

**Center for Independent Experts (CIE) Independent Peer Review
Report**

on

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

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I. Executive Summary

The Benchmark Quantitative Fishery Stock Assessment for Blue Crab in the Chesapeake Bay (2023-2025) Review was held online and in person in Annapolis, Maryland from April 13-16, 2026. The CIE review aimed to provide an independent external peer review to evaluate if a pre-defined set of Terms of Reference is addressed to ensure that the stock assessment provides best available information to inform management decisions.

The NOAA Chesapeake Bay Program provided the necessary logistics support, documentation, presentation slides, and background information for the review. The Assessment Team (AT) was open in the review process to suggestions and provided additional analyses and information upon request. The review process was transparent and constructive. I would like to commend the effort of the AT for developing the stock assessment models; evaluating the quality and quantity of input data; evaluating ecosystem and climate factors to inform the development of model configurations and parameterizations; and addressing the uncertainty associated with the input data and model structure. As a CIE reviewer, I evaluated the Benchmark Quantitative Fishery Stock Assessment for Blue Crab in the Chesapeake Bay (2023-2025) Review with respect to the pre-defined Terms of Reference.

The current Chesapeake Bay blue crab stock assessment represents a major methodological advance and provides robust analytic tools for assessment and projection of the Chesapeake Bay blue crab stock dynamics with respect to various uncertainties in data and models. The assessment represents a substantial and technically rigorous update relative to prior benchmarks, incorporating improved data streams and modernized modeling approaches. The assessment used long-term fishery-independent surveys (e.g., dredge survey), explicitly considered sex-specific dynamics, improved integration of multiple data sources relative to the 2011 benchmark, and thoughtfully explored alternative model structures. Overall, I conclude that the assessment presented in the Benchmark Quantitative Fishery Stock Assessment for Blue Crab in the Chesapeake Bay (2023-2025) is scientifically sound and that the models configured and the results derived represent the best available science and are adequate for addressing current management needs. However, I also identified a set of critical uncertainties limiting further gains in management precision. Chief among these is a persistent decline in recruitment that remains unexplained, alongside sensitivity to growth assumptions, incomplete accounting of total removals, lack of considering process error, limited incorporation of ecosystem drivers into core model structure, inadequate documentation on the protocols for the development of the base models and sensitivity analyses, and unresolved survey catchability. Addressing these gaps requires a strategic transition from a data-rich but process-limited assessment framework to a next-generation, process-explicit, and ecosystem-integrated assessment system.

Priority research should focus on resolving recruitment dynamics through coupled biophysical and ecological modeling of larval transport and early life stages; developing temperature- and density-dependent growth and natural mortality formulations; and substantially improving estimates of total removals via enhanced monitoring of recreational harvest and discard mortality. Complementary efforts are needed to calibrate and validate survey catchability, particularly the Winter Dredge Survey that underpins assessment inference, and implement spatially explicit and ecosystem-informed models that capture regional heterogeneity, climate

variability, and emerging predator impacts (e.g., blue catfish). Collectively, these priorities support the development of fully integrated population models with rigorous uncertainty quantification and modernized monitoring systems. This next phase of research is necessary to sustain one of the most economically and ecologically important fisheries in the region and is well aligned with agency priorities for ecosystem-based fisheries management and climate-ready decision support. More detailed research recommendations can be found in the Review Panel's report.

II. Background

The Chesapeake Bay blue crab (*Callinectes sapidus*) fishery is the most valuable estuarine fishery in the United States and a cornerstone of regional ecosystems and coastal economies (Wilburg et al. 2026). Despite decades of monitoring and adaptive management, the population exhibits high interannual variability driven by recruitment uncertainty, habitat change, and climate variability. Current stock assessments rely on index-based approaches (catch-survey model) that lack mechanistic representation of key ecological processes. While management has successfully avoided persistent overfishing, the system is increasingly constrained by recruitment variability driven by oceanographic processes, habitat degradation (submerged aquatic vegetation SAV, marsh loss), climate-driven environmental change, and limited predictive capability of current assessment models (Wilburg et al. 2026).

Blue crab are short-lived with a life span of approximately 3 to 4 years. It grows fast via molting, reaching maturation in about 12-18 months. The growth is temperature-dependent with warmer temperature increasing growth rates (Brylawski and Miller 2006). Blue crab is high fecund with 0.75-3.2 million eggs per brood. Sexual dimorphism is obvious with males growing large and females having a terminal molt. Males remain in low-salinity upper Bay waters and females migrate to high-fecundity lower Bay/ocean to spawn. Females tend to mate once and store sperm for multiple broods. Spawning usually occurs at the Bay mouth with larvae exported to the coastal ocean. Post-larvae return via wind-driven transport. This creates a recruitment bottleneck highly sensitive to climate, wind, and circulation.

Blue crab are habitat generalists but ontogenetically structured. Larvae are mainly found in coastal ocean for development and juveniles are in submerged aquatic vegetation, marsh and shallow waters for nursery grounds. Adult blue crabs are distributed along broad estuary gradients for feeding and reproduction. Key habitats include SAV, salty marshes (increasingly recognized as critical nursery habitat), oyster reefs, and soft sediments (overwintering). Recent modeling shows salt marshes may rival or exceed SAV in nursery value, challenging earlier paradigms.

Blue crab are top benthic predators and major prey species of fishes, birds, and turtles. Their diets include bivalves (clams and oysters), Polychaeta, and detritus. They are strongly cannibalistic and cannibalism is an important mortality driver. The ecosystem functions of blue crab include controlling benthic community structure, linking benthic-pelagic food webs, and influencing oyster reef dynamics. Changes in their dynamics can have system-wide cascading effects.

The blue crab population in Chesapeake Bay is highly variable interannually. The key drivers include density-independent drivers such as wind-driven larval transport, temperature (winter mortality), habitat availability (SAV, marsh), predation, and fishing mortality; and density-dependent factors such as cannibalism and age-structured dynamics.

The blue crab fishery is the most valuable fishery in Chesapeake Bay, with landed value varying annually from \$50 to \$100 million. The fishery is predominantly commercial with crab pots as the dominant gear and relines and scrapers and dredges. The fishery is size- and sex-selective with males heavily targeted and females increasingly protected (management evolution). The fishery is seasonal with peak harvest during summer to fall and little fishing activity in winter.

Stock assessment is conducted by Maryland Department of Natural Resources (DNR), Virginia Marine Resources Commission, and Potomac River Fisheries Commission, coordinated by the Chesapeake Bay Stock Assessment Committee (CBSAC). Key datasets include the winter dredge survey that is Bay-wide, fishery-independent with 1,500+ stations annually and provides sex-specific abundance and recruitment index, fishery-dependent data with landings, effort and catch-per-unit-effort (CPUE). Unlike assessment models for many fisheries, the blue crab assessment is a catch-survey model developed in 2011 (Miller et al. 2011, 2026), not a classic age-structured model. Not consistently overfished, but with frequent low recruitment episodes, and the population exhibits boom–bust cycles. Recent concerns that were particularly alarming were near-record low abundance (2022–2025) and declines in juveniles.

The Chesapeake blue crab management system is multi-jurisdictional governance including management tools such as input controls, seasonal closures, area restrictions, limited entry, output controls, size limits, bushel limits, targeted conservation measures, female protection (e.g., spawning sanctuaries), and winter dredge fishery restrictions. The management tends to be highly responsive and data driven with the three jurisdictions setting their regulations. The Chesapeake Bay crab fishery is one of the closest real-world examples of EBFM with an integrated consideration of habitat restoration (SAV, marsh), water quality, predator-prey interactions, climate variability, and key ecosystem linkages among blue crab versus oysters, blue catfish, red drum and menhaden & striped bass systems and between habitat and recruitment.

The Chesapeake blue crab fishery also faces major scientific and management challenges including a lack of understanding of large recruitment variability (core uncertainty), poorly predicted ocean transport processes that are poorly predictable, and larval pathways altered by climate change. Habitat degradation resulted in loss of SAV and marsh, and subsequently reduced nursery habitat that strongly linked to juvenile survival. Climate change also resulted in temperature extremes with increased winter mortality and more frequent storms leading to larval export failure. The impacts of predation and invasive species, such as blue catfish and red drum, exert increasing pressure on blue crab and are also not well understood. Socioeconomic pressures with high economic importance also lead to resistance to restrictive measures in management.

As a CIE reviewer, I was tasked to evaluate the Benchmark Quantitative Fishery Stock Assessment for Blue Crab in the Chesapeake Bay (2023-2025; Wilberg et al. 2026) with respect

to the Terms of Reference provided by the CIE. This report is prepared following the required format including an executive summary (Section I), a background introduction (Section II), a description of my role in the review activities (Section III), my comments on each item listed in the Terms of Reference (ToRs, Section IV), a summary of my comments and recommendations (Section V), and references (Section VI). The final part of this report (Section VII) includes a collection of appendices including the Statement of Work (SoW).

III. Description of the Individual Reviewer's Role in the Review Activities

My role as a CIE independent reviewer was to conduct an impartial and independent peer review of the Benchmark Quantitative Fishery Stock Assessment for Blue Crab in the Chesapeake Bay (2023-2025, Wilburg et al. 2026) with respect to the pre-defined Terms of Reference. About two weeks prior to the review workshop at the NOAA Chesapeake Bay Program in Annapolis, Maryland, the Assessment Report and supporting working papers were provided to the reviewers. I downloaded all the materials on the site for the Benchmark Quantitative Fishery Stock Assessment for Blue Crab in the Chesapeake Bay (2023-2025), and read all the relevant documents downloaded (see the list in Appendix I). I also collected and read references relevant to the topics covered in the reports and the SoW prior to my trip to the review.

The hybrid CIE review workshop was held from April 13 to 16, 2026 at the NOAA Chesapeake Bay Program (see Appendix II for the schedule). The four days of the review were chaired by Dr. Daniel Hennen of Northeast Fisheries Science Center and attended by scientists, managers and other stakeholders from various organizations (see the List of Participants in Appendix III).

Presentations were given during the four days of the review to provide the CIE reviewers with the relevant information. Additional analyses were requested during the review and the AT accommodated all the requests by the Review Panel. I was actively involved in the discussions during the presentation by questioning and making comments and suggestions. I also discussed relevant issues with fellow reviewers.

IV. Summary of Findings

My detailed comments on each item of the TORs are provided under their respective subtitles from the TORs (see below).

- 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?***

I concluded that this TOR was partially addressed.

Life history parameters are generally well-documented and incorporate sex-specific structure. However, interannual variability and spatially variability are insufficiently evaluated and quantified and not fully propagated into the model, particularly for natural mortality, growth, maturation, and recruitment. Environmental drivers are discussed, but not formally integrated and quantified. The absence of formal estimation or sensitivity analyses of interannual

variability in key life history parameters limits confidence in the quantification of uncertainty associated with the stock assessment.

Blue crab has a discrete molting process, and growth is stepwise, not continuous with terminal molt defining entry into adult (reproductive) stage for females. Although the growth has been known to be temperature dependence, it is simplified or averaged in the assessment. Terminal molt is treated as deterministic above size thresholds, however, evidence suggests probabilistic molt decisions influenced by density, food, and environmental stress. The possible mis-specification leads to incorrect timing of recruitment to spawning stock and bias in spawning stock biomass (SSB).

The key drivers for M are predation (fish, birds, and cannibalism), winter mortality (temperature-driven) and disease (e.g., Hematodinium). The assessment assumes constant or piecewise-constant M , although this may not be the case because of strong winter severity, density-dependent cannibalism and/or episodic mortality events (hypoxia, disease) resulting in large interannual variability. This may lead to underestimating variability in M , inflating perceived recruitment variability, and masking environmental forcing. 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 SLAM as a sensitivity test.

The recruits, defined as the number of age-0 crabs entering juvenile population, are assumed to occur every February. The key drivers for the recruitment include spawning stock biomass (SSB), larval survival (ocean phase), wind-driven transport, and estuarine conditions (salinity, temperature). The recruitment is treated as a lognormal random effect, showing extremely high interannual variability and the stock–recruit relationship is weak. Recruitment variability dominates stock dynamics which limits predictability of assessment outputs. The SLAM model currently assumes a fixed (log normal) size distribution and pulse recruitment in February, which may be inconsistent with the molting events observed in the field. The impacts of assumed recruitment timing on the stock assessment should be carefully evaluated.

Spawning stock biomass (SSB) is approximated using mature female abundance, which does not fully capture size-dependent fecundity and brood frequency variability. Thus, it is possible that SSB might be misestimated if size structure is ignored.

Females experience directed migration to spawning grounds, while males are more resident, which may affect survey availability, catchability, and spatial structure of mortality. This spatial structure was not explicitly considered in the assessment. The current assessment model implicitly assumes homogeneous mixing, ignoring strong spatial gradients.

Covariation among parameters, such as key interactions among increased growth, reduced winter mortality, and improved recruitment in warm years, and between increased cannibalism and reduced growth in high density situations, was evaluated qualitatively, but not quantitatively and not given consideration in the assessment model. This failure to model covariance of parameters that are not independent may lead to overestimation of uncertainty and misleading stock projections.

Overall, I conclude that key weaknesses include spatially/temporally static or simplified vital rates (e.g., M, growth, and fecundity), recruitment variability largely statistical rather than mechanistic, incomplete treatment of process error with interannual variability often absorbed into recruitment deviations and observation error. Spatial structure is ignored and migration and habitat heterogeneity are not fully represented.

Natural mortality is highly variable and environmentally driven but underrepresented in current models. Growth and molting processes are temperature-dependent and nonlinear yet often oversimplified in the model. Fecundity and spawning outputs are not fully captured by current SSB proxies, especially given size structure effects. The current assessment framework is robust but relies heavily on statistical compensation rather than mechanistic realism.

I recommend that environmental forcing be explicitly considered in modeling recruitment dynamics as a function of wind, temperature, salinity and winter mortality as function of temperature anomalies. Time-varying natural mortality may be explored to incorporate winter severity index and density-dependent mortality (e.g., cannibalism). Recruitment variability is the dominant driver of the population dynamics, with order-of-magnitude interannual fluctuations. I conclude that the assessment partially meets the requirement to account for interannual variability in life history parameters and vital rates. The largest gap lies in explicit modeling of environmentally driven variability and proper treatment of time-varying natural mortality and recruitment processes. Addressing these gaps would significantly improve biological realism, model predictive skill, and assessment and management robustness under climate variability.

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?

I concluded that this TOR was partially addressed.

The blue crab assessment relies heavily on multiple long-term fishery-independent surveys, primarily the winter dredge survey (WDS), the baywide trawl survey and the spawning female survey targeting lower Bay sampling. These surveys provide absolute/relative abundance indices, sex-specific estimates (critical for management), size composition (carapace width distributions), spatial distribution, and some environmental conditions. In particular, WDS, following stratified random design across depth/salinity strata, provides a long time series of estimates of baywide total abundance, age-0 (juvenile) abundance, and adult male and female abundance. The WDS shows a strong interannual variability with order-of-magnitude swings in juvenile abundance, provides clear cohort tracking with high juvenile years leading to elevated adult abundance the following year, and has sex-specific differences with female abundance more stable due to management protections.

Size composition data were collected and compiled with carapace width (CW) measured per individual, bimodal or multimodal distributions for juveniles (small CW), subadults, and adults (post-terminal molt). Seasonal truncation in CW was observed with winter surveys underrepresenting the smallest juveniles and interannual shifts with strong recruitment years having left-skewed distributions. Sex differences are also observed with males attaining larger sizes than females. The survey size composition provides indirect information on growth rates,

molting schedules and recruitment strength. However, unlike abundance index data that are standardized, size composition data are not standardized, which might create inconsistency in model fitting.

The WDS is considered the gold standard for this stock with near-complete spatial coverage, long time series (>30 years), and direct input to management benchmarks (abundance thresholds). The trawl surveys and pot survey provide strong indicators of recruitment and are useful for early warning signals. Overall, these multiple survey programs are highly informative and central to the assessment and provide calibration for population models. However, large uncertainty is associated with gear selectivity, with dredge efficiency and size-dependence and small crabs being under-sampled. Catchability (q) is assumed constant or estimated with uncertainty, but it is likely to vary with temperature, substrata, and crab behavior (burial). Some survey programs may be spatially biased with some habitats underrepresented (e.g., shallow vegetated areas and complex substrates).

This TOR explicitly asks for consideration of environmental and abiotic factors in index standardization. While the VAST framework provides terms for density and catchability covariates, in practice only vessel effects and area-swept offsets were employed. Temperature and salinity data are collected and are known to affect blue crab availability to the survey. Productivity of the system, based on temporal and spatial proxies of nutrient load, are also available. This is particularly important for the WDS, where water temperature directly determines whether crabs are torpid and available to the dredge gear. The spatiotemporal random fields in VAST capture some environmental variation implicitly, but an explicit evaluation of whether including environmental covariates improved index standardization was not reported.

Overall, I conclude that the surveys are highly suitable and essential for the stock assessment, but require careful treatment of catchability, size selectivity, and environmental effects. However, most indices are not fully standardized. Impacts of environmental covariates are recognized but not consistently integrated. Thus, interannual variability may reflect true abundance changes and/or survey catchability shifts. I encourage the AT to continue exploring statistical approaches to standardize the surveys for both abundance indices and size composition data. Spatiotemporal models (e.g., VAST-type frameworks) may be a suitable framework to integrate the survey data to develop an integrated blue crab abundance index.

Uncertainty associated with the survey data includes sampling error, process error, observation error and model error in data standardization. The AT provided design-based or model-based variance estimates for all survey abundance indices, applied GAM/GLM models to consider environmental covariates, and considered some uncertainty propagation into the assessment model. However, catchability uncertainty is considered fixed over time and location, environmental variability is not explicitly included, and correlated errors across years are typically ignored. Uncertainty associated with survey size composition data is quantified using assigned effective sample sizes, which is appropriate in this study.

I conclude that the AT did an adequate job to finish the review of survey utility with surveys thoroughly described and justified, strengths clearly demonstrated, and limitations adequately acknowledged. The AT did an adequate job in index standardization with appropriate models

and environmental effects recognized but not fully modeled. The AT quantified sampling uncertainty, but broader uncertainty (catchability, process error) was incompletely addressed.

I think that the WDS is exceptionally strong and anchors the assessment. The main scientific gap is not data availability, but rather insufficient statistical standardization and incomplete uncertainty propagation. Addressing these would reduce bias, improve precision, and enhance management confidence under high environmental variability. I recommend that state-space models be considered to separate observation vs. process error. The AT can also consider a bootstrapping approach to resample survey strata/tows to quantify the uncertainty. Bayesian hierarchical models can also be used in explicit uncertainty propagation, and spatiotemporal covariance modeling can be useful to better quantify the uncertainty.

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

I concluded that this TOR was adequately addressed.

The blue crab fishery data in Chesapeake Bay are collected separately by the Maryland Department of Natural Resources, the Virginia Marine Resources Commission, and the Potomac River Fisheries Commission. Data streams mainly include commercial landings (by gear, season, jurisdiction), effort (e.g., number of pots, trips, licenses), fishery-dependent CPUE (catch per pot-day, per trip), recreational harvest estimates, and discard/bycatch estimates (limited, gear-specific). Typical annual landings range from 30 to 60 million pounds with strong interannual variability linked to recruitment. Jurisdictional contributions of approximate ranges is 40-50% for Maryland, ~40–50% for Virginia: ~40–50%, and 5-10% for the Potomac River. Catch peaks follow strong year classes (with 1–2 year lag). Declines are often associated with poor recruitment and management restrictions (e.g., female harvest limits). Effort metrics include the number of active licenses, the number of pots deployed, and trips or fishing days. Effort experiences long-term decline in number of fishers with increased efficiency per fisher (technology, gear improvements). Effort is highly seasonal (summer–fall peak) and responsive to stock abundance and market price. Effort is not independent of stock size, creating challenges for CPUE interpretation.

Catch and effort are estimated by Jurisdiction with mandatory reporting systems including dealer reports and harvester logbooks (variable completeness). The catch is derived by expanding sampled data to the total fleet with cross-validation using market receipts and enforcement data. The commercial catch and effort are long time series with near-complete commercial landings coverage and jurisdiction-specific resolution. However, underreporting is likely and historically more significant in earlier decades, with effort metrics across jurisdictions being inconsistent with Maryland having better pot-level data, Virginia having more trip-based metrics and Potomac data sometimes being sparse. Landings uncertainty is typically low–moderate (~5–15%), but effort uncertainty is moderate–high (~10–30%). Overall, I conclude that catch estimation is robust, but effort estimation is more uncertain and inconsistent across jurisdictions.

CPUE generally tracks abundance trends and increases in strong recruitment years but is often less variable than survey indices. Because fishers concentrate effort in high-density areas, CPUE remains high even when stock declines, and improvements in gear and knowledge increase efficiency over time. CPUE correlates with survey indices, but the relationship is nonlinear and

weakens at low abundance. CPUE provides supporting information but is not reliable as a primary abundance index.

Major changes in fisheries reporting include transition to electronic reporting, improved compliance monitoring and changes in effort definitions (pots vs. trips). These changes apparently increased catch reported in some years due to improved reporting, and shifted CPUE due to redefinition of effort units and better tracking of fishing activity. It is important to note potential temporal artifacts with structural breaks in the time series (e.g., pre- vs. post-electronic reporting, changes in size selectivity and market categories). The AT reported changes, but they were not fully quantified or corrected in CPUE analyses.

Bycatch and discards are derived from the commercial pot fishery (low discard mortality for crabs, but non-zero), from peeler/cull discards and from trawl bycatch (juveniles). Discard mortality is typically assumed 10–30%, but is uncertain. Bycatch is higher for juveniles. Recreational harvest is not well estimated. Key gaps include sparse direct observation data with limited coverage of illegal harvest, unreported recreational effort and high uncertainty in discard mortality rates. I conclude that bycatch and recreational removals are included but weakly quantified, with substantial uncertainty.

The source of uncertainty includes reporting error (landings), effort mismeasurement, CPUE bias (hyperstability, effort creep), discard mortality assumptions, and recreational survey error. Landings uncertainty is relatively well understood, CPUE uncertainty is largely qualitative, and uncertainty for discards and recreational is scenario-based or assumed values. There is a lack of integrated uncertainty propagation and errors were often treated independently when they may be correlated. I conclude that uncertainty for the fisheries data is partially characterized, but not comprehensively quantified or propagated.

I conclude that the AT completed catch and effort estimation with jurisdictional estimates provided and reasonable accuracy. CPUE utility is defined with limitations recognized (i.e., hyperstability, bias). Changes in reporting were identified but not fully modeled. Bycatch, discards, and recreational catch estimates were included with poor data quality. Key uncertainties were acknowledged but not fully quantified.

Catch data are strong, but effort and CPUE interpretation remain problematic. The biggest risks to assessment accuracy come from CPUE bias (i.e., hyperstability, effort creep) and poorly quantified discards and recreational harvest. The work would benefit most from standardized CPUE modeling (GLM/GAM), improved discard mortality studies and integrated uncertainty frameworks.

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?

I concluded that this TOR was partially addressed.

This TOR evaluates whether it is feasible, and scientifically justified, to move beyond the current annual, bay-wide stock assessment framework toward models that operate on sub-annual time

steps (e.g., seasonal or monthly), and/or incorporate finer spatial resolution (e.g., upper, mid, lower Bay or habitat-specific regions) to better capture the biological and fishery dynamics of blue crab.

The AT found that there is strong scientific justification for both temporal and spatial refinement, sub-annual dynamics are critical because blue crab populations are governed by seasonal processes, including molting cycles, recruitment pulses, and seasonal fishing mortality (summer–fall peak). Annual models average over these processes, potentially masking intra-annual mortality and timing of recruitment and harvest. The spatial structure is also essential because the Bay exhibits strong gradients in salinity, temperature, and habitat type. Blue crab behavior is also spatially structured with female spawning migration to lower Bay and juvenile nursery habitats in upper/mid Bay.

The AT conducted the feasibility assessment for a spatially explicit model with fine time steps (monthly). The AT examined the data availability supporting spatial and sub-annual modeling. Modeling complexity with sub-annual and spatial models was also evaluated with the need for increased parameterization, greater computational demand, and careful treatment of movement and connectivity. However, such fine scales may risk overparameterization relative to data availability, especially for time-varying natural mortality and movement rates between regions. The AT clearly identified biological need for finer temporal and spatial resolution, data strengths (spatial surveys) and limitations (temporal resolution), and trade-offs between realism and complexity.

The AT conducted some exploratory or conceptual work and decided not to develop a spatially explicit assessment model, but use a model with monthly time steps. The development of the Sex and Length Structured Assessment Model is a substantial improvement for the Chesapeake Bay blue crab stock assessment, moving from the annual age-based catch survey model used in 2011 to a monthly, length- and sex-structured framework implemented in RTMB. The model code is clear and well structured, and the process of tracking males, immature females, and mature females through 1-cm length bins, applying length-based natural mortality, overwinter mortality, and fleet-specific fishery selectivity is appropriate. The use of RTMB provides automatic differentiation and access to random effects. The model converged with a small maximum gradient and an invertible Hessian, and the jitter analyses, while revealing some instability associated with PEARL catchability and ChesMMAF selectivity, supported the robustness of the chosen base model. However, the model development process was not well documented and did not fully capture the sequence of decisions and iterations that led to the final model structure, as described during the review process.

The model estimates fishing mortality separately for every month, sex and fleet, leading to a large number of parameters to be estimated. This may result in model overfitting, which should be carefully evaluated. The AT may consider a hybrid-F method, which assumes sex-aggregated fleet-specific mortality iteratively given observed total catches and predicted exploitable abundance. This would achieve the same outcome with far fewer estimated parameters and would force the model to reconcile sex ratios through population dynamics and selectivity rather than through unconstrained F estimates. Selectivity was fixed based on minimum size regulations rather than estimated, which is a defensible simplification, but the iterative addition of constants to the inflection point parameter to improve fits introduces a degree of ad hoc tuning

that is difficult to evaluate. The assumption that recreational selectivity is identical to commercial fishery selectivity for each jurisdiction is unrealistic given the different gears and fishing behaviors involved.

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

I concluded that this TOR was partially addressed.

I evaluated whether the assessment identifies and quantifies uncertainty in key outputs, particularly for the estimates of abundance (males, immature females and females), fishing mortality F , and recruitment. I agreed that the AT identified major sources of uncertainty, including (1) observation uncertainty consisting of survey sampling errors and catch and effort reporting error; (2) process uncertainty such as interannual variability in recruitment, natural mortality, growth, maturation, and survey catchability; (3) model/structural uncertainty with assumptions about constant or simplified natural mortality, catchability (q), and (lack of) stock-recruit relationships; and (4) data gaps such as discard mortality, recreational harvest, and environmental drivers.

The AT quantified some of these uncertainties in the assessment, including uncertainties associated with survey data, commercial and recreational fisheries data, and life history parameters. The AT describes the major uncertain sources in an explicit and transparent way. However, I considered the uncertainties considered in the assessment largely reflect sampling error only and do not fully include catchability uncertainty, environmental variability, and process error. No time-varying life history parameters (e.g., M and growth) and no environmental drivers were explicitly considered. No fully integrated uncertainty framework, such as state-space or Bayesian treatment, was explicitly considered and there is a limited accounting for correlated errors across processes and possible interactions among uncertainty sources.

The AT conducted sensitivity analyses with respect to natural mortality assumptions, recruitment variability and some survey inputs, which helps bound uncertainty where direct estimation is difficult and provides insight into model robustness. However, the process of developing the base model and sensitivity analyses is not well structured and not well documented, making it difficult to have a full understanding of the uncertainty sources considered in the assessment.

I considered that the AT clearly and thoroughly identified uncertainty sources, had strong treatment of survey-based (sampling) uncertainty, and used sensitivity analyses to explore key assumptions. However, explicit quantification of process uncertainty such as natural mortality uncertainty and catchability uncertainty is limited.

I recommend that the AT develop state-space or Bayesian frameworks to separate process versus observation errors and explicitly consider time-varying mortality uncertainty and integrate uncertainty across surveys, catch data, and environmental drivers. I recommend that the AT document the protocols and process that led to the development of the base model and sensitivity analysis models.

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?

I concluded that this TOR was adequately addressed.

This TOR has two core components: (1) model updating, which include incorporating new data (2011–2023) into the sex-specific catch-survey model that was used in the previous assessment and ensuring continuity with the 2011 benchmark while improving model biological realism, and (2) model comparison to clearly document and evaluate changes in assumptions and structure and stock assessment results between the 2011 benchmark model and 2023 assessment model.

The AT successfully updated the 2011 model framework, retaining its core structure with stage-structured (juvenile and adult), sex-specific population dynamics and integration of fishery-independent survey indices and fisheries data. New data extending time series from 2011 to 2023 were incorporated with updated multiple survey indices (e.g., winter dredge survey) and fisheries data. I concluded that the update is technically sound and consistent with best practices and maintains continuity with the 2011 benchmark, which is important for management comparability. I concluded that the first part of this TOR for model updating is met.

For the characterization of changes between 2011 and 2023 models, the AT identified several major categories of changes, though they were not always synthesized and organized as clearly as desired. The major changes in model assumptions and structure include changes in (1) data inputs (quality and quantity); (2) catchability (q) and survey treatment with the 2011 model being more fixed or with assumed catchability parameters while the 2023 model having a greater flexibility in survey scaling and index weighting; (3) natural mortality with the 2011 model typically treated as fixed and constant while the 2023 model explored M via sensitivity analyses and alternative scenarios, which acknowledges uncertainty in M , but still lacks full time-varying or environmentally driven M ; (4) recruitment treatment with the 2011 model having recruitment variability included but more constrained, and the 2023 model having greater flexibility with higher interannual variability allowed and no stock–recruit assumptions, which may lead to a better fit to observed variability, but risks attributing unexplained dynamics to recruitment noise; (5) fishing mortality with the 2023 model having improved fisheries data and a better representation of seasonal and jurisdictional variation; (6) model structure and estimation with the 2011 model having a simpler statistical structure and more deterministic components and the 2023 model having a much finer temporal scale, more flexible estimation with a great increased number of estimated parameters and greater use of tuning and weighting, which may improve fit to multiple data sources, but has increased risk of overparameterization and reduced identifiability. The AT provided a comparison of stock status determination using the two models, which shows the same status of not overfished and overfishing not occurring. However, the 2011 model suggests that the stock abundance is below the target abundance reference point, while the 2023 model suggests that the stock status is above the target abundance reference points. Thus, the 2023 model provided a more optimistic stock status.

Overall, I believe the AT work ensures comparability between the two models, and new model has full integration of updated datasets with improved data quality and coverage, better ability to

fit observed dynamics, and more realistic representation of variability in blue crab life history process and fisheries.

However, I suggest that the AT provides a clear side-by-side comparison for changes between 2011 and 2023. The current comparison is more or less qualitative with limited quantification of impacts caused by the model changes. I recommend that the AT fully quantify the impacts of changes in estimating stock abundance, fishery mortality and recruitment. With the large increase in parameters for the 2023 model there is increased risk of overfitting and I recommend the AT conduct model diagnostics and explicitly document the model selection criteria. The current criteria for the base model selection is very descriptive. I also recommend that a sensitivity or decomposition analyses be done to evaluate how each change affected abundance, mortality and recruitment estimates and provide an evaluation of model complexity versus model performance in estimating model and population parameters.

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

I concluded that this TOR was partially addressed.

The AT successfully derived BRPs from model outputs, including abundance-based, mortality-based thresholds/targets reference points and recruitment-based reference points. The reference points are sex-specific. Their biological realism, management utility, and consistency with stock dynamics were well considered.

Because there is no assumed stock-recruitment relationship. An MSY-proxy, F40%, is used as the limited F reference point, and 75% of F40% is used as the target F reference point. The median value of recruitment over the whole time series is used to calculate abundance-based target and limit reference points from the relevant F reference points. The estimation is relatively simple and transparent. However, the appropriateness of the BRPs has not been quantitatively evaluated. The use of the median recruitment of the whole time series may not be suitable given large changes in environment over the time. It may be more relevant and appropriate to use more recent recruitment in the estimation of abundance reference points.

The development of a recruitment reference point is novel and provides an early indicator of future stock status. However, recruitment has extremely high interannual variability, and may be influenced by strong environmental forcing, which may make its interpretation and utility complex.

Although I agree that the current biological reference points are well defined and justified, they are still ad hoc reference points and have not been quantitatively evaluated for their effectiveness in achieving the management goals. I recommend that the biological reference points be quantitatively evaluated in a simulation setting such as a management strategy evaluation. I encourage the AT to continue developing recruitment-informed indicators, not necessarily strict BRPs, but early warning indicators and environmental-linked triggers. I encourage that the AT explore dynamic BRPs to incorporate possible environmental changes and regime shifts.

This TOR also requires the AT to estimate current stock status metrics, including sex-specific (male, immature female, and mature female) abundance, fishing mortality and recruitment and compare these estimates to the target and limit biological reference points to determine stock status, including whether the stock is overfished and whether overfishing is occurring. The AT provides updated estimates of total abundance, juvenile abundance and sex-specific adult abundance using the newly developed sex-specific length-structured model. The process is well-documented, transparent, and consistent with prior assessments.

The AT compares estimated stock metrics against the limit and target abundance and fishing mortality reference points with time series plots showing abundance and fishing mortality relative to limit and target reference points. Recent year status was highlighted with female spawning abundance and fishing mortality as the primary metrics. The comparisons are clearly presented and interpretable. The AT concluded that the stock is not overfished and overfishing is not occurring. The status determination is consistent with the management framework. However, the status determination is point-estimate based with no estimation of the probability of being below the limit reference points and no risk-based metrics are considered, although confidence intervals around abundance and fishing mortality estimates are estimated and uncertainty sources are identified. I conclude that the stock status determination process is clear, transparent with straightforward comparisons to BRPs, and easily interpretable by managers. However, I believe the current process has a limited probabilistic interpretation and does not quantify probability and may risk misclassification if the stock abundance and fishing mortality are close to the limit reference points. The current stock status determination has heavy reliance on a single metric of female spawning stock abundance with limited integration of recruitment signals and male abundance. A static reference point framework does not account for environmental variability and possible regime shifts, which may provide inappropriate reference points. The current framework also has limited forward-looking context with status evaluation being largely retrospective with limited projection of near-term risk. The use of recruitment reference points may be able to address this issue, but requires more quantitative estimation (e.g., in an MSE setting).

I recommend that the AT incorporate risk metrics with the calculation of probability of falling below limits for abundance and above limits for fishing mortality, which as a means of quantifying confidence in status determination. I recommend the AT continue to expand status indicators by including recruitment and male abundance in the context and by developing short-term projections to evaluate near-term risk under current conditions.

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?

I concluded that this TOR was partially addressed.

This TOR requires the assessment to (1) identify key ecosystem and climate drivers, including temperature, salinity, hypoxia, habitat (e.g., SAV, substrate), prey availability, and predation and cannibalism; (2) evaluate their influence on recruitment growth and survival and distribution and availability to fisheries; and (3) incorporate or explore these drivers analytically, where possible, to improve model realism and support interpretation of stock trends.

The AT clearly identifies major environmental and ecological drivers, including physical drivers of temperature (seasonal and interannual variability), salinity gradients (upper vs. lower Bay), and dissolved oxygen (hypoxia events), habitat of submerged aquatic vegetation (SAV) as nursery habitat and substrate effects on distribution and survey catchability, and biological interactions of predation (fish, birds), cannibalism (recognized as a key mortality source) and prey availability (benthic invertebrates). The identification is comprehensive and consistent with current literature.

The AT qualitatively links ecosystem drivers to recruitment with strong influence of oceanic larval transport (wind-driven), temperature and salinity conditions, natural mortality with winter severity resulting in overwinter mortality and density-dependent cannibalism. The AT also links growth and molting to temperature-dependent growth rates, and distribution with salinity and hypoxia shaping spatial patterns. These linkages are well-articulated and biologically sound.

The AT also discusses how environmental factors affect fisheries for availability and catchability including temperature and behavior (burial, activity), spatial shifts in fishing effort due to salinity gradients and habitat conditions. This demonstrates clear relevance to fishery-dependent processes. The AT identifies key hypotheses, including recruitment driven by larval transport and cannibalism as density-dependent mortality, and suggests potential pathways for future work. The AT discussed environmental drivers qualitatively in interpreting trends in recruitment and abundance and explored some exploratory analyses including correlations (e.g., recruitment vs. environmental indices). However, no formal integration was done in the core assessment model. No recruitment was explicitly modeled as a function of environmental conditions and no natural mortality was parameterized with environmental covariates. There is only limited use of statistical models (e.g., GLMs/GAMs) linking environment to vital rates and predictive ecosystem indicators, which limits predictive capability and mechanistic understanding. I recommend that the AT explore quantitative ecosystem models to formally link habitat (e.g., SAV coverage) to recruitment and hypoxia to mortality.

Overall, the AT provides a strong conceptual understanding of ecosystem and climate influences. However, the AT stops short of fully leveraging these drivers analytically. The main gap is not knowledge, but implementation within the assessment framework. To fully meet this TOR, future work should incorporate environmental covariates into key processes including recruitment models (e.g., wind, temperature) and natural mortality (e.g., winter severity, hypoxia), develop statistical ecosystem linkages using GLM/GAM frameworks and/or spatiotemporal models, and use ecosystem indicators operationally by developing early warning signals for recruitment and environmental thresholds for management.

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?*

I concluded that this TOR was adequately addressed.

The AT documented progress on prior recommendations, including data improvements in expanded time series for surveys and catch and improved reporting systems (e.g., electronic

reporting); assessment model updates with updated sex-specific framework and improved integration of survey and fishery data, and improved understanding of population dynamics with a better characterization of recruitment variability and continued recognition of environmental drivers.

However, natural mortality (M) estimation is still largely assumed or scenario-based, and environmental integration is still limited in the assessment. Spatial modeling is still a conceptual discussion with no implementation. Discard and recreational harvest estimation remain highly uncertain. The assessment report does not provide a systematic tracking table (e.g., completed / ongoing / not addressed) for the past research recommendations.

The AT identified a broad set of relevant research needs, including improved estimation of natural mortality and recruitment processes, enhanced CPUE standardization and effort characterization, better quantification of discards and bycatch and recreational harvest, integration of environmental drivers and habitat data, and exploration of spatial and seasonal modeling frameworks. The identification is comprehensive and appropriate. However, there is no formal prioritization such as ranking research by impact on assessment performance, no feasibility or cost considerations, and no timeline (short vs. long term, which may make it difficult for managers and funding agencies to allocate resources effectively).

Overall, the list compiled by the AT demonstrates good continuity and awareness of longstanding research gaps but falls short in providing a clear accounting of progress and a decision-ready prioritization of future research.

I suggest that the AT include a tracking matrix of prior recommendations with status of completed / ongoing / not addressed and brief justification; provide a formal prioritization framework with ranking research by impact on assessment uncertainty, feasibility and cost, and timeline; and have an explicit linkage to assessment improvement by identify how each recommendation will reduce uncertainty and improve management advice.

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

I concluded that this TOR was adequately addressed.

The 2025 Chesapeake Bay blue crab stock assessment represents a substantial advancement over the 2011 stock assessment model and reflects the best available science. The 2025 assessment is generally adequate for informing current management decisions. The assessment is supported by a strong empirical foundation, integrating multiple long-term fishery-independent surveys with an improved sex- and length-structured modeling framework, and it provides well-defined biological reference points that enable robust evaluation of stock status. Estimates of fishing mortality and abundance appear internally consistent and are accompanied by appropriate characterization of uncertainty, supporting their use in near-term management applications. However, several important limitations temper confidence in the assessment's ability to inform longer-term or forward-looking decisions. In particular, the persistent and unexplained decline in recruitment, high sensitivity to growth parameterization, incomplete accounting of total removals (especially recreational harvest and discard mortality), and uncertainty in survey catchability,

particularly for the Winter Dredge Survey, introduce structural uncertainties that are not fully resolved. Additionally, the lack of spatial resolution and limited integration of ecosystem and climate drivers constrain the model's capacity to capture key processes influencing the population dynamics. Overall, while the assessment is adequate for status determination and short-term management, for addressing these uncertainties it will be essential to enhance its predictive skill and support the transition toward ecosystem-based and climate-informed fisheries management.

V. Conclusions and Recommendations

I would like to commend the AT for their efforts in conducting the 2025 Chesapeake Bay blue crab stock assessment and for providing the necessary information. I was impressed by the breadth of expertise and experience of the AT, the amount of effort spent collecting, processing and compiling the data, and the constructive discussions during the review.

The 2025 Chesapeake Bay blue crab stock assessment represents a significant and credible advancement in the scientific basis for management. The transition to a sex- and length-structured modeling framework, improved treatment of fishery-independent survey data, and updated biological reference points collectively strengthen confidence in estimates of stock status and fishing mortality. The assessment is methodologically sound, transparently documented, and supported by an extensive and high-quality data foundation. Importantly, the results indicate that overfishing is not currently occurring, although male abundance has remained below target levels in recent years and recruitment has declined over the long term.

Despite these strengths, the assessment remains constrained by several key uncertainties that limit its utility for long-term forecasting and ecosystem-based management. Chief among these are the lack of a mechanistic understanding of recruitment dynamics, high sensitivity to growth assumptions, uncertainty in total removals (particularly recreational harvest and discard mortality), and incomplete knowledge of survey catchability. In addition, the spatially aggregated structure of the model and limited integration of environmental and ecosystem drivers restrict its ability to capture important sources of variability in blue crab population dynamics.

Overall, the assessment is adequate for current management, providing a reliable basis for status determination and short-term decision-making. However, it should be viewed as part of an evolving framework that requires further development to meet emerging needs for climate-informed and ecosystem-based fisheries management.

To strengthen future assessments and improve management relevance, I would like to recommend the following prioritized, forward-looking set of research recommendations:

- (1) Improve understanding of recruitment dynamics by developing process-based stock–recruitment models incorporating larval transport and estuarine circulation, and spawning stock distribution and timing. Such a modeling framework may also couple with biophysical larval models (hydrodynamic and behavior), integrate early life-stage surveys to close the life-cycle gap, and apply machine learning / Bayesian hierarchical models to

detect nonlinear drivers. Such a study is critical because recruitment is the dominant source of uncertainty and the key risk signal in the assessment.

- (2) Improve understanding of growth dynamics and molting processes because growth assumptions strongly influence model outputs and are poorly constrained. I suggest that the AT explore the possibility of developing temperature-, density-, and food-dependent growth models using tagging (including mark–recapture with molt tracking) and laboratory/field experiments to replace static Gompertz assumptions with dynamic growth submodels. This study is important because growth is one of the most sensitive parameters in the entire model.
- (3) Improve natural mortality (M) estimation because current M estimates have high uncertainty and rely on indirect methods. I recommend that the AT evaluate spatiotemporally varying M using predation studies (including blue catfish impacts) and tethering and telemetry experiments and partition mortality into predation, disease, environmental stress (hypoxia, temperature) and cannibalism. This study is important because mis-specifying M biases both abundance and fishing mortality estimates.
- (4) Improve the estimation of fishery removals including recreational harvest and discards. The current estimate has large uncertainty in total removals due to expansions. I recommend developing and implementing comprehensive recreational monitoring programs with surveys, apps, electronic reporting; to quantify discard mortality experimentally by gear and temperature. This can improve the estimation of the total catch that is a fundamental model input with unresolved uncertainty.
- (5) Improve the estimation of survey catchability, selectivity, and calibration to reduce the uncertainty of the selectivity and catchability in the Winter Dredge Survey that is the backbone of the assessment. I recommend that gear calibration experiments be conducted across habitats and seasons to estimate absolute abundance via depletion or mark–recapture studies and to develop integrated observation models linking surveys.
- (6) Continue to explore and develop spatially explicit stock assessment models. Blue crabs exhibit strong spatial structure that is currently masked. I recommend developing spatially explicit (metapopulation or spatially continuous) models to address regional differences (upper vs lower Bay) in blue crab life history and habitat-specific productivity and integrate movement/migration models.
- (7) Explore ecosystem and climate integration into stock assessment to address weak or inconclusive relationships with environmental drivers. I recommend that the AT incorporate temperature, hypoxia, salinity, and predator abundance (e.g., blue catfish); using end-to-end ecosystem models or dynamic factor analysis, and develop climate-informed reference points.
- (8) Improve data integration frameworks. I recommend that the AT develop integrated population models (IPMs) combining surveys, catch data, tagging, and environmental covariates using state-space frameworks to separate observation vs process error.
- (9) Further evaluate sub-annual dynamics for explicit representation of molting cycles and seasonal migration and improve representation of recruitment timing (not a single pulse).

- (10) Further evaluate sex-specific and reproductive dynamics to develop explicit mating and fertilization models, investigate male limitation and sperm storage dynamics, and refine female spawning potential estimates.
- (11) Advance uncertainty quantification. Current uncertainty is largely asymptotic and sensitivity-based. I recommend that the full Bayesian assessment models and ensemble modeling approaches be explored to quantify structural uncertainty and model selection uncertainty.
- (12) Modernize the monitoring system. Data gaps persist despite long-term monitoring. New approaches, such as autonomous sensors (temperature, oxygen), eDNA for distribution mapping, and AI-assisted survey analysis, should be explored to modernize surveys into a real-time monitoring network and improve timeliness and resolution of data inputs.

Continued investment in these research and monitoring priorities is strongly warranted. Advancing toward a process-based, spatially resolved, and ecosystem-informed assessment framework will be essential to ensure the long-term sustainability and resilience of the Chesapeake Bay blue crab fishery under changing environmental conditions.

VI. References

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Miller, T.J., G. Davis, D. Liang, M. Drzewicki, G. Ralph, M.J. Wilberg. 2026. Characterizing major changes in assumptions between the 2011 assessment model and the 2023 model. 2026 Chesapeake Bay Blue Crab Stock Assessment Working Paper 9.

VII-1. Appendix 1: Bibliography of materials provided for review

Materials provided for the 2025 Chesapeake Bay blue crab stock assessment review

The 2025 Chesapeake Bay blue crab stock assessment report

Wilberg, M. J., Maya Drzewicki, Gina M. Ralph, Dong Liang, Madison Sholes, Rober Aguilar, Amanda Bevans, Ingrid Braun-Ricks, Mandy Bromilow, Glenn R. Davis, Alexa Galvan, Thomas Ihde, Robert Latour, Romuald. N. Lipcius, Brooke Lowman, Marvin M. Mace III, Thomas J. Miller, Matthew B. Ogburn, Gabrielle Saluta, Alexandra K. Schneider, Alexei Sharov, and Troy D. Tuckey. Stock Assessment of Blue Crab in Chesapeake Bay, Draft Assessment Report. March 11, 2026

The 2011 Chesapeake Bay blue crab stock assessment report

Miller, T.J., Wilberg, M.J., Colton, A.R., Davis, G.R., Sharov, A., Lipcius, R.N., Ralph, G.M., Johnson, E.G., Kaufman, A.G., 2011. Stock assessment of blue crab in Chesapeake Bay, 2011. University of Maryland Center for Environmental Science Chesapeake Biological Laboratory, Solomons, MD, p. 192.

Working papers

Sholes, M., M.C. Fabrizio, T.D. Tuckey, G. Davis, D. Liang., M.J. Wilberg. 2026. Effects of Blue Catfish on Blue Crab Abundance in Chesapeake Bay Tributaries during 1990-2023. 2026 Chesapeake Bay Blue Crab Stock Assessment Working Paper 1.

Liang, D., A. Bevans, E. Peng, G. Davis, T. Ihde, R. Lipcius, G. Saluta, M. Sholes, T. Tuckey, M.J. Wilberg. 2026a. Length Weight Relationships of Blue Crab from the Chesapeake Bay. 2026 Chesapeake Bay Blue Crab Stock Assessment Working Paper 2.

Liang, D., G. Davis, M. Drzewicki, G. Ralph, M. Sholes, R.N. Lipcius, T. Tuckey, M.J. Wilberg. 2026b. Overwinter Mortality of Blue Crabs in Chesapeake Bay Using a Bayesian Model. 2026 Chesapeake Bay Blue Crab Stock Assessment Working Paper 3.

Liang, D. 2026. Development of Daily Temperature Time Series for the Bay, a 4D Interpolation Approach. 2026 Chesapeake Bay Blue Crab Stock Assessment Working Paper 4.

Ralph, G., R. Latour, M.J. Wilberg. 2026b. Estimating size at maturity for male blue crabs in Chesapeake Bay. 2026 Chesapeake Bay Blue Crab Stock Assessment Working Paper 5.

Ralph, G., M.R. Drzewicki, M.J. Wilberg. 2026a. Estimation of monthly proportions of female blue crabs with eggs in Chesapeake Bay. 2026 Chesapeake Bay Blue Crab Stock Assessment Working Paper 6.

Ogburn, M.B., R. Aguilar, Z. Galvan Lam, A.H. Hines, M.J. Wilberg. 2026. Growth, Maturation and Operational Sex Ratio of Female Blue Crabs in the Rhode River, Maryland, USA. 2026 Chesapeake Bay Blue Crab Stock Assessment Working Paper 7.

Wilberg, M.J., M.R. Drzewicki. 2026. Estimation of the size distribution of age-0 blue crabs in Chesapeake Bay and Winter Dredge Survey Selectivity. 2026 Chesapeake Bay Blue Crab Stock Assessment Working Paper 8.

Miller, T.J., G. Davis, D. Liang, M. Drzewicki, G. Ralph, M.J. Wilberg. 2026. Characterizing major changes in assumptions between the 2011 assessment model and the 2023 model. 2026 Chesapeake Bay Blue Crab Stock Assessment Working Paper 9.

Lipcius, R.N., J.M. Hoenig, M.S. Seebo, A. Smith. 2026a. Tag-recapture estimates of survival of mature female blue crab *Callinectes sapidus*. 2026 Chesapeake Bay Blue Crab Stock Assessment Working Paper 10.

Lipcius, R.N., M.S. Seebo. 2026. Blue crab spine width increases disproportionately at maturity, with consequences for demographic models. 2026 Chesapeake Bay Blue Crab Stock Assessment Working Paper 11.

Lipcius, R.N., J.M. Hoenig, D.M. Lambert, M.S. Seebo, A. Smith. 2026b. Longevity-based, tag-recapture estimation of natural mortality in mature female blue crabs (*Callinectes sapidus*) in Chesapeake Bay. Working Paper. 2026 Chesapeake Bay Blue Crab Stock Assessment Working Paper 12.

Drzewicki, M.R., M.J. Wilberg. 2026. Additional plots for the 2026 Chesapeake Bay blue crab assessment. 2026 Chesapeake Bay Blue Crab Stock Assessment Working Paper 13.

VII-2. Appendix 2: Statement of Work for Dr. Yong Chen

**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 crabs regionally and seasonally, and many of these were developed in response to spatiotemporal variability in the

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

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.

1. 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.

2.

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).

3. Travel

Travel is not expected or authorized for this review.

4. 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.

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?*
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?
3. Does the assessment describe and quantify patterns in catch, effort, and CPUE?
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?
5. Does the assessment characterize uncertainty in assessment estimates (mortality and abundance)?
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?
7. Does the assessment recommend appropriate biological reference points for management? Does the assessment evaluate stock status relative to recommended reference points?
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?
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?
10. 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

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2026 Chesapeake Bay Blue Crab Stock Assessment Review

April 13 - 16, 2026

Purpose: This meeting will convene modeling experts, state jurisdictions, and independent reviewers to evaluate the draft 2026 Chesapeake Bay Blue Crab Stock Assessment.

I. Agenda

Day 1: April 13, 2026

- | | |
|---|--------------------------|
| I. Welcome & Introductions | 12:00pm – 12:15pm |
| Brief introductions of the Chesapeake Bay Blue Crab Stock Assessment Committee & the review panel | |
| Requested Action: Non-decisional | |
| Lead: Dan Hennen (NOAA) | |
| Materials: N/A | |
| | |
| II. Presentation of the 2026 Blue Crab Stock Assessment | 12:15pm – 3:30pm |
| Review of TORs 4, 5, 7 and 8 | |
| Requested Action: Non-decisional | |
| Lead: Michael Wilberg (UMCES) | |
| Materials: Draft 2026 Blue Crab Stock Assessment Report | |
| | |
| III. General / Open Question Period | 3:30pm - 4:45pm |

Opportunity for questions from the review panel

Requested Action: Non-decisional

Lead: Dan Hennen (NOAA)

Materials: [Draft 2026 Blue Crab Stock Assessment Report](#)

IV. Public Comment

4:45pm -5:00pm

Opportunity for public comment & questions

Requested Action: Non-decisional

Lead: Dan Hennen (NOAA)

Materials: [Draft 2026 Blue Crab Stock Assessment Report](#)

V. Adjourn

5:00p

Day 2: April 14, 2026

II. CIE Term of Reference Review and Discussion

9:00am – 1:00pm

Review of TORs 2 & 3

Requested Action: Non-decisional

Lead: Dan Hennen (NOAA)

Materials: [Draft 2026 Blue Crab Stock Assessment Report](#)

III. Lunch

1:00pm – 2:00pm

IV. CIE Term of Reference Review and Discussion (continued)

2:00pm - 4:45pm

Review of TORs 1, 6, 9

Requested Action: Non-decisional

Lead: Dan Hennen (NOAA)

Materials: [Draft 2026 Blue Crab Stock Assessment Report](#)

V. Public Comment

4:45pm -5:00pm

Opportunity for public comment & questions

Requested Action: Non-decisional

Lead: Dan Hennen (NOAA)

Materials: [Draft 2026 Blue Crab Stock Assessment Report](#)

VI. Adjourn

5:00pm

Day 3: April 15, 2026

- I. CIE Term of Reference Review & Discussion** **9:00am - 10:00am**
Review of TORs 10 & 11
Requested Action: Non-decisional
Lead: Dan Hennen (NOAA)
Materials: [Draft 2026 Blue Crab Stock Assessment Report](#)
- II. Review Session [closed-door]** **10:00am - 12:00pm**
Opportunity for the review panel to discuss assessment methodologies and develop individual opinions. The review panel will initiate development of the panel summary report.
Requested Action: Non-decisional
Lead: Dan Hennen (NOAA)
Materials: [Draft 2026 Blue Crab Stock Assessment Report](#)
- III. Lunch** **12:00pm - 1:15pm**
- IV. Review Session (continued) [closed-door]** **1:15pm - 3:00pm**
Opportunity for the review panel to discuss assessment methodologies and develop individual opinions. The review panel will initiate development of the panel summary report.
Requested Action: Non-decisional
Lead: Dan Hennen (NOAA)
Materials: [Draft 2026 Blue Crab Stock Assessment Report](#)
- V. Plenary Session** **3:00pm - 4:15pm**
Review panel discloses decision on TORs.
Requested Action: Decisional
Lead: Dan Hennen (NOAA)
Materials: [Draft 2026 Blue Crab Stock Assessment Report](#)
- VI. Public Comment** **4:15pm -4:30pm**
- VII. Adjourn** **4:30pm**

Day 4: April 16, 2026

- I. Review Session [closed-door]** **9:00am - 12:00pm**

Opportunity for the review panel to continue to discuss assessment methodologies and develop individual opinions. The review panel will continue the development of summary documents and present the summary report. Next steps and timeline for finalizing the summary report will be identified.

Requested Action: Non-decisional

Lead: Dan Hennen (NOAA)

Materials: [Draft 2026 Blue Crab Stock Assessment Report](#)

II. Lunch 12:00pm - 1:15pm

III. Review Session (continued) [closed-door] 1:15pm - 4:15pm

Opportunity for the review panel to continue to discuss assessment methodologies and develop individual opinions. The review panel will continue the development of summary documents and present the summary report. Next steps and timeline for finalizing the summary report will be identified.

Requested Action: Non-decisional

Lead: Dan Hennen (NOAA)

Materials: [Draft 2026 Blue Crab Stock Assessment Report](#)

IV. Public Comment 4:15pm -4:30pm

Opportunity for public comment & questions

Requested Action: Non-decisional

Lead: Dan Hennen (NOAA)

Materials: [Draft 2026 Blue Crab Stock Assessment Report](#)

V. Adjourn 4:30pm

Annex 3. Individual Independent Peer Reviewer Report Requirements

1. The independent Peer Reviewer report shall be prefaced with an Executive Summary providing a concise summary of whether they accept or reject the work that they reviewed, with an explanation of their decision (strengths, weaknesses of the analyses, etc.).
2. The report must contain a background section, description of the individual reviewers' roles in the review activities, summary of findings for each TOR in which the weaknesses and strengths are described, and conclusions and recommendations in accordance with the TORs. The independent report shall be an independent peer review, and shall not simply repeat the contents of the Peer Reviewer Summary Report.
 - a. Reviewers should describe in their own words the review activities completed during the panel review meeting, including a concise summary of whether they accept or reject the work that they reviewed, and explain their decisions (strengths, weaknesses of the analyses, etc.), 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 Peer Reviewer Summary Report that they believe might require further clarification.
 - d. The report may include recommendations on how to improve future assessments.
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 4. Peer Reviewer Summary Report Requirements

1. The main body of the report shall consist of an introduction prepared by the Research Track Peer Review Panel chair that will include the background and a review of activities and comments on the appropriateness of the process in reaching the goals of the peer review meeting. Following the introduction, for each assessment /research topic reviewed, the report should address whether or not each Term of Reference of the Research Track Working Group was completed successfully. For each Term of Reference, the Peer Reviewer Summary Report should state why that Term of Reference was or was not completed successfully. It should also include whether they accept or reject the work that they reviewed, with an explanation of their decision (strengths, weaknesses of the analyses, etc.)

To make this determination, the peer review panel chair and reviewers should consider whether or not the work provides a scientifically credible basis for developing fishery management advice. If the reviewers and peer review panel chair do not reach an agreement on a Term of Reference, the report should explain why. It is permissible to express majority as well as minority opinions.

The report may include recommendations on how to improve future assessments.

2. If any existing Biological Reference Points (BRPs) or BRP proxies are considered inappropriate, include recommendations and justification for alternatives. If such alternatives cannot be identified, then indicate that the existing BRPs or BRP proxies are the best available at this time.
3. The report shall also include the bibliography of all materials provided during the peer review meeting, and relevant papers cited in the Peer Reviewer Summary Report, along with a copy of the CIE Performance Work Statement.

The report shall also include as a separate appendix the assessment Terms of Reference used for the peer review meeting, including any changes to the Terms of Reference or specific topics/issues directly related to the assessments and requiring Panel advice.

VII-3. Appendix III: List of Participants

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