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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June 2023

Executive Summary

The Gulf of Mexico Atlantis model is being considered for application in support of Ecosystem-Based Fishery Management. The model is being redeveloped to use the latest version of the Atlantis source code, and to focus on shrimp and their closest components within this ecosystem.

Atlantis is an end-to-end ecosystem modelling framework well suited to exploring scenarios that consider a wide range of impacts and effects. Simulations can include explicit modelling of climate change through oceanographic variables, inputs from rivers, changes in habitat, nutrient and light limitation effects, and a comprehensive harvest component that allows for exploring alternative fishing strategies against a background of varying environmental and ecological conditions.

Following the development phase of an Atlantis model, the model then requires calibration. This involves edits to model parameters until the model returns acceptable outputs. The current implementation of the Gulf of Mexico Atlantis model was still being calibrated at the time of this review, and hence much of the review recommendations were speculative.

The shrimp components of the developed Gulf of Mexico Atlantis model were found to have errors in specification of lifespan, spawning timing and duration, animal size, growth rates, natural mortality rates, and recruitment. These need to be resolved before model calibration is continued.

Focus species were found to have questionable diets and these need to be checked against raw diet data, and experts consulted where they are available. Bringing the emergent diets in line with 'best knowledge' diets can then be continued as a goal of the model calibration.

Growth and mortality rates of focus species were not correct in the presented model during the review. These can be resolved through further model calibration.

Background

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.

The GOM Atlantis model has been peer reviewed in the literature and has been used academically to explore scenarios and test effects of uncertainty resulting in a range of publications (*see* Appendix 1: *GOM Atlantis applications*). The GOM Atlantis model had not prior to this review been peer-reviewed for its application in management. The latter requires a higher standard of capturing realism of the system it represents (the Gulf of Mexico) and the ecosystem model needs to reflect best current knowledge of this system albeit in a simplified version due to being a model.

This report presents the merits and limitations of the current GOM Atlantis model as at the time of this review under the headings of TORs 1 and 2, and with respect to the CIE review objectives.

Objectives of the CIE review were:

- 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.

Description of reviewer's role in review activities

This reviewer read the material in Appendix 1 prior to the review meeting, attended the in-person review meeting (March 28th–March 30th, 2023), and produced this report following the in-person review meeting. This reviewer has a background in both single species stock assessment and ecosystem modelling, with the latter primarily using the Atlantis framework. As a result, they were particularly able to contribute to assessment of population and stock dynamics as they relate to fisheries assessments, and technical aspects of the Atlantis framework as they relate to the implementation of the GOM Atlantis model.

Findings for each TOR

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

    a. **What are the data requirements of the methodology?**

Due to the complexity of the Atlantis model framework, there is the potential to include a large range of data inputs, however there are almost certainly going to be data gaps. The model requires initial conditions, which in the GOM Atlantis model were defined to reflect the best knowledge of the modelled system in 2010. The initial conditions consist of numbers at age (where 'age' refers to age-class which may represent multiple years), weights at age specified as reserve mg nitrogen and structural mg nitrogen for age-structured groups; mg nitrogen per m^3 for biomass pools, species that exist in 2 dimensions spatially; and mg nitrogen per m^2 for species groups defined only in the sediment layer and hence are defined only in 1 dimension spatially. Nutrient values are also required including oxygen, carbon, ammonia, silica, chlorophyll a, detrital silica, and nitrogen. The initial conditions are required spatially with values for each cell (polygon and depth layer).

Diets were a key data input into the models (21,153 samples analyzed) and these were used to inform the prey availability matrix. However, the prey availability matrix was noted as a key tuning component of the model, with realized diets then needing to be compared with intended diets. Realized diets are the result of spatial/temporal overlap, feeding functional response, ratios of prey availability (i.e., if a prey species becomes very abundant, it can overwhelm a diet), and the prey availability matrix.

Natural mortality rates are not inputs into the model but can be checked against model outputs from modelled age-composition in the absence of fishing. Model initial conditions should align with best knowledge of natural mortality as this would affect the age-structure of a population.

Growth rates are not inputs into the model but can be used to compare outputs of weight-at-age to check if emergent growth rates from the model are realistic. Model initial conditions should align with best knowledge of growth rates as these will affect size-at-age of the population.

Spawning stock recruitment parameters (Beverton-Holt alpha and beta) are entered into the model, although the realized spawning stock recruitment relationship could also be checked against expected as its application within Atlantis can be more complicated than when applied in a stock assessment, as it can be parameterized to consider the fitness (reserve to structural weight ratio) of adults in spawning success.

Fleets were defined with target species, bycatch species, selectivity coefficients (knife-edge used here for all species and fleets), and F values (instantaneous fishing mortality). F values were tuned to achieve catches that matched those in 2018–2020 fishing years.

The model was forced with oceanographic parameters summarized from an oceanography model developed for 2012. These parameters were then recycled throughout the model simulations. Ideally, oceanographic parameters used in future scenarios will include climate change effects.

Migrating species require specification of growth and mortality rates while outside of the model domain. Migrating species parameterizations were not focused on during this review. The Atlantis code for migration has been developed recently, so it could have been useful to have a little more focus on this aspect of the model.

Seagrass was forced in the model, and this required growth rates of the 'pseudo age-classes' and spatial distribution. The model was simulated with alternative growth rates and the flow-on effects of these were explored.

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)

Atlantis models are well suited to exploratory or scenario-based applications, management strategy evaluation (MSE), considering qualitative outputs, highlighting important gaps in the research, and including climate change into scenarios. The idea of exploring ecosystem effects on shrimp as well as fleet dynamics and potentially economic aspects (e.g., cost of fuel vs the ease of importing shrimp for less) is perfect, once the shrimp lifecycle is more appropriately modelled. The spatial scale is coarse and that needs to be remembered when implementing scenarios and interpreting them. Also, any environmental driver needs to be tested in itself first, and its connections to the system (e.g., if changes in water flow from the rivers are being explored, do they come in at appropriate rates, do they consist of the correct physical properties such as salinity, temperature, nutrients; and is the modelled system designed to respond to these (e.g., are there temperature, salinity, nutrient responses)).

The spatial distribution of species functional groups in the model can be dynamic with functionality such as density dependent movement, or they can be more static with spatial distributions defined and fixed such as for every season. This will need to be considered if spatial movements are possible in response to an environmental driver, and the team have begun looking at that with temperature and salinity movement options.

c. What are the assumptions of the methodology?

Atlantis models assume homogeneity within spatial cells, and as such, the size, dimensions, and position of the cells need to be considered when setting up scenarios. For example, river inputs to a cell are uniformly distributed within that cell, and on moving to neighboring cells are then uniformly distributed within the neighboring cells and so on.

Homogeneity within species functional groups is also assumed. The model is specified with 90 species functional groups, which should capture the key differences between species within the Gulf of Mexico ecosystem.

There is no annual variability through the physical forcing of the model from the oceanographic variables as one year (2012) is repeated indefinitely. This assumes 2012 to be sufficiently typical although it was not clear whether this had been tested.

Age-structured species were modelled with no senescence assumed, and hence no ‘plus’ group. This can mask inadequate natural mortality rates, although these can be tested for through the age structure in the absence of fishing.

Predator-prey interactions were assumed homogeneous within adult and juvenile states, and without any effect with respect to size of the prey or predator.

Feeding functional response Holling Type II was assumed for all species. This allows for handling time to limit predation when prey are abundant, and searching time to limit predation when prey are scarce. The implementation of this feeding response in Atlantis applies to all prey for a given predator and so only reduces predations rates if all prey for a given predator become scarce. Hence, it doesn't necessarily offer protection to a depleted prey.

Alternatives to this could be explored by specifying gape sizes which can restrict smaller predators to predating on smaller prey. This would then allow for reduced predation (and hence natural) mortality on larger (likely older within a species) animals as they would be vulnerable to less predators. In the current specification of the Gulf of Mexico Atlantis Model, a smaller animal can predate on a larger animal.

All species were assumed to have one spawning window within the annual cycle. The timing of spawning can matter as it relates to seasonal dynamics of nutrients, light, and primary production. It is possible in Atlantis to have multiple spawning windows within a year, and this may be more appropriate for some Gulf of Mexico species such as shrimp which spawn throughout the year and have more than one peak spawning season.

Knife-edge selectivities were assumed for all fisheries and the effect of this assumption did not appear to have been tested. Corresponding selectivity ogives will be available for stock assessments, and assessing how close these are to knife-edge (e.g., a steep logistic) would be a good start. Selectivity ogives in an assessment are sometimes accounting for more than just physical gear selectivity; they can also be a proxy for spatial dynamics not captured in the assessment model. For example, smaller fish existing at a different depth to the main fishery, or older fish moving further away and hence less vulnerable to the fishery. The Atlantis model should not need to incorporate spatial dynamics of the fishery through the selectivity because it is a spatially explicit model. Hence, it is possible the selectivities applied in the Atlantis model can be simpler than in the corresponding assessments, but this still needs to be checked.

d. **Is the methodology correct from a technical perspective?**

The Atlantis framework is correct from a technical perspective, although there are aspects of its application to the Gulf of Mexico model that require further development and validation.

Repeating oceanography from 2012 is unlikely to be correct and the effects of this don't appear to have been explored. This is of particular importance if scenarios are to include climate change effects.

Exploring management scenarios relating to the shrimp fisheries was identified as a key motivator for this work, but ensuring the shrimp species functional groups were modelled to reflect current best knowledge had not been done at the time of this review. Shrimp were modelled to live for 10 years whereas they generally have a 1-year lifespan. The size-at-age of shrimp in the model suggested the initial conditions, as well as growth resulting from food consumption within model simulations, were incorrectly defined, both resulting in shrimp an order of magnitude larger than they should be. The spawning windows specified for shrimp species did not match peak spawning seasons presented within the review presentations.

Growth rates of other species groups in the model did not appear to be realistic, although these need to be looked at as weight-at-age plots rather than tracers of weights over time for each age-class. Tracers showing changes with respect to the weights in the initial conditions can be helpful for assessing stability of the model dynamics, but they are not useful for assessing realistic growth rates of individuals within a population.

Diets of some species were questioned by local experts at the in-person review. A statistical sampling method had been applied to the original diet data to specify the prey-availability matrix. It would be helpful to show comparisons of the diet links resulting from this method to the raw data, and to work through these with local experts to obtain a realistic starting point.

The realized diets from the model then need to be compared to the intended diets, and these should be considered spatially and temporally. There can be challenges in balancing the prey availability of a biomass-pool prey species with an age-structured prey-species, with the former prone to saturating a diet if it becomes over abundant in a particular spatial cell. For example, a dinoflagellate bloom in a particular part of the model can saturate the diet of predators even if they have only a small prey availability for dinoflagellates. This is more of a problem during model tuning, although this model was still being tuned at the time of this review, and so it is relevant.

Natural mortality in the model is mostly predation mortality, but can also include starvation, disease, oxygen or nutrient limitation, light limitation, and additional mortality. All processes were defined separately for adults and juveniles of age-structured species functional groups. One of the goals the team set in assessing model performance was natural mortality declining with age. The numbers-at-age were reviewed in the absence of fishing, and it was found that natural mortality did not decline with age. It was not apparent how it could reduce with age given all the dynamics were specified to be homogeneous within the adult population. However, given stock assessments often assume constant natural mortality with respect to age, it is probably not too unrealistic to assume it here, but it should be removed from the model performance criteria.

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

Robustness of results to departures from the assumption of the methodology will depend on the scenarios and questions being explored. Simulations focusing on seasonal dynamics will not be robust to the current spawning windows for shrimp as these are incorrect. Simulations focusing on temperature effects on growth rates will not be as complete given size does not affect prey availability.

The model was tested for sensitivity of shrimp biomass to initial conditions of their prey species. The resulting biomass of shrimp was found to be sensitive to pulsed perturbations of infaunal meiobenthos, but not of small phytoplankton. These simulations could be repeated once shrimp have been amended in the model.

An earlier version of the model presented responses to an oil spill and included uncertainty in the prey availability matrix. Results in this paper were presented with bounds that reflected uncertainty in diets. Some bounds were wide such as for seatrout and small demersal fish and some appeared non-existent such as shallow serranidae and skates and rays (Morzaria-Luna et al., 2018).

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

Efforts have been made to explore the effects of uncertainty with previous versions of the Gulf of Mexico Atlantis model. While Atlantis doesn't provide estimates of uncertainty directly, the effects of uncertainty can be explored through multiple simulations. There are many ways this can be done in such a complex model. Looking at key aspects of the model such as diets, initial conditions, physical forcing, and productivity are sensible areas to focus on.

The model was tested with pulse perturbations to shrimp prey species, sampling from diet data (21,153 samples), bounded scenarios (e.g., initial biomass of shrimp halved and doubled), and persisting perturbations of seagrass. Under the pulse perturbations, the model returned to its equilibrium. Diet sampling gave confidence intervals around biomass responses to an oil spill, although some species showed no variability under these. Changes in seagrass growth caused persistent changes in the model.

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

The model was tuned over a historical time-period of 1980 to 2010 to obtain parameter values that produced realistic steady state dynamics. These values were then applied with the initial conditions of 2010 and run forward. This review was focused on outputs from the 2010 onward model of which the first 30 years were considered 'burn-in' years.

The prey availability matrix was noted as the key focus during model calibration. While the initial prey availability matrix was informed by diet data, the realized diets in the model are more complex due to spatial and temporal dynamics between predators and prey, and so the prey availability matrix is often adjusted to achieve desired realized diets (Pethybridge et al., 2019).

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

The panel agreed that the model in its current state is not ready for use as a management tool for the Gulf of Mexico ecosystem.

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

There were inconsistencies between the shrimp information presented on day 2 and the parameterization of shrimp in the model and these need to be resolved before the model can be considered for management uses. Areas to focus on for shrimp are:

- Life-span
  The current 10-year lifespan needs to be reduced to one-year.
- Spawning timing and duration
  Timing of spawning is incorrect for all shrimp species.
- Recruitment
  Recruitment will be too small when the lifespan is reduced from 10 years down to one.
- Growth rates and size distribution
  Initial size distribution is incorrect and remained incorrect through simulations with animals unrealistically large.
- Natural mortality rates
  Numbers did not decline sufficiently to reflect natural mortality rates of an annual life-cycle.

Model calibration was incomplete at the time of the review. Key problems were growth rates, natural mortality rates, and diets of the focal species groups.

Growth and mortality rates were particularly poorly modelled for snapper, but the other focus species groups appeared to have concerns too.

Some biomass pool prey species were over-represented in some diets, in particular dinoflagellates and seagrass. These species should be checked spatially for exploding biomass in only one or some model cells.

All modelled diets need to be checked against intended diets. The review presented comparisons against model diets after one model-year, which is interesting with respect to model stability, but not helpful for assessing realistic diets without being an expert on the predator-prey interactions of this ecosystem.

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

F estimates and Maximum Sustainable Yield (MSY) estimates from the literature were missing so values from other models were considered, but these were not quite right. Consider attempting MSY estimates using Ecopath with Ecosim in simulation mode. F possibly could be obtained (values were given) but the problem was more in not knowing how these had been defined or calculated, such as what was used as the biomass value in the denominator, whether this was mature biomass, vulnerable biomass, total biomass.

k. Prioritized recommendations for future research and data collection.

1. Resolve shrimp errors:
    - Life span
      Resolve how to best model the shrimp annual lifespan in Atlantis.
    - Spawning timing and duration
      Edit spawning windows to reflect timing of shrimp spawning. Some spawn all year but have peaks, and it could be just the peaks that are deemed spawning windows. Spawning occurs uniformly within a spawning window in Atlantis.
    - Recruitment
      Check the spawning stock recruitment relationship as recruitment will be too small when the lifespan is reduced from 10 years down to one if this is not adjusted.
    - Growth rates and size distribution
      Set initial size distribution to be realistic for the animal and assess how the weights track over simulations to ensure growth rates are realistic.
    - Natural mortality rates
      Set initial numbers to be realistic for the animal and assess how numbers-at-age track over simulations to ensure mortality rates are realistic.
2. Check intended diets against data and seek expert input.
   It may be helpful to seek expert input on diets based on prey types as well as specific prey – e.g., Predator A should eat mostly crustaceans.

3. Check (and fix) initial conditions against best knowledge for growth rates and natural mortality rates.
4. Recalibrate.
5. Focus on growth and mortality rates emergent against expected and diets emergent against expected. Check diets spatially as well as temporally – not just summaries, although consider summarizing over prey types rather than individual prey species.
6. Present growth and mortality rates over time through size-at-age and numbers-at-age and compare these to curves based on values from the literature.
7. Present hindcast from the model against available abundance indices (e.g., CPUE, surveys, stock assessment biomass).

TOR 2. Model readiness concerning priority capabilities

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

The model skill failed in the review due to incorrect modelling of the main focus species, and incomplete model calibration.

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

Yet to be explored. The mechanism of temperature or salinity prompted movement has been tested but not in a way considered realistic.

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

The Atlantis framework is well suited to performing climate change simulations, including habitat effects. The model can be forced with values from an oceanography model that reflect climate change scenarios, and there is scope to include species responses to changes in temperature and salinity. There might not be information to inform these responses, in which case bounds could be explored. The timing of spawning windows for shrimp could be important in climate change simulations as seasonal dynamics could be impacted.

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

The novel seagrass routine used pseudo age-classes to represent three states of sea grass (roots, leaves, and epiphytes). Modelling seagrass in these states allows for more accurate predation on seagrass (some species will eat only the epiphytes, some will eat only the leaves, and some will feed on the whole plant). The above-ground components of seagrass are more responsive to seasonal environmental effects while longer term impacts will affect the roots. The growth rates of all components are modelled the same as primary producers, with the following additional dynamics:

- Light available to leaves is reduced as the ratio of epiphyte to leaves biomass increases (shading of the leaves by the epiphytes).
- Growth of the leaves is reduced as ratio of roots to leaf biomass decreases (leaves need roots to support them).
- Growth of epiphytes is increased as the ratio of leaf biomass to epiphyte biomass increases (epiphytes need leaves to grow on).

  While the actual code was not available to review, the descriptions of the routine were sound. The dynamic nature of the growth rates of the states of seagrass don’t appear to have been tested, as seagrass growth are currently forced in the Gulf of Mexico Atlantis model.

Comments on the review process

Complex ecosystem models need more time for the in-person review component. There needs to be time to review the model spatially, temporally, and to examine each of the focus species as well as the interactions between them.

There needed to be more links to reality as the model was presented. For example, the information presented on shrimp that included lifespan and biology could have been presented alongside the model outputs and specification for shrimp. Had this been prepared for the review, the modellers would have likely noticed they didn’t match and resolved the issues ahead of the review.

For each focus species, the outputs from the model and implementation within the model should have been presented along with best knowledge on the species. For example, here is what we think we know on this species, here are the data sources, here is how we’ve parameterized this species to best reflect these attributes and dynamics, and here’s how they’re performing in the model.

The model calibration wasn’t complete at the time of the review which meant it wasn’t ready for this level of review. We could at best speculate on what the model might produce once it is ready.

Conclusions and Recommendations

Atlantis models are well suited to exploratory or scenario-based applications, with potential to include climate, environmental, anthropogenic, and ecological effects. The GOM Atlantis model has the potential to address management questions that relate to shrimp productivity within the GOM ecosystem, as well as broader questions relating to the environment and management of its marine resources.

The current version of the GOM Atlantis model was not ready for application in management due to errors in the modelling of shrimp, in realized diets of focus species groups, and in realized growth and mortality rates of focus species groups. The model was still being calibrated at the time of this review, and model calibration will need to be continued following edits to the model specification.

Recommendations are listed in TOR 1.k. and are therefore not repeated here.

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Appendix 1: Bibliography of materials provided for review

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Appendix 2: Performance Work Statement

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., Kaplan, 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

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 or other pertinent information from the panel review meeting.

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Review Panel

CIE Reviewers: Drs. Vidette McGregor, Daniel Howell, and Ken Drinkwater
Regional Reviewers: Drs. Luiz Barbieri, Joshua Kilborn, Dave Chagaris

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 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