Center for Independent Experts (CIE) Independent Peer Review of the Atlantis Ecosystem Model in Support of Ecosystem-Based Fishery Management in the Gulf of Mexico Large Marine Ecosystem

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Executive Summary

During March 28-30, 2023, the Gulf of Mexico (GOM) ecosystem model Atlantis was reviewed in St. Petersburg, Florida. In the first two days of the review, NOAA and University of South Florida scientists presented the model and recent updates. The third day was initially given to short presentations by Atlantis team members on homework they were given during the first two days. This was followed by discussions between the CIE and local reviewers only. The CIE panel also drafted a list of general conclusions, some of the major ones include:

1. It was not shown that the Atlantis model is ready for management applications at this stage for shrimp. For example, the present version of the model has a maximum age of 10 years for shrimp, whereas in reality it is around 1 year. An attempt to quickly fix this model problem on the last day was unsuccessful.
2. The GOM Atlantis model is not ready to investigate environmental effects on shrimp until the aging problem is resolved.
3. In addition, the weight-at-age and the changes in the weights of the shrimp do not appear to have been checked against observed data to determine how realistic the model is.
4. There are major concerns in the model's diet matrix as to the possibility that some unrealistic and/or impossible predator/prey relationships may be included, e.g., it was noted that snook is not eaten by red snapper as their habitats do not overlap. It is recommended the Atlantis team consult with local scientists, including those involved in stock assessments, who have developed their own diet matrix using the same stomach analysis database (MARFIN) as the Atlantis team, to confirm or reject any contentious predator-prey relationships. Also, consultations on life history and fishery structure are recommended to ensure the model represents reality.
5. The GOM Atlantic model is forced by an oceanographic submodel representing conditions only during 2012. While this captures some of the seasonal variability in physical and chemical conditions in the Gulf of Mexico, it does not include interannual variability and as such limits its use for exploring environmental effects on the ecosystem and climate change scenarios.
6. Relationships between the wind and physical and biological variables were preformed using wind velocity. However, the force of the wind on the water is related to the wind stress, which is a function of the wind speed squared. It is recommended to redo the wind relationships using wind stress, including for larval dispersion.
7. The addition of seagrass dynamics to the GOM Atlantis model was welcomed but some problems such as certain fish feeding on sea grasses in the model is not considered realistic.
8. The current version of the GOM Atlantis model is not considered to be at the stage for skill assessment.

While these conclusions are largely focused on model problems, the panel agreed that the GOM Atlantis model has potential and the work should continue. It is believed that many of the problems can be resolved, although this needs to be shown.

Background

During March 28-30, 2023, the Gulf of Mexico (GOM) ecosystem model Atlantis was reviewed in St. Petersburg, Florida. The general purpose of the review was to evaluate the performance characteristics and to identify appropriate management applications of the model. More specific objectives were to evaluate the data, parameterisation, and skill of the Atlantis model, with emphasis on predicting stock dynamics and catch of Penaeid shrimp (Brown, White and Pink Shrimp groups) in the GOM and their major interacting species; to identify the extent to which the model is suitable for incorporating environmental effects relevant to shrimp production; to determine the readiness of the model to conduct simulations that assess ecosystem-level impacts of climate change; and to review updates to the GOM Atlantis model code which improves representation of seagrass dynamics.

Tasks for the Reviewers

The CIE reviewers were required to familiarized themselves with numerous Background Documents (see Reference list below, Appendix 1) and attend the Panel Review in person. They assist the Chair of the review meeting with contributions to the summary report from the meeting. In addition, each reviewer shall complete an independent peer review report in accordance with the Performance Work Schedule within three weeks of the end of the review meeting. Their reports should include the findings for each Term of Reference including weaknesses and strengths.

TOR 1. Comment on the technical merits and deficiencies of the methodology and recommendations for remedies for the following.

a. What are the data requirements of the methodology?

Atlantis is an end-to-end model (from physics and chemistry to marine mammals and seabirds, fisheries, fleet dynamics and fisheries economics) for the purpose of supporting ecosystem-based fisheries management. Within the Atlantis models are dynamical submodels for the physics, biology, harvesting, assessment and economics. The models and submodels are spatially-resolved in three dimensions. There are three types of general habitats (water column, epibenthic habitat and sediment). The biological submodel consists of functional groups representing vertebrates, which include fish, birds and marine mammals, and are age-structured, as well as invertebrates and primary producers that are represented by biomass pools. In the GOM Atlantis model there are 91 functional groups of which 61 are age structured and 30 are biomass pools.

Central to any Atlantis model is the diet matrix (within the biology submodel). The GOM diet matrix was developed based on analysis of over 30,000 stomachs in the Marine Fisheries Investigation (MARFIN) database, updated in 2020. While this is laudable, during panel discussions it was stated that other groups using the same database have developed some different predator-prey relationships. This brings the

diet matrices into question. It is essential that the Atlantis team members responsible for the diet matrices meet with the other groups who have developed diet matrices for the Gulf of Mexico to resolve these differences and agree on the diets of the different species. It was also noted during the panel review that in the Atlantis model no links between predators and prey were eliminated. This could have resulted in some incorrect linkages within the diet matrix caused by species misidentification, clerical errors, non-overlapping habitat, etc. The GOM Atlantis team needs to review this practice and to eliminate those that are believed to be wrong or highly improbable. In addition, examination of possible spatial differences in diet is needed for those species inhabiting different locations around the Gulf. This is to ensure that if the diets are assumed the same within the Gulf that they indeed are similar. Another problem is the lack of diet data in Mexican and Cuban waters and that most of the US data are from the eastern Gulf with less from the western Gulf, which could contribute to bias.

Fisheries catch data are also used in Atlantis models (harvest submodel), which in the case of the GOM is from both commercial and recreational fisheries. Initial biomass estimates for the groups are required as are weight and growth curves and fishing mortalities. Seasonal fish and shellfish distributional data are also required for certain fisheries. Important recent (positive) updates to the model have been on fleet structure, incorporating spatial restrictions on the fishing fleets including those due to Marine Protected Areas (MPAs), estimates of the discards in both the otter trawl fishery and recreational fisheries, and updated estimates of the US fishing mortality by species based on 2020 recent NOAA estimates of commercial and recreational fisheries.

Ocean environmental data, such as currents, temperature, salinity, mixed layer depths, pH, nutrients, etc. affect fish growth and recruitment in the Atlantis model. These physical variables are generally provided by the underlying physics submodel, which for the GOM is the AMSEAS model. The daily physical conditions through a single year representing 2012 are looped through to represent multiyear runs. While this can capture general seasonal variability of the environmental conditions, it does not provide interannual variability which limits the model's use for investigating climate change (see further discussion related to question 2c).

b. What are the general situations, management uses, and spatial scales for which the methodology is applicable? (also to be discussed further in TOR 2)

Spatial scales of any Atlantis model are set early in their development and horizontally consist of a number of irregularly-shaped polygons within a broad geographical region. For the Gulf of Mexico, the broad region lies inside of the Yucatan and Florida straits and borders on the southern coast of the US, the southeastern coast of Mexico north of the tip of the Yucatan Peninsula, and northwestern Cuba. This broad area is divided in 66 polygons, each of which is selected on the basis of general similarity in topography, bottom type, habitat and biological communities. Five of the polygons represent estuaries, all of which are situated in US waters. The polygons in the inshore areas from the coast through to the shelf break tend to be smaller in size but greater in the number than the polygons offshore in the deep regions. The on-shore / offshore distances of the polygons are generally much less than

the alongshore distances. The polygons across the Yucatan and Florida straits are non-dynamically with imposed flows. All of the other polygons are dynamic. The choice of the GOM polygons seems reasonable.

In the vertical, the GOM Atlantis model has up to six water column depth layers in the deepest regions plus a sediment layer. The water column layers in the deepest regions of the Gulf in m are 0-10, 10-20, 20-50, 50-200, 200-2000 and 2000-4000. The depth layers are horizontally uniform within the polygons.

Atlantis models have been used to assess the impact of environmental processes on the distribution and abundance of marine organisms, and to provide strategic advice to fisheries managers and stakeholders. They have been used for exploring different fisheries management strategies in a variety of different marine regions, such as off Australia (e.g., Fulton et al., 2011; Fulton et al., 2014), in the California Current (Kaplan et al., 2012), in the Barents and Norwegian seas (Hansen et al., 2019) and elsewhere. The GOM Atlantis model has been used to examine red tides and red grouper. It also has been used for investigating fish management strategies (Masi et al., 2018). In addition, it has been used to explore ecosystem indicators (Masi et al, 2017), together with other Atlantis models around the globe to examine the impact of ocean acidification on the ecosystem (Olsen et al., 2018), oil pollution effects from the Deep Water Horizon spill (Ainsworth et al., 2018; Court et al., 2020; Morzaria-Luna et al., 2022; Dornberger et al., 2023), and the effects of point-source nutrient introductions (Dornberger et al., 2023).

c. What are the assumptions of the methodology?

Each depth layer in a polygon is assumed to contain multiple habitats that together cover the entire area of the layer. The habitats are dynamic and thus can change through time. Primary production drives the productivity of higher trophic levels and is dependent on the availability of limiting nutrients, light and available space. Growth and mortality rates are species-specific. Predation is based on the diet matrix derived from stomach analyses after taking into account the spatial overlap of the predator and prey.

Atlantis models are highly parameterized. Parameters include those related to growth, predator-prey linkages, recruitment and additional mortality other than fishing. These parameters' values are usually initially estimated from available data, or if these are lacking then from historic literature, other models, from other species or functional groups, or from other regions. In the GOM Atlantis model, linear mortality has been assumed and while quadratic mortality was considered and programmed into the model, it has not yet produced usable results.

d. Is the methodology correct from a technical perspective?

I consider the Atlantis methodology to be generally correct from a technical, perspective. However, some applications are not always valid, such as the assumption of non-variable parameters. While some parameters in the model are allowed to vary, for example seasonally, most are held constant over time. In reality, some parameters

can vary substantially over time and/or space or as a function of environmental conditions. For example, parameters related to growth or production can fluctuate depending on available food quality. Food availability may modify the diet matrix. The assumption of spatial uniformity may not be valid in terms of the diet matrices, especially where the stomach data derived in one location are applied in a different region without checking if the prey is even present. Such assumptions obviously will lead to errors for these species.

e. How robust are results to departures from the assumptions of the methodology?

The Atlantis results are generally considered to be reasonably robust to the methodology assuming the model has been properly calibrated initially. However, incorrect model structure or incorrect parameterization can lead to errors causing poor results for some of the processes and/or species.

f. Does the methodology provide estimates of uncertainty? How comprehensive are those estimates?

Atlantis models have both structural and parameter uncertainties. Structural uncertainty arises because of incomplete knowledge of how the ecosystem works and is the most difficult to estimate. Parameters relate one variable to another and are usually determined by graphical fitting. Parameter uncertainty is obviously related to the error in the parameter values. There are also uncertainties in the initial conditions imposed upon the model as well as in the estimates of fishing pressure and the choice of natural mortality for each species.

The Atlantis methodology allows for estimates of these uncertainties. They can be obtained by perturbing the parameters or numerical constants (e.g., initial conditions) and then analyzing the effects. The range of possible values (uncertainties) are those that give realistic model results in comparison to observations, e.g., in the biological submodel it could be biomass estimates of certain species of fish. The submodel structure of Atlantis models allows for undertaking perturbation analyses on different components and not having to perform such analyses of the entire model at the same time.

g. What is the process of model fitting and calibration?

Calibration of the model begins by making sure that in the absence of fishing, there is biomass stability through time (no extinctions or population explosions) and the variability remains close to historic levels. Second, with a reasonable range of fishing values, there are still realistic biomasses. Third, that the model reproduces realistic biomass trends. Once these are confirmed, calibration of the parameters is achieved by changing the parameter values and then comparing model results with measured data. The selected parameter range is then that which provide the best fit to the historical data.

h. Areas of disagreement regarding panel recommendations: among panel members; and between the panel and proponents.

There were no significant disagreements regarding recommendations among CIE panel members that I am aware of. Nor did there seem to be any major disagreements between panel members and the proponents as to the recommendations made orally by the panel members during meeting discussions. Indeed the proponents generally indicated that they would follow up on the recommendations that were expressed verbally during the meeting.

i. Unresolved problems and major uncertainties, e.g., any issues that could preclude use of the methodology.

The aging problem with the shrimp may preclude use of the Atlantis model to examine this short-lived species. This could be the case if a resolution to the use of fractional years for the cohorts cannot be resolved. However, I do not believe that there should be any reason why fractional years cannot be accepted for the cohorts of shrimp. However, this needs to be proven.

j. Management, data or fishery issues raised during the panel review.

In terms of fisheries issues and management, much of the discussion during the review focused on shrimp. As stated above, a major issue in the present model in regard to shrimp was the incorrect aging, resulting in a maximum age of shrimp of 10 years, when it should be around 1 year. This brings into question much of the results concerning shrimp. This included the possibility of the weights-at-age being too heavy, which needs to be checked out.

Another major issue brought up was the validity of the diet matrix. It was noted by the Regional Reviewers that different groups of researchers using the same stomach analysis data have different diets for certain predator-prey combinations. This needs to be resolved.

k. Prioritized recommendations for future research and data collection.

Immediate priority should be given to resolving the most important of the problems identified during the review. Foremost amongst these are the correction to the aging of the shrimp; comparing the diet matrix used in the model with diet matrices produced by other groups based on the same stomach analysis data but with different results; and comparing the weight-at-age data for shrimp from the model with observations.

In terms of future research, and given some of the problems with shrimp, especially if it appears that it might take a lot of time to sort out the problems there, I recommend examining the stock dynamics of one of the important finfish species. This might help to more quickly show the potential of Atlantis in terms of management issues.

Future data collections should focus upon better resolving the spatial non-homogeneous nature of the diet data. There is at present a bias with more data on one

side of the Gulf than the other. Also, I recommend communicating with Mexican and Cuban scientists to determine if the lack of diet data from those regions can be resolved.

Lower on the priority list, I was wondering if Atlantis could be used to investigate the recent problems with the sargassum weed given that this is causing major disruption to tourism and hence the economies within the Gulf and potentially to biological organisms in their waters.

TOR 2. Model readiness concerning priority capabilities

a. Evaluate data, parameterizations and skill of GOM Atlantis with emphasis on Penaeid shrimp.

A major problem with shrimp was discovered during the panel review, i.e. the maximum age of the shrimp in the model turned out to be 10 years although the actual age is around 1 year. The cause of this error was discovered during the review by the proponents. In the model, each species is assigned 10 age categories labeled as "cohorts". The increase in the age of successive cohorts is 10% of the maximum age of the species so if the maximum age of the species was 10 years, the cohorts would represent ages 1, 2, 3,...to 10. Because the observed maximum age of shrimp is around 1 year, each shrimp cohort should only represent a fraction of a year. The meeting was informed that to investigate a problem that arose in the model a few years ago, the cohort ages of the shrimp were set to an integer of 1. Thus, because there are 10 cohorts, the maximum age automatically became 10. The cohort ages and the maximum age were never reset. An effort to reset the cohort ages for shrimp to fractions of a year during the last day of the review meeting was unsuccessful. This obviously needs to be fixed before exploring shrimp dynamics any further with the present version of the model.

A possible related issue that seems to appear in the model is that the shrimp weights-at-age may be heavier than observed. A thorough comparison of model weights-at-age with measured values is needed to determine if indeed they are too high or are close to the observations.

b. Evaluate the treatment of environmental processes in the model relevant to shrimp production.

It was stated during the review that shrimp are strongly influenced by their environment. In the introduction to the Atlantis approach it was also stated that Atlantis models are ideal test beds for hypothesis testing. The team did note that in nature shrimp tended to avoid low salinity water. They then ran the model to test this by decreasing the salinity inshore, e.g., as occurs with increased river flows from the Mississippi or other rivers. The model results indicated that with lower salinity water inshore, shrimp were pushed offshore, thus avoiding the low salinity waters inshore as has been observed.

I recommend that further hypotheses related to environmental forcing of shrimp should be formulated and then tested with the model. In particular, relationships

between the environment and production, growth or recruitment of shrimp need to be explored within the Atlantis model. This is especially relevant given that shrimp are considered to be influenced by the environment and its variability, at least as much and possibly more than the fishery. Prior to the meeting, I would have liked to have been directed to a few papers that proposed various environmental impacts on shrimp life history traits.

A recent update to the GOM Atlantis model incorporated larval dispersal, which had not been considered previously. I believe this to be an important addition. During the presentation on larval dispersion, it was noted that wind plays a major role in dispersion of shrimp larvae, a result consistent with studies on forcing of shelf waters and on larval dispersion. It was stated that larval drift was estimated using winds averaged over 12 hours. However, the wind acting on the water is related to the wind stress rather than the wind per se. The wind stress is given by

$$\text{Wind Stress} = \text{Drag Coefficient} * \text{Density of air} * \text{Wind Speed}^2$$

The wind stress is the drag coefficient (CD) times the density of air (around 1.293 Kg/m^2 but should use local air density) times the square of the wind speed (ideally taken at 10 m above the ocean surface). CD has a value around 0.0014 for wind velocities (V) of $3<V<10$ ms^{-1} (Trenberth et al., 1989) and up to around 0.0025 under very strong winds, around 25 ms^{-1} (Curic and Haush, 2020). The stress, as calculated by the above formula, is in Pa (pascals). Because the function is nonlinear in wind speed, the stress should be calculated using hourly wind speed data and no more than a maximum average of 4 hourly winds. The larval drift and dispersion (or other wind-affected variables) should be based on the wind stress to confirm any statistical relationship with the wind. While the physical oceanographic model underlying Atlantis most likely uses wind stress to estimate wind-generated currents, this should be checked that it is indeed the case.

The larval drift of shrimp off the West Coast of Florida in the GOM Atlantis model was estimated to be primarily northward. Some of the local scientists expressed the opinion that the northward distances travelled were too large. This should be checked and results discussed with the local scientists to ensure that the larval drift is considered relatively accurate.

c. Evaluate the readiness of the model to perform climate change simulations, including habitat effects.

The GOM Atlantis model in its present form could be used for providing a first estimate of the impact of climate changes on the GOM ecosystem. For example, model runs representing anticipated anthropogenic-induced environmental changes could be made by imposing spatially uniform increases or decreases (anomalies) from 2012 conditions for temperature and/or other environmental variables. However, such a method would not capture the spatial variability across the Gulf, the temporal pattern of the environmental changes and their impacts, nor the correct impacts caused by interactions between time varying changes in different environmental variables. Therefore, I believe the model needs major improvements before it will be ready to be used for reliable testing of the effects of climate changes on the ecosystem.

Foremost, the underlying physical model ideally should produce climate change scenarios with spatial and interannual variability. This is because it is not only the amplitude of the change that is important but also its time dependency, e.g., a rapid rise vs a slow rise vs variable rates of change over time. Each of these could have different impacts on different aspects of the ecosystem. The Atlantis model could then be used for evaluating the impacts of these environmental changes on the modeled biological components of the ecosystem. I recognize that this would be a major step and require a significant effort on behalf of the GOM Atlantis team. Also, I am not sure whether such a climate change model is available for the GOM. For these reasons I believe that this should be a lower priority.

d. Evaluate the use of a novel seagrass routine (C++) developed for the GOM by USF and CSIRO.

The recent inclusion of seagrass dynamics into the GOM model is a positive step. A pseudo-age structure is introduced representing slow growth (roots and rhizomes) and fast growth (leaves and epiphytes) components. Production depends on the balance between growth and mortality. Growth is dependent upon limiting factors such as light, nutrients and space. Mortality includes predation but in the GOM does not include wave stress mortality although it is an option within Atlantis models. It is recommended that an estimate of wave stress mortality be include in any report to convey to the reader how important or not this component is. Presumably it becomes important during very high winds such as during tropical storms or hurricanes, however because of their relatively short duration perhaps they do not cause significant mortality.

The diet matrix had some fish species feeding on sea grass. This was questioned and felt to be unrealistic. This needs to be sorted out whether any fish feed on sea grass, and if so then which species.

Conclusions and Recommendations

1. The Atlantis model is not ready for management applications for shrimp. A priority is to fix the aging problem of shrimp and once this is resolved to compare the weight-at-age from the model with observations to ensure that they are relatively similar. Once this is done, the model could be examined for possible management applications and investigation of environmental effects on shrimp.

2. Consultations with local scientists, such as those doing stock assessments, who have developed their own diet matrices should be carried out to confirm or reject any contentious predator-prey relationships.

3. The physical oceanographic submodel underlying the GOM Atlantis model presently only represents conditions during 2012. To adequately examine environmental effects on the ecosystem, including climate change scenarios, conditions based on a longer time period is required, preferably at least 30 years, and longer if possible. Ideally, a climate change physical model should be used.

4. The relationships of the wind with other environmental variables or biological organisms should be carried out using the wind stress and not the wind speed per se. This includes wind effects on larval dispersal and transport.

5. Fish feeding on seagrass needs to be revisited to determine, what species or even if fish truly feed on seagrass.

6. More hypotheses related to environmental forcing of shrimp should be formulated and then tested with the Atlantis model. In particular, these should include environmental impacts on production, growth and recruitment of shrimp.
7. The current version is not at the stage for a comprehensive skill assessment, especially for shrimp.

8. In spite of the problems identified during the review, I believe that the GOM Atlantis model has great potential, and the work should continue. I think that many of the problems can be resolved, although this needs to be demonstrated.

In regard to the review process itself, I would suggest that for any complex model, such as Atlantis, the length of the review should be at least four days as opposed to three. This would allow more time for the reviewers to absorb the material and ask the essential questions.

Given the focus on shrimp, I was expecting some papers on environmental effects on shrimp as part of the literature review before the meeting.

I felt that the GOM Atlantis team was not fully prepared for the review as indicated by several of the problems with the model identified during the meeting. Problems included the 10-year maximum age of the shrimp, the difference in the diet matrices with other regional groups although apparently based on the same stomach analysis database, plots being produced at the meeting which the GOM Atlantis team itself saw for the first time, and in some cases there was an apparent lack of comparison between model results and observations.

Appendix 1

a. References provided for the Review prior to the meeting.

GOM Atlantis technical update

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b. Additional References

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Appendix 2: Performance Work Statement

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Performance Work Statement

External Independent Peer Review by the Center for Independent Experts

Review of the Atlantis Ecosystem Model in Support of Ecosystem-Based Fishery Management in the Gulf of Mexico Large Marine Ecosystem

March 28 - 30th, 2023

Background

The National Marine Fisheries Service (NMFS) 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). NMFS 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 standards[1].

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

Scope

The purpose of this review is to evaluate the performance characteristics and to identify appropriate management applications of an Atlantis ecosystem model, employed by the University of South Florida to support SEFSC's evaluation of Ecosystem-Based Fishery

Management (EBFM) strategies for the Gulf of Mexico (GOM) Large Marine Ecosystem. This review is being undertaken as part of an EBFM funded project at the SEFSC.

NMFS strongly endorses the concept of Ecosystem-Based Fisheries Management and the related need for the development of Integrated Ecosystem Assessments, in support of EBFM. Although this review is directed at efforts in the SEFSC, and more specifically for the U.S. federal waters of the Gulf of Mexico, the findings will be more broadly applicable throughout the agency.

Objectives of the CIE review are as follows. Objective 1 is to evaluate the data, parameterization, and skill of the GOM Atlantis model, with emphasis on predicting stock dynamics and catch of Penaeid shrimp (Brown, White and Pink Shrimp groups) and major interacting species. Objective 2 is to identify the extent to which the GOM Atlantis model is suitable for incorporating environmental effects relevant to shrimp production. Objective 3 is to determine the readiness of the model to conduct simulations that assess ecosystem-level impacts of climate change. This could include representation of habitat changes, changes in environmental conditions, and tolerances of species. Objective 4 is to review recent updates to the Atlantis code base specific to the GOM Atlantis model which improves representation of seagrass dynamics. A novel routine was developed in 2021-2022 with CSIRO Australia. The routine partitions seagrass using pseudo age structure to improve representation of herbivory. The review will not otherwise focus on the Atlantis code base nor will it focus on data quality except as it pertains to model performance.

The Terms of Reference (ToRs) of the peer review are attached in **Annex 2**. The tentative agenda of the panel review meeting is attached in **Annex 3**.

Requirements for the Reviewers

Three reviewers shall conduct an impartial and independent peer review of the GOM Atlantis ecosystem model provided, and this review should be in accordance with this Performance Work Statement (PWS) and the methodology review ToRs herein. The chair, who is in addition to the three reviewers, will be provided by the Southeast Regional Office; although the chair will be participating in this review, the chair's participation (i.e. labor and travel) is not covered by this contract.

The reviewers shall have working knowledge and recent experience in the application of multi-species or ecosystem models of marine ecosystems. This application of Atlantis includes a full dynamic, spatial representation of the marine food web including ocean circulation, biogeochemistry and fisheries. Reviewers should have expertise with models that span these levels of complexity, at a minimum coupling several species to fisheries. Reviewers should have published or supervised development of at least two different types of such models (different model platforms or frameworks), though experiences with the Atlantis model itself is not a requirement. Reviewers shall have direct

experience in model development with EBFM application, including direct senior level policy applications or recommendations in addition to scientific publications.

Tasks for the Reviewers

Task 1. Review background material.

The CIE reviewers are asked to familiarize themselves with all the articles listed in Background Documents list below. The reviewers should especially be familiar with these publications: Ainsworth *et al.* (2015, 2018); Masi et al. (2017, 2018), Tarnecki et al. (2016), Morzaria-Luna et al. (2018, 2022), Court et al. (2020), Dornberger et al. (2020, 2022). Full references for these articles and other supporting documents are found below in the table Background Documents.

Two weeks before the peer review, the NMFS Project Contact will send by electronic mail or make available at an FTP site to the CIE reviewer any recent information required for this peer review. This will include a draft technical document in preparation by Perryman et al. and other technical output.

> *Perryman, H., et al. Draft technical document describing updates to Atlantis. (MS in preparation). Contact: ainsworth@usf.edu.*

Background Documents

GOM Atlantis technical documentation

> Ainsworth, C. H., Schirripa, M. J., and Morzaria-Luna, H. (eds.) 2015. An Atlantis Ecosystem Model for the Gulf of Mexico Supporting Integrated Ecosystem Assessment. NOAA Technical Memorandum NMFS-SEFSC-676, 149 p.

GOM Atlantis applications

> Morzaria-Luna, H.N., Ainsworth, C.H. and Scott, R.L., 2022. Impacts of deep-water spills on mesopelagic communities and implications for the wider pelagic food web. Marine Ecology Progress Series, 681, pp.37-51.
>
> Ainsworth, C.H., Paris, C., Perlin, N., Dornberger, L.N., Patterson, W., Chancellor, E., Murawski, S., Hollander, D., Daly, K., Romero, I., Coleman, F., Perryman, H. 2018. Impacts of the Deepwater Horizon oil spill evaluated using an end-to-end ecosystem model. PLoS One. 2018 Jan 25;13(1):e0190840. doi: 10.1371/journal.pone.0190840
>
> Court, C., Hodges, A.W., Coffey, K., Ainsworth, C.H., Yoskowitz, D. 2020. Effects of the Deepwater Horizon Oil Spill on Human Communities: Catch and Economic Impacts. In: Deep Oil Spills, (pp. 569-580). Springer, Cham. https://doi.org/10.1007/978-3-030-11605-7_33

Dornberger, L., Montagna, P., Ainsworth, C.H., 2022. Simulating oil driven abundance changes in benthic marine invertebrates using an ecosystem model. Environmental Pollution (in press).

Dornberger, L.N., Ainsworth, C.H., Coleman, F. and Wetzel, D.L., 2020. A synthesis of top-down and bottom-up impacts of the Deepwater Horizon oil spill using ecosystem modeling. In Deep Oil Spills (pp. 536-550). Springer, Cham.

Masi, M.D., Ainsworth, C.H. and Jones, D.L., 2017. Using a Gulf of Mexico Atlantis model to evaluate ecological indicators for sensitivity to fishing mortality and robustness to observation error. Ecological indicators, 74, pp.516-525.

Masi, M.D., Ainsworth, C.H., MC, I.C. and Schirripa, M.J., 2018. Interspecific interactions may influence reef fish management strategies in the Gulf of Mexico. Marine and Coastal Fisheries, 10(1), pp.24-39. DOI: 10.1002/mcf2.10001

Diet

Tarnecki, J.H., Wallace, A.A., Simons, J.D. and Ainsworth, C.H., 2016. Progression of a Gulf of Mexico food web supporting Atlantis ecosystem model development. Fisheries Research, 179, pp.237-250.

Morzaria-Luna, H.N., Ainsworth, C.H., Tarnecki, J.H. and Grüss, A., 2018. Diet composition uncertainty determines impacts on fisheries following an oil spill. Ecosystem services, 33, pp.187-198.

Spatial biomass calculations for GOM Atlantis

Grüss, A., Drexler, M.D., Chancellor, E., Ainsworth, C.H., Gleason, J.S., Tirpak, J.M., Love, M.S. and Babcock, E.A., 2019. Representing species distributions in spatially-explicit ecosystem models from presence-only data. Fisheries Research, 210, pp.89-105.

Grüss, A., Drexler, M.D., Ainsworth, C.H., Babcock, E.A., Tarnecki, J.H. and Love, M.S., 2018a. Producing distribution maps for a spatially-explicit ecosystem model using large monitoring and environmental databases and a combination of interpolation and extrapolation. Frontiers in Marine Science, 5, p.16.

Grüss, A., Perryman, H.A., Babcock, E.A., Sagarese, S.R., Thorson, J.T., Ainsworth, C.H., Anderson, E.J., Brennan, K., Campbell, M.D., Christman, M.C. and Cross, S., 2018b. Monitoring programs of the US Gulf of Mexico: inventory, development and use of a large monitoring database to map fish and invertebrate spatial distributions. Reviews in Fish Biology and Fisheries, 28(4), pp.667-691.

Grüss, A., Drexler, M.D., Ainsworth, C.H., Roberts, J.J., Carmichael, R.H., Putman, N.F., Richards, P.M., Chancellor, E., Babcock, E.A. and Love, M.S., 2018c. Improving the spatial allocation of marine mammal and sea turtle biomasses in

spatially explicit ecosystem models. Marine Ecology Progress Series, 602, pp.255-274.

California Current Atlantis model review

Horne, P.J., Kaplan, I.C., Marshall, K.N., Levin, P.S., Harvey, C.J., Hermann, A.J. and Fulton, E.A. (2010) Design and Parameterization of a Spatially Explicit Ecosystem Model of the Central California Current. *NOAA Technical Memorandum* **NMFS-NWFSC-104**, 1–140.

Kaplan, I.C., Marshall, K N. 2016. A guinea pig's tale: learning to review end-to-end marine ecosystem models for management applications. ICES J Mar Sci, 73: 1715-1724.

Kaplan, I.C., Brown, C.J., Fulton, E.A., Gray, I.A., Field, J.C. and Smith, A.D.M. (2013) Impacts of depleting forage species in the California Current. *Environmental Conservation* **40**, 380–393.

Kaplan, I.C., Gray, I.A. and Levin, P.S. (2012a) Cumulative impacts of fisheries in the California Current. *Fish and Fisheries* **10.1111/j.1467-2979.2012.00484.x**.

Kaplan, I.C., Horne, P.J. and Levin, P.S. (2012b) Screening California Current Fishery Management Scenarios using the Atlantis End-to-End Ecosystem Model. *Progress In Oceanography* **102**, 5–18.

Olsen, E., Kaplan, I.C., Ainsworth, C., Fay, G., Gaichas, S., Gamble, R., Girardin, R., Eide, C.H., Ihde, T.F., Morzaria-Luna, H.N. and Johnson, K.F., 2018. Ocean futures under ocean acidification, marine protection, and changing fishing pressures explored using a worldwide suite of ecosystem models. Frontiers in Marine Science, 5, p.64.

Task 2. Attend review panel meeting

Reviewers will attend and participate at a panel review meeting. The draft meeting agenda is provided in Annex 3. The meeting will consist of presentations by NOAA. Other scientists will be available to answer questions from the reviewers and to provide additional information required by the reviewers. The review panel will be chaired by a member of the Gulf of Mexico's Fishery Management Council's Scientific and Statistical Committee (SSC), and the panel will include other SSC members as well as Center for Independent Experts (CIE) reviewers. The review will follow the Methodology Review Process established by the Pacific Fishery Management Council, and the Terms of Reference below adapt portions of those Terms of Reference for our application in the Gulf of Mexico.

Task 3. Produce summary report from meeting

Reviewers will assist the Chair of the review meeting with contributions to the summary report from the meeting.

Task 4. Prepare peer-review report

Reviewers will prepare an independent peer review with report following the review meeting in accordance with the requirements specified in this PWS, OMB guidelines, and TORs, in adherence with the required formatting and content guidelines in Annex 1 and peer-review TORs in Annex 2. Reviewers are not required to reach a consensus. Reviewers will deliver their reports to the Government according to the specified milestones dates listed below.

Foreign National Security Clearance:
When reviewers participate during a panel review meeting at a government facility, the NMFS Project Contact is responsible for obtaining the Foreign National Security Clearance approval for reviewers who are non-US citizens. For this reason, the reviewers shall provide requested information (e.g., first and last name, contact information, gender, birth date, passport number, country of passport, travel dates, country of citizenship, country of current residence, and home country) to the NMFS Project Contact for the purpose of their security clearance, and this information shall be submitted at least 30 days in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations available at the Foreign National Guest website.

Place of Performance:
Each reviewer shall conduct an independent peer review during the panel review meeting scheduled in St. Petersburg, FL during the following dates: March 28 - 30, 2023.

Period of Performance
The period of performance shall be from the time of award through May 2023. Each reviewer's duties shall not exceed 14 days to complete all required tasks.

Delivery
Each reviewer shall complete an independent peer review report in accordance with the PWS. Each reviewer shall complete the independent peer review according to required format and content as described in **Annex 1**. Each reviewer shall complete the independent peer review addressing each stock assessment ToR listed in **Annex 2**.

Tentative Schedule of Milestones and Deliverables
The contractor shall complete the tasks and deliverables described in this PWS in accordance with the following schedule.

Within two weeks of award	Contractor selects and confirms reviewers

Two weeks prior to the panel review	NMFS Project Contact provides reviewers the pre-review documents
March 28 - 30, 2023	Each reviewer participates and conducts an independent peer review during the panel review meeting
Within three weeks of the panel review meeting	Reviewers submit draft independent peer review reports to the contractor's technical team for independent review
Within two 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.

Modifications to the Performance Work Statement: Each reviewer will write an individual review report in accordance with the PWS, OMB Guidelines, and the TORs below. Modifications to the PWS and TORs cannot be made during the peer review, and any PWS or TORs modifications prior to the peer review shall be approved by the Contracting Officer's Representative (COR) and the CIE contractor. The PWS and ToRs shall not be changed once the peer review has begun.

Acceptance of Deliverables:
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 TOR as specified; and (3) The reports shall be delivered as specified in the schedule of milestones and deliverables.

Travel
All travel expenses shall be reimbursable in accordance with Federal Travel Regulations (https://www.gsa.gov/policy-regulations/regulations/federal-travel-regulation). International travel is authorized for this contract. Travel is not to exceed $15,000.00.

Restricted or Limited Use of Data
The contractors may be required to sign and adhere to a non-disclosure agreement.

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Annex 1: Format and Contents of Independent Peer Review Report

1. The report must be prefaced with an Executive Summary providing a concise summary of the findings and recommendations, and specify whether the science reviewed is the best scientific information available.

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.

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 that they believe might require further clarification.

d. Reviewers shall provide a critique of the NMFS 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 TOR, 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

Peer review of the Atlantis Ecosystem Model in Support of Ecosystem-Based Fishery Management in the Gulf of Mexico Large Marine Ecosystem

TERMS OF REFERENCE

These terms of reference are meant to provide guidance for technical requirements for the final peer review report. It is assumed this report will be developed after the panel meeting and will contain inputs from CIE reviewers, SSC members, and others. The final report should address the readiness of the model to address priority model capabilities in TOR 1. Model capabilities can be evaluated on the basis of technical merits and deficiencies indicated in TOR 2.

1. **TOR 1. Reviewers will comment on the technical merits and deficiencies of the methodology and recommendations for remedies.**

    a. What are the data requirements of the methodology?
    b. What are the general situations, management uses, and spatial scales for which the methodology is applicable? (also to be discussed further in TOR 2)
    c. What are the assumptions of the methodology?
    d. Is the methodology correct from a technical perspective?
    e. How robust are results to departures from the assumptions of the methodology?
    f. Does the methodology provide estimates of uncertainty? How comprehensive are those estimates?
    g. What is the process of model fitting and calibration?
    h. Areas of disagreement regarding panel recommendations: among panel members; and between the panel and proponents.
    i. Unresolved problems and major uncertainties, e.g., any issues that could preclude use of the methodology.
    j. Management, data or fishery issues raised during the panel review.
    k. Prioritized recommendations for future research and data collection.

2. **TOR 2. Reviewers will address model readiness concerning priority capabilities**

    a. Evaluate data, parameterizations and skill of GOM Atlantis with emphasis on Penaeid shrimp.
    b. Evaluate the treatment of environmental processes in the model relevant to shrimp production.
    c. Evaluate the readiness of the model to perform climate change simulations, including habitat effects.

d. Evaluate the use of a novel seagrass routine (C++) developed for the GOM by USF and CSIRO

e. **Annex 3: Tentative Agenda – (***Final agenda to be provided two weeks prior to the meeting***)**

Review of the Atlantis Ecosystem Model in Support of Ecosystem-Based Fishery Management in the Gulf of Mexico Large Marine Ecosystem

March 28 – March 30, 2022

Florida Fish and Wildlife Research Institute

100 8th Avenue SE

St. Petersburg FL 33701

Tuesday March 28th, 2023

9:00-9:30	Introduction to the role of Atlantis ecosystem model at the Southeast Fisheries Science Center (Michelle Masi)
9:30-10:00	History, goals, and evolution of Atlantis model development at NWFSC and CSIRO (Isaac Kaplan)
10-10:20	Current and potential role of Atlantis ecosystem models for the Gulf of Mexico Integrated Ecosystem Assessment and/or Council's Fishery Ecosystem Plan (Chris Kelble/Mandy Karnauskas)
Break	
10:30-12	Atlantis modeling framework overview (Cameron Ainsworth/Holly Perryman)
Lunch	
1:00-2:00	History of GOM Atlantis and published work (Cameron Ainsworth/Holly Perryman)
Break	
2:15-3:30	Major updates to 2023 tech memo: larval dispersal, seagrass routine/dynamics (TOR #)
	Management strategy evaluation (Cameron Ainsworth/Holly Perryman) (TOR #)
3:30-4:30	Panel deliberation— 1 hr

Wednesday March 29th, 2023

Published Atlantis model (Cameron Ainsworth/Holly Perryman)

9:00 - 9:30 Aims of the modeling effort

9:30 - 9:45 Geography and functional groups

9:45 - 10:30 Data (Cameron Ainsworth)

- Lower trophic levels
- Fish
- Protected species
- Fisheries and management representation

Break

10:45-12:00 Example applications and recent publications (Cameron Ainsworth)

- Testing management scenarios
- Cumulative impacts of groundfish fisheries
- Forage fish harvest and effects on food web
- Linking of Atlantis to economic impacts models

Lunch

1:00 - 2:30 Model calibration (Cameron Ainsworth/Holly Perryman)

- Estimates of unfished biomass
- Sensitivity to fixed fishing mortalities, estimates of MSY and FMSY

2:30-3:30 Handling of uncertainty (Cameron Ainsworth/Holly Perryman)

- Bounded scenarios – uncertainty in biomass estimates
- Bounded scenarios – uncertainty in rate parameters
- Temperature driven movement of shrimp

3:30-4:00 Discussion regarding the appropriate role of this model for management needs defined in TOR 1.

4:00-5:00 Panel deliberation

Thurs, March 30th, 2023

Public Comment & CIE Panel Discussion and Q&As

9:30-11:30 Public Comment (Open to the Public)

Lunch

12:30-2:30	Extra time to discuss any provided model diagnostic material

Appendix 3: Panel membership and Meeting attendees

Review Panel

CIE Reviewers: Drs. Vidette McGregor (New Zealand), Daniel Howell (Norway), and Ken Drinkwater (Norway/Canada)

Regional Reviewers: Drs. Luiz Barbieri, Joshua Kilborn, Dave Chagaris (USA)

Meeting Facilitator

Matt Freeman (Gulf Council)

Project Team

PIs & Co-PIs: Drs Michelle Masi (SEFSC/SERO), Cameron Ainsworth (USF), Isaac Kaplan (NWFSC), Howard Townsend (OST), S. Sagarese (SEFSC), C. Kelble (AOML) and , Mandy Karnauskas (SEFSC)

Modeling Team: Dr. Cameron Ainsworth (USF), Dr. Holly Perryman (USF/IMR), Rebecca Scott (USF)

Other Attendees

SEFSC and SERO personnel, interested public

Appendix 4: Final agenda

Review of the Atlantis Ecosystem Model in Support of Ecosystem-Based Fishery Management in the Gulf of Mexico Large Marine Ecosystem

March 28 – March 30, 2022

Florida Fish and Wildlife Research Institute

100 8th Avenue SE

St. Petersburg FL 33701

Tuesday March 28th, 2023

Day 1 Goals: Overview of the Gulf of Mexico Model Configuration and applications (2015 NOAA Tech Memo and peer-reviewed literature)

9:00-9:20 am	Introductions, TORs, roles and rules review (Matt Freeman)
9:20-9:30 am	Aims of the modeling effort: project overview & the intended simulation/strategic application of the model post-CIE review (Michelle Masi)
9:30-9:50 am	CIE review recap of the NWFSC Atlantis Model, and overview of why we elected to hone in on a subset of species (Isaac Kaplan)
9:50-10:05 am	How the southeast region is building ecosystem modeling capacity to better address strategic management priorities (Mandy Karnauskas)
Break	25 mins
10:30-12 pm	Atlantis End-to-End Model (TOR 1.a,b,c,d) ● The Atlantis Approach (General references) ● CSIRO & world community GOM Atlantis model ● GOM Atlantis Model Tech Memo (2015) (TOR 1.a,b) Fitting (TOR 1.g) ● GOM Atlantis Tech Memo (Draft) ○ With updates to Feb 2023 (TOR 1.a,b) ○ TOR 1.a, 2.a: Data refinements and parameterization ● Hydrodynamic forcing data ● Biomass of species ● GOM Atlantis fisheries, high-level overview ○ Fleet structure ● Migration ● Statistical habitat effects - Spatial distribution of species

    - 40 fish & invertebrate groups (Drexler and Ainsworth 2013)
    - Pink shrimp PSH (Gruss et al. 2014)
    - 61 fish & invertebrate groups (Gruss et al. 2018b)
    - 32 fish & invertebrate groups (Gruss et al. 2018a.)
    - 2 bird groups DBR SBR (Gruss et al. 2019)
    - 2 marine mammals and 2 sea turtles (Gruss et al. 2018c.)
    - 2 sea turtle (ICHTHYOP) (Scott et al. *in prep*)
- Predator-prey dynamics
    - Food web diagram
    - Dirichlet model (Masi et al. 2014)
    - Improved Western GOM diet data (Tarnecki et al. 2016)
    - Diet uncertainty in simulations (Morzaria-Luna et al. 2022)
    - Improving pelagic interactions (Scott et al. *in prep*)

Lunch 1 hour

1:00-1:45 Additional applications of the methodology (TOR 1.b)

- Effects of the Deepwater Horizon Oil Spill on Human Communities: Catch and Economic Impacts (Court et al. 2020)

GOM model applications (TOR # 1.b, 1.e, 1.f, 1.g)

- Oil fate model coupling (Ainsworth et al. 2017)
    - Uncertainty (TOR 1.f)
- Impacts of deep-water spills on mesopelagic communities and implications for the wider pelagic food web (Morzaria Luna et al. 2022)
- Ecological indicators (Masi et al. 2017)
- Management Strategy Evaluation (Masi et al. 2018)

Break 30 min

2:15 - 3:30 GOM Atlantis model updates to improve representation of environmental processes that drive the distribution and abundance of shrimp, and may be impacted under a changing climate (TOR # 2.b, c. and d.)

- Larval dispersal (Kelly Vasbinder UC Santa Cruz); Hydrodynamics ; Vertical migration behavior
- Nutrient & Detritus cycles (e.g., Dornberger et al. 2022)
- Seagrass routine affect carrying capacity
- Habitat affinity statistical model (in prep)

3:30 - 4:30 Public comment / discussion

Wednesday March 29th, 2023

Day 2 Goals: Overview of GOM Atlantis model updates (New NOAA Tech Memo) and improvements, focused on Penaeid shrimp and their top 10 major interacting species

9:00 - 9:30 Shrimp biology/ecology overview (Michelle Masi, for Jen Leo)

9:30-10:15 GOM Atlantis model tuning and diagnostics regarding Penaeids and their major interacting species groups (TOR #2.a)

- Population dynamics
- Life history and ecology

Break 30 mins

10:45 - 12:00 GOM Atlantis model tuning and diagnostics regarding Penaeids and their major interacting species groups (continued) (TOR #2.a)
[Penaeid shrimp fisheries representation, particularly as compared to Southeast Data, Assessment and Review (SEDAR) reports]

- Updates and improvements to GOM Atlantis Model fisheries
- Landings and discards
    - Bycatch adjustments, following internal panel recommendations
        - Dead discard setup: US otter trawl fishery
        - Dead discard setup: US recreational fishing
    - Summary of simulated US catches and fishing mortalities (Atlantis vs SEDAR)

Lunch 1 hour

1:00 - 2:00 Model sensitivity for penaeids and focal groups (TOR 2.a, TOR 1.e, 1.g)

- Productivity for Penaeids - estimates of shrimp MSY and FMSY from a selection of GOM EwE models
- Equilibrium state under no fishing pressure?
- Penaeid sensitivity to food availability

Break 30 mins

2:30-3:30 Handling of uncertainty (Cameron Ainsworth/Holly Perryman) (TOR 2.a-.c, TOR 2.f)

- Diet composition uncertainty determines impacts on fisheries following an oil spill (Morzaria-Luna et al. 2018)
- Bounded scenarios

- uncertainty in initial penaeid shrimp biomass estimates
- uncertainty in seagrass coverage
  - Is shrimp abundance/distribution altered under these scenarios?
- uncertainty in rate parameters
  - Temperature impacts on recruitment and movement

3:30-4:30 Public comment / discussion

Thurs, March 30th, 2023

Day 3 Goals: Initiate peer review report writing and ensure that the reviewers have all necessary materials to complete the review.

9:00-10:30	CIE Panel Discussion and Q&As discussion: extra time to discuss any diagnostic material
10:30-12:00	Panel deliberation and Report writing
Lunch	1 hour
1:00-2:30	Additional deliberation & closeout