braun-Ricks (PRFC), Alexei Sharov (MDNR), Trey Mace (MDNR), Mandy Bromilow (MDNR), Amanda Bevans (MSU PEARL), Tom Ihde (MSU PEARL), Rob Latour (VIMS), Alexa Galvan (VMRC), Brooke Lowman (VMRC), Matt Ogburn (SERC), Rob Aguilar (SERC), Tom Miller (UMCES), Troy Tuckey (VIMS), Nick Caputi (DPIRD), Simon De Lestang (DPIRD), William Stoker (MDNR), Amy Schueller (NOAA), Sharon McBreen (PCT), Danielle Kozkinski (MBA), Matthew Zink (NCDEQ), Holly Funkhouser (SC DNR), CJ Schick (SC DNR), Jeff Brunson (SC DNR), Graham Wagner (SC DNR), Ron Owens (PRFC)

Day 2:

Dan Hennen (NOAA), Michael Wilberg (UMCES CBL), Bruce Vogt (NOAA), Christina Garvey (CRC), Nick Staten (CRC), Madison Sholes (UMCES CBL), Dong Liang (UMCES CBL), Gina Ralph (VIMS), Gabrielle Salula (VIMS), Rom Lipcius (VIMS), Carrie Kennedy (MDNR), Maya Drzewicki (UMCES CBL), Yong Chen (Stony Brook University/CFE), Ingrid Braun-Ricks (PRFC), Alexei Sharov (MDNR), Trey Mace (MDNR), Mandy Bromilow (MDNR), Amanda Bevans (MSU PEARL), Tom Ihde (MSU PEARL), Rob Latour (VIMS), Alexa Galvan (VMRC), Brooke Lowman (VMRC), Matt Ogburn (SERC), Troy Tuckey (VIMS), Nick Caputi (DPIRD), Simon Delestang (DPIRD), William Stoker (MDNR), Matthew Zink (NCDEQ), CJ Schick (SC DNR), Ron Owens (PRFC), Adriana Celtruda (UMD), Matthew Damiano (NC DMF)

Day 3:

Dan Hennen (NOAA), Michael Wilberg (UMCES CBL), Bruce Vogt (NOAA), Christina Garvey (CRC), Nick Staten (CRC), Madison Sholes (UMCES CBL), Dong Liang (UMCES CBL), Gina Ralph (VIMS), Gabrielle Salula (VIMS), Rom Lipcius (VIMS), Carrie Kennedy (MDNR), Maya Drzewicki (UMCES CBL), Yong Chen

(Stony Brook University/CFE), Ingrid Braun-Ricks (PRFC), Trey Mace (MDNR), Mandy Bromilow (MDNR), Amanda Bevans (MSU PEARL), Tom Ihde (MSU PEARL), Rob Latour (VIMS), Alexa Galvan (VMRC), Brooke Lowman (VMRC), Matt Ogburn (SERC), Troy Tuckey (VIMS), Nick Caputi (DPIRD), Simon Delestang (DPIRD), Heather Hayden (MDNR), William Stoker (MDNR), Tom Miller (UMCES)