The Atlantis Ecosystem Model in Support of Ecosystem-Based Fishery Management in the California Current Large Marine Ecosystem

Northwest Fisheries Science Center, Seattle, WA

External Independent Peer Review

By

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Executive Summary

A peer review of the California Current Atlantis model (CCAM), developed by the Northwest Fisheries Science Center (NWFSC) with Dr. Isaac Kaplan as the lead investigator, was conducted during 30 June – 2 July 2014 at the Northwest Fisheries Science Center (NWFSC) in Seattle, WA. The review panel consisted of Center for Independent Experts (CIE) reviewers Drs. Reg Watson (University of Tasmania), Daniel Howell (Institute of Marine Research, Norway) and Kenneth Frank (Fisheries and Oceans Canada) and members of the Pacific Fisheries Management Council's Scientific and Statistical Committee (SSC). The review panel was chaired by SSC panel member Dr. Martin Dorn. Members of Dr. Kaplan's team who made presentations during the review included Drs. Phil Levin, Kristin Marshall, Chris Harvey, and Al Herman. The review panel followed the Methodology Review Process established by the Fishery Management Council with the aim of identifying the Atlantis models' strengths, weaknesses, applicability, and potential areas of improvement with respect to specific management needs in the California Current ecosystem.

Atlantis is an "end-to-end", spatially explicit simulation model originally developed at Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Australia) intended for use as a strategic management tool. The model is not designed for tactical decision making such as setting annual quotas or to replace stock assessment models. Instead, such a modeling framework can help to synthesize large volumes of unconsolidated biophysical, human use and other data types that accumulate over time. Two previous versions of the Atlantis model have been developed for the California current (Brand et al. 2007; Horne et al. 2010). Adopting the Atlantis model was viewed by the NWFSC as a testing ground for exploring model complexity, and improving ecological and whole ecosystem understanding. The Atlantis model has been viewed as a flight simulator for exploration of both fishing and non-fishing effects such as oceanographic variability, ocean acidification and nutrient loading on species spatial distributions and productivity. These models, their applications and uncertainties were carefully and concisely documented in the literature, the power-point presentations, and in responses to questioning during the review. While continued development of the Atlantis model for the California Current ecosystem was strongly encouraged it was recognized that ecosystem models with numerous parameters are not necessarily better and tend to produce higher variances and unrealistic behavior than simpler models. Exploration of alternative models and inter-comparison of their performance with CCAM was recommended. One such inter-comparison was made with an Ecosim model for the Northern California current. Ecosim yielded similar responses to depletions of forage groups as CCAM, but because it has more trophic resolution at the species level it predicted larger impacts for more groups. The divergent results between Ecosim and Atlantis were noted as in need of further investigation.

The lower trophic levels within the ecology sub-model of Atlantis are not very well modeled because of lack of data and some highly uncertain assumptions associated with the data that is used. For example, large amounts of spatially and temporally resolved lower trophic level data exist from the California Current Oceanic Fisheries Investigation (CalCOFI) monitoring program were not incorporated into the model. As well, readily available remote sensing data provides many data products that could have been used to parameterize primary production and associated

attributes. Information is available on spatially resolved chlorophyll fields in the California Current as well as their time trends that could be easily incorporated into CCAM.

Atlantis did not predict strong declines in marine mammals or seabirds due to forage fish depletion. The model did capture the interaction between forage and their prey in the simulations but was unresponsive to the depletion of forage groups on higher trophic levels. Either because of the poor parameterization of the lower trophic levels or the structure of the model itself, Atlantis is largely a top-down driven (consumer driven) model. Not capturing this bottom-up (resource driven) process is considered a major limitation of Atlantis given the strong environmental forcing that characterizes the California Current large marine ecosystem.

The model domain in earlier versions of the Atlantis model may have been too restrictive to resolve some important species dynamics. The poor performance of the sardine and hake population dynamics within the model is problematic given that hake is a key predator in the system and sardine is an important forage component. These discrepancies, in part, stem from the inability of the Atlantis model to handle variable recruitment as each of these species produce irregular, highly episodic recruitment not captured by output from a theoretical stock and recruitment relationship. In addition, sardines extend beyond the offshore boundary of the model and hake are generally distributed northward of it for considerable amounts of time on an annual basis. There existed boundary boxes (so-called non-dynamic boxes) to the north, south and western edges of the domain that allow for exchange of water and nutrients to the main model domain but no other processes are modeled in these areas. For example, myctophid biomass may be exceedingly high and spatially variable along the western boundary boxes and this situation needs to be better resolved.

Conversely, there was limited discussion of the hydrographic sub-model itself and coupling to other sub-models in Atlantis due largely to the lack of expertise within the review panel. The ocean circulation model ROMS was probably a good choice for the California Current large marine ecosystem which is strongly influenced by deep ocean processes and less so by shallower shelf dynamics. The application of the Atlantis model to examine system wide effects of climate change focused mainly on acidification, while the primary manifestation of increases in atmospheric carbon dioxide are rising water temperatures. However, the California Current is more prone to ocean acidification than other large marine ecosystems and field evidence already suggests the manifestation of negative effects on some shell-forming invertebrates. Model runs of Atlantis simulating such negative effects on shell-forming invertebrate species did not reveal any compensatory increases in non-shell forming, lower trophic level groups. It was further noted that the processes and resultant dynamics of the groups represented in the benthic boxes of the model are among the least reliable. Acidification effects can act directly on the fish themselves, particularly during the early egg and larval development period, resulting in impairment of otolith development and behavioral changes leading to reductions in survival and growth which should be investigated in the future. Also, providing reference points in terms of biomass levels associated with such scenarios was not advised given their high uncertainty.

A key requirement of any food web model involves detailed knowledge of diets. Since there has been no systematic, coast-wide diet analysis initiative within the California Current marine ecosystem, a synthesis of the published literature was undertaken by the NWFSC and summarized by predator species and/or predator functional groups. However, given the existence of annual trawl surveys within the California Current model domain consideration should be given to the development of a standardized, sub-sampling protocol of fish stomachs for subsequent diet analysis.

While it known the seabirds generally exhibited high spatial aggregation in colonies/rookeries, this spatial detail was not included in the model. Six functional groups of marine mammals were also included in the model but similar to seabirds, no spatial structure was included in the model for any of the groups. Several data sources were available ranging from surveys to stock assessments although it was noted that additional data source for abundance of many of the mammal species do exist.

Concerns were raised about documentation of the Atlantis model as there is no user manual available for general distribution. In addition, the software is not truly open source and this restriction has been imposed by CSIRO. The model is also very data demanding with long run and calibration times and repeated reference to the model as a "flight simulator" is not completely appropriate given the lack of graphical output one might anticipate from this sort of analogy. However, there is Wiki access for all users where ancillary tools and documentation exist including discussion groups focusing on troubleshooting modelling methodology and software requests.

Many of the concerns and criticisms expressed during the first days of the review had been anticipated by the research team and substantial progress has been made toward their completion as revealed during day 3 when the research team presented the most recent version of the CCAM. Given the repeatedly stated intention that the Atlantis model be viewed as a strategic complement to traditional approaches used in fisheries assessment and management, it is concluded that the body of research reviewed is of an extremely high standard and can be considered at the cutting edge of ecosystem model development and application within the California Current large marine ecosystem. The provision of integrated as opposed to piecemeal solutions to complex fisheries problems is most definitely the way forward and it certainly appears that the Atlantis model has this potential. Fisheries managers and councils are by their very nature highly traditional and movement towards more integrative approaches will take time requiring greater exposure to ecosystem modelers and their methodologies. Development and implementation of end to end models such as Atlantis demands a very high level of knowledge of computer programming, mathematics, ecological modeling and a fundamental understanding of marine ecosystem dynamics ranging from physics to fish. Meeting such a challenge as successfully as Dr. Kaplan and his research team demonstrated during the review is a strong endorsement for a continuation of this line of research for addressing strategic management issues within the California Current marine ecosystem.

Background

The process of conducting the review began with reading all of the material provided which ranged from publications in the primary scientific literature to various technical documents associated with the Atlantis model and its different applications within the California Current ecosystem (Appendix 1). The review took place at the NWFSC in Seattle, WA and lasted for three days from 30 June to 2 July 2014. Each day began with a series of presentations made primarily by the lead investigator – Dr. Isaac Kaplan with follow up questions and discussion after each presentation. All of the power-point presentation files were made available to the Panel during the course of the review. Written responses to outstanding questions at the end of day 1 were discussed on day 2 but the same procedure was not followed on day 2.

The review panel chair Dr. Martin Dorn stated that the general intention of the review was to consider how the Atlantis modelling framework could assist the Pacific Fisheries Management Council in their management of the diverse array of invertebrate and vertebrate fisheries in the California Current marine ecosystem.

The CIE requested that each expert reviewer participate fully in the Panel review during the three day meeting and that the report of each expert be a stand-alone document. This request is fulfilled here as the document represents the review of Dr. Kenneth Frank.

Review Activities

The review started at 9:00 am on 30 June 2014. Introduction of participants was the first order of business with a general statement by the panel chair Dr. Martin Dorn that the general intention was to consider how the Atlantis modelling framework could assist the Pacific Fisheries Management Council in their management of the diverse array of invertebrate and vertebrate fisheries in the California Current marine ecosystem. Emphasis was to be placed on an objective review of the technical aspects of the Atlantis Ecosystem Model.

The first presentation was made by Dr. Phil Levin who provided a rationale for the research direction leading to adapting the Atlantis model as a research tool for strategic planning associated with ecosystem based fisheries management and in the ongoing California Current Integrated Ecosystem Assessment (IEA) process. A large unconsolidated base of biophysical, human use and other data types had accumulated over time. Obtaining and collating such data is a great challenge and can provide opportunities for synthesis that might lead to improved understanding of ecosystem structure and function, cumulative impacts of human use and other anthropogenic activities, and trade-offs to be considered in fisheries management systems. The first objective of obtaining the necessary data was met and is an on-going initiative as not all potentially useful data sources have been secured.

There are a number of approaches to forecasting future ecosystem states ranging from strictly empirical/statistical to analytical/simulation models. A great deal of emphasis has recently been given to the use of simulation models as forecasting tools. An end to end simulation model was considered most appropriate as a means to move forward towards several objectives for ecosystems based management in the California Current region and Atlantis was the model of choice. The model is considered most appropriate for strategic decisions and for providing multiple options in comparison to other, simpler models that provide fewer options and that are not spatially resolved, particularly in three dimensions as is the Atlantis model. The panel did note that bigger models with numerous parameters are not necessarily better and tend to produce higher variances associated with their output and that model selection needs to be tailored to the questions under consideration. For example, minimum realistic models are examples of simpler, multispecies models that may be adequate for addressing ecosystem based fisheries management questions involving closely interacting species within a larger ecosystem context. This important precaution was recognized by the research team who noted that Atlantis is a system model that is simultaneously fit across multiple parameters and data sets, many of which are highly uncertain. For this and other reasons it was acknowledged that the focus was on model accuracy as opposed to precision which renders it best for strategic direction setting as opposed to specific tactical fisheries and conservation management questions.

The history, goals, and evolution of the Atlantis model development at NWFSC was presented by the scientific leader of this research initiative Dr. Isaac Kaplan. Adopting the Atlantis model was viewed as a testing ground for exploring model complexity, and improving ecological and whole ecosystem understanding. The Atlantis model has been viewed as a flight simulator for exploration of both fishing and non-fishing effects such as oceanographic variability, ocean acidification and nutrient loading on species spatial distributions and productivity. Oceanographic processes are modeled using ROMS that provides spatially explicit fields of temperature, salinity, and currents that are exchanged within the Atlantis model domain. Other key features of the model include the incorporation of age structure, biogeochemistry, and habitat considerations and easy coupling with fishery models. The Atlantis model is considered a tool for strategic planning and may have limited application in the short term, i.e. for informing annual stock assessments or sighting of marine reserves. Two previous versions of the Atlantis model have been developed for the California Current (Brand et al. 2007; Horne et al. 2010) with applications to ocean acidification impacts, development of spatial fishery management scenarios, cumulative impacts of fisheries, the role of forage species within the ecosystem and identifying spatial ecosystem indicators. These previous models and their applications formed the basis for most of the external review by the panel both prior to the meeting as recommended/background readings and during the review meeting associated with presentations made primarily by Isaac Kaplan. A new version of the Atlantis model currently under development was reviewed on the final day.

A technical overview of the mechanics, assumption and functional relationships of the California Current Atlantis model was provided by Dr. Kaplan during the afternoon of day 1. The model is a set of two-way coupled, differential equations that are spatially resolved linking processes occurring in 3D between a hydrographic, ecology and human impacts sub-models solved on a 12 h time step with a user defined reporting interval typically set at a quarterly or annual time scale. The modeled processes occur in each polygon and depth layer. A 50 y model run takes about 16 hours. The vertebrate consumers are modeled in much greater detail than most other components in the ecology sub-model of Atlantis so that for most fish species and functional groups, numbers at age per age class and dynamic weights at age can be obtained. Simulation of adult movement ranged from diel to seasonal migrations within the model domain to larger migratory events involving fish, marine mammals and seabirds where the species or functional groups temporally reside outside of the model domain.

The sub-model involving human impacts was intended to simulate fishery effects and responses due to various management options. The human impacts sub-model handles catch in three general ways: forced time series of catch, fixed fishing mortality rates, and age-specific catch. Age specificity was derived from parameterizations of selectivity, effort, availability, and catchability with several gear or age-specific selectivity options available in the model. Options also exist for the incorporation of dynamic or forced fleet dynamic models. Fisheries management involved options for inclusion of quotas and harvest strategies or control rules. Non-fishing pressures that can influence or interfere with fishing may also be a future application, for example, the potential ecosystem-wide effects of the proliferation of wind farms at sea.

The afternoon of day 1 featured an in-depth presentation on the current Atlantis ecosystem model with a focus on model specifications and calibration. The geographic domain of the model ranges from Point Conception in the south to Cape Flattery in the north just short of the Canadian border within which 82 polygons across several depth zones were devised. The chosen functional group structure was as follows: 4 primary producers, 18 invertebrates, 26 fish, 3 seabirds and 6 mammal groups. Detail discussions followed after each presentation which highlighted a particular functional group. One of the goals for calibration of the Atlantis model was for the calibrated model productivity to be biologically plausible when forced without fishing, with constant fishing and historical fishing pressure. A second calibration involved applying a range of fishing mortalities to evaluate the biomass responses to fishing.

One topic reviewed as part of model specifications focused on the fisheries and management representation based on i) historical catch, ii) constant fishing mortality and iii) status quo (2007) management. Appendix B in Horne et al. (2010) provided details associated with development of the historical database for total catch beginning in 1950 – the year considered representative of each species unfished biomass or B_0. The application of constant fishing mortality involved the imposition of spatial management such that a proportion of each model spatial polygon that was open or closed to a particular fleet was specified. Status quo management involved 20 fleets (or gear sectors) and constant fishing mortality with no harvest control adjustments or bycatch of marine mammals or birds. At this point the presentation moved onto the outcomes of the various simulations which were broken down into three parts reflecting the different approaches used to calibrate the dynamic behavior of California Current Atlantis model. Several questions were raised by the panel at the end of day 1 that are listed below (**in bold**) along with answers provided by Dr. Kaplan and his team.

Day 1 Requests, Atlantis PFMC Methodology Review

Request 1: Find out the order of calculations for solving the sets of differential equations, if it is not simultaneously. For example, growth first or M first? [Response provided by Dr. Beth Fulton, CSIRO]:

Step 1: Copy final biomasses of old time step to a "working array" so that while the equations are referring to old biomasses the working array is taking on all the outcomes (that way we avoid order of operation issues). Step 2: Move. In terms of biology the first action of each biological time step is to move things (as that means it's consistent with advection of plankton, etc., happening with the physics time step which happens between each biological time step). Step 3: Rest of fluxes - growth and mortality (including harvesting). Note that everything is calculated on a per-second rate first - this is important as there are two kinds of time steps (described more below). Then flux terms are determined based on the biomasses at the end of the previous time step, with everything responding to those values (i.e. no incremental update). Then the final flux is all done together so the order of operations is not important (i.e., we do not suffer the issue of mortality depleting population before growth happens, etc., as they are effectively simultaneous actions). For everything except plankton and bacteria the time step is as defined in input files (12 hours for California Current models). For the fast growing groups (small plankton and bacteria and their primary predators) they use an adaptive time step so as to avoid numerical artefacts. This means that the fastest turnover group (typically small phytoplankton) dictates the time step based on their flux / standing_stock. This means that this sub time step is squeezed so that no flux can exceed a specific proportion of their standing biomass. If that means that the effective time step they would experience is tiny (<< 1 sec) then the model fails to execute and basically gives an error message as it means there is likely a parameterisation problem. Any running model has already dealt with that so no need to worry there for the California Current models. These fast turn over groups execute as many shrunken time steps as necessary to add up to a "big time step" (12 hours) before Atlantis continues on. As buffering groups (medium and large zooplankton) sit between the most volatile "fast" groups and "slow" groups there is no loss in mass conservation (i.e. fish can't be eating biomass that doesn't actually exist).

Request 2: Clarify how Atlantis tracks a recruitment event through the age bins?
[Response provided by Dr. Beth Fulton]: For computational efficiency Atlantis does most things based on an age cohort (which can be multiple years). However it does actually keep a histogram of actual annual age cohorts behind that. The code assumes that animals are in effect taken from these sub-bins in proportion to the relative biomass in each sub-bin. Thus strong age classes cane seen to flow through the population without being artificially damped out.

Request 3: when catch time series are specified, can the model incorporate fishing selectivity? The forced catch can be allocated to specific age classes. If the specified age classes are not present, the catch shifts to the existing age classes.

Request 4: provide a table listing possible options for terms and functions in the Atlantis model and which options are applied in the California Current Ecosystem model.
This will be posted as Excel File Tuesday morning to FTP site \Requests\Monday .

Request 5: distribute user manual to panel members See HowToBuildAnAtlantisModel.doc , on FTP site in \Requests\Monday . Note this should be viewed as an internal working document and not official Atlantis documentation from CSIRO.

Request 6. Provide all PowerPoints. Uploaded to \Presentations on FTP site.

Example applications of the Atlantis model, based on findings contained in recently published studies that served as recommended reading, were reviewed during day 2. The first example application reviewed was based on the recent publication by Kaplan et al. (2013) who addressed the question: what are the indirect trophic effects of depleting various forage groups including forage fish (small pelagics), euphausiids (krill), myctophids (laternfish) and mackerel in the California Current? Utilizing the version of Atlantis detailed in Horne et al. (2010) each one of the four functional groups were depleted to assess their effects on the food web. Forage fish/group depletion impacts were also modeled using the Northern California Current Ecosim model. Results were roughly similar between the two models, however more groups and larger impacts were predicted by Ecosim which has more trophic resolution at the species level in comparison to Atlantis.

The second example application involved developing a set of alternative fisheries management scenarios based on a range of spatial management options and shifts in the usage of particular fishing gear types (i.e. shifting away from bottom trawling). The Atlantis model was used to simulate the ecological and socio-economic impact of the various management scenarios. The third example application linked Atlantis with an input-output economic model of the Pacific coast fisheries (IO-PAC). IO-PAC has the capacity to explore how changes in landings impact the economy and an example output from the model was shown illustrating the extent to which reduced harvest rates among sablefish fixed gear vessels influenced incomes from a variety of supporting industries, businesses and activities directly associated with the fishery itself. The economic analysis was related to Atlantis scenarios representing status quo and four others identical to those developed in the second example application (Kaplan et al. 2012). The final example application reviewed dealt with an evaluation of the risks of climate change, ocean acidification, and cumulative impacts (recommended readings included Kaplan et al. 2010 and 2013). This exercise involved a simulation of possible catch scenarios under a catch shares or ITQ program with ocean acidification impacts of shelled benthos and plankton, using an earlier version of the Atlantis model (Brand et al. 2007) to run the simulations.

A brief discussion followed during the afternoon of day 2 on the topic of informing parameters such as natural mortality (M) within single species stock assessment utilizing the Atlantis model. Food web modeling explicitly takes predator-prey relationships into account and therefore can be used to determine whether or not simplifying assumptions such as constant M are reasonable approximations or not. Recent examples from publication by Gaichas et al. (2010, *Can. J. Fish. Aquat. Sci*. **67**:1490) and Tyrrell et al. (2011, *Fish. Res.* **108**:1) highlight the differences between traditional estimates of M derived from single species stock assessments in comparison to estimates of M based on food web models.

Near the end of the day Dr. Kaplan presented information on some recent research involving simulation testing with Atlantis of new methods and metrics for ecological indicators and an assessment of their performance across local and coast-wide scales. Some of the topics investigated included whether or not different attribute-indicator pairs were needed for each scale (i.e. local and coast-wide) and the determination of whether or not local (coast-wide) indicators provide meaningful information about coast-wide (local) attributes. The last presentation on day

2 dealt with the treatment of uncertainty in the Atlantis model for the California Current using two bounded scenarios involving uncertainty in biomass estimates and uncertainty in rate parameters. An example was presented illustrating the robustness of food web impacts of euphausiid depletion to uncertainty in hake biomass.

The morning of day 3 began with a presentation by Dr. Kaplan dealing with the ongoing revisions to the California Current Atlantis model. Many of the concerns and criticisms expressed during the previous two days of the review had been anticipated by the research team and progress has been made toward their completion. In terms of the food web impacts of ocean acidification, recent research has indicated the likelihood of a much faster progression of ocean acidification in the California Current than earlier anticipated such that by 2050, surface pH may be strongly impacting shell forming invertebrates and possibly certain fish species directly. In addition, monitoring results from 2011 has provided evidence of shell dissolution in pteropods from various locations across the California Current where the water masses were under-saturated with respect to aragonite (such areas have a low buffering capacity and are therefore highly prone to more rapid acidification). These and other studies have heightened the awareness of this problem in the California Current ecosystem and Dr. Kaplan and his team consider this a priority research topic for use of the new version of the Atlantis model. The ocean acidification goals for the new Atlantis model were presented and will be expanded upon significantly over the previous analyses conducted by Kaplan et al. (2010). Future goals have been established for the forage fish component in the new Atlantis model as well. Few changes have been made to the diet database although some revision has taken place based on the availability of recent data. Overall, the new version of the Atlantis model is providing encouraging preliminary results.

The panel review concluded in mid-afternoon of day 3 and the chair thanked the NWFSC for hosting the meeting and the participants for their extremely constructive input during the review process. It is anticipated that the body of results presented to the review panel will eventually prove highly beneficial in assisting the Pacific Fisheries Management Council and its advisory committees of what represents the best available science for ecosystem based fisheries management in the California Current large marine ecosystem.

Findings specific to Terms of Reference

1. TOR 1. Reviewers will be asked to consider the strengths, weaknesses, appropriate uses, and potential areas of improvement for the Atlantis models with respect to these management needs, in the context of ecosystem-based management.

a) Food web impacts of groundfish fisheries, pelagic fisheries, and other anthropogenic impacts. Policy example: evaluating trophic impacts of forage fish harvest policies on abundance and yield of other species.

Utilizing the version of Atlantis detailed in Horne et al. (2010) each one of the four functional groups were depleted to assess their effects on the food web. Depleting forage groups to 40% of their unfished biomass was found to produce both positive and negative effects on other species. As expected, the most common impacts were on predators of forage groups, some of which declined by > 20% when forage groups were depleted to 40% of unfished levels. Depleting forage fish and euphausiids to 40% of unfished levels, each of which comprised > 10% of the system biomass, altered the abundance of 13-50% of the other functional group by > 20%. Atlantis did not predict strong declines in marine mammals or seabirds due to forage fish depletion. Harvesting forage fish in the model did have some positive effects on several of their prey and competitors.

Inter-comparisons were made with an Ecosim model for the Northern California Current which yielded roughly similar responses to the depletions of forage groups. However, more groups and larger impacts were predicted by Ecosim which has greater trophic resolution/interaction at the species level in comparison to Atlantis. The divergent results between Ecosim and Atlantis are problematic and in need of further investigation. While the Atlantis model captured the interaction between forage and their prey in the simulations it was somewhat unresponsive to the depletion of forage groups on higher trophic levels. Not capturing this bottom-up process is a major limitation of Atlantis given the strong environmental forcing that characterizes the California Current large marine ecosystem. In addition, responses should be evaluated on a 3-5 year time scale instead of the 20 year projections due to the typically short generation times of the forage groups considered.

b) Ranking of potential fishery management strategies, including spatial management, harvest rates, quota systems. This expands beyond trophic impacts to include habitat, bycatch, and economic indicators. Discussion may differentiate between pelagic vs groundfish fisheries. Potential policy context: Tier 1 Environmental Impact Statements (10 year strategic planning).

The Atlantis model was used to simulate the ecological and socio-economic impact of the various management scenarios. Comparisons were made between the status quo, gear shift from bottom trawl to pot and longline, and two spatial management scenarios. The spatial management scenarios involved prohibition of all bottom-contact gear in the rockfish conservation area and protection of essential fish habitat on the shelf. Each scenario was evaluated on the basis of several performance metrics generated from within the model including habitat integrity, projected landed value and abundances of protected species, rockfish biomass and age structure, and rockfish bycatch. A variety of results were presented examining the effects at either a coast-wide or local management scale. The management scenarios that were explored yielded results that were generally within 10% of the status quo. Stock rebuilding was a common result. Local scale management actions (e.g. in Monterey Bay) had minor coast-wide effects but had larger effects on the local habitat and bycatch. The main message from this research was that no single scenario maximized all performance metrics such that any policy choice involved trade-offs. Concerns were raised during that the scenarios devised at small spatial scales, such as for Monterey Bay, may be less reliable as some processes become more important at these scales such a local movements and fluxes that are not adequately resolved in the model.

Another example application linked Atlantis with an input-output economic model of the Pacific coast fisheries (IO-PAC). IO-PAC has the capacity to explore how changes in landings impact the economy and an example output from the model was shown illustrating the extent to which reduced harvest rates among sablefish fixed gear vessels influenced incomes from a variety of supporting industries, businesses and other activities directly associated with the fishery itself.

The economic analysis was related to Atlantis scenarios representing status quo and four others identical to those developed in Kaplan et al. (2012). Bottom trawl revenue declined by as much as 40% under the rockfish conservation area closure to the bottom contact gear scenario and by about 25% under the gear switch scenario. Other fleets varied between -13 % and 25% relative to the status quo scenario. Processor and wholesaler revenue tracked the pattern of revenue for the bottom trawl fleet since that fleet accounts for about 60% of the revenue under status quo. Stock rebuilding was predicted under all four scenarios leading to 23-33% increases in revenue with broader economic impacts (e.g. an additional $25M in income and 400 new jobs). While this coupling of models is a step in the right direction, the use of the IO-PAC model for longer term projections may be inappropriate, given that the economic model is tailored to short term (1-5y) prediction and not the 20+ y simulations characteristic of the Atlantis model runs. In addition, expression of the economic metrics in absolute terms (jobs and dollars) suggested a level of certainty in the model output that is not warranted and, instead, metrics expressed in relative terms was recommended.

c) Evaluation of risks of climate change and ocean acidification. Example: cumulative impacts analysis under National Environmental Policy Act (NEPA), which may consider the impact of actions (e.g. fishing) in the context of global change.

The first part of this exercise involved a simulation of possible catch scenarios under a catch shares or ITQ program with ocean acidification impacts of shelled benthos and plankton, using an earlier version of the Atlantis model (Brand et al. 2007) to run the simulations. The scenarios reflected the possibility that incentives created through catch shares might lead fishermen to improve their ability to avoid overfish species with low quotas and thereby allow the vessels to catch higher amounts of target species. The scenarios associated with the level of improvement in terms of avoiding overfished species ranged from minimal to moderate to high success and were judged against the status quo (2003-2006) prior to the implementation of catch shares. Scenarios for ocean acidification were based on linear mortality rates (1% daily) on all shelled benthos groups including snails, bivalves, corals, sea urchins and sea stars (susceptibility of these groups was supported by several published lab studies) which led to 20-80% declines. Results of the simulations involving the various harvest scenarios alone did not have strong impacts on the food web beyond the direct effects on harvested species. When the impacts of ocean acidification were added to the various scenarios, the abundance of those species dependent on shelled prey items in their diet declined from 20-80%, notably arrowtooth flounder, yellowtail rockfish, and English sole. Strong acidification effects resulted in a 10-fold decline in potential catch and economic yield of English sole. Management reference points for English sole were also estimated and compared between the various scenarios.

It was questioned whether there were any compensatory increases among other functional groups or species that occurred as a result of the decline in shell-forming species. It was further noted that the processes and resultant dynamics of the groups represented in the benthic boxes of the model are among the least reliable. It was also noted that acidification effects can act directly on the fish themselves, particularly during the early egg and larval development period, resulting in impairment of otolith development and behavioural changes leading to reductions in survival and growth. Climate change is a multi-faceted problem and the primary CO_2 problem is ocean warming. It was recommended that future scenarios based on such increases in the thermal environment be evaluated. Also, providing references points in terms of biomass levels was not advised given the high uncertainty in the estimates.

The assessment of cumulative impacts of fisheries in the California Current focused on determining which fleets have the strongest direct and indirect effects on the food web as well as the aggregate effect of all fleets combined. Simulations testing the effects of single fleets revealed impacts on different aspects of the ecosystem. For example, groundfish gears such as bottom trawls and fixed gear caused reductions in piscivore abundance whereas hake trawls and purse seines resulted in krill increasing through a reduction in the abundance of planktivores.

d) Informing parameters within single species assessments, e.g. M.

Food web modeling explicitly takes predator-prey relationships into account and therefore can be used to determine whether or not simplifying assumptions such as constant M are reasonable approximations or not. Recent publications by Gaichas et al. (2010, *Can. J. Fish. Aquat. Sci.* **67**:1490) and Tyrrell et al. (2011, *Fish. Res*. **108**:1) highlighted the differences between traditional estimates of M derived from single species stock assessments in comparison to estimates of M based on food web models. In most cases, particularly for lower trophic level species such as walleye pollock, squids, silver hake, and herring, the magnitude of M was substantially higher when based on food web models. As part on an ongoing calibration with the newest version of the California Current Atlantis model, a simulation was presented showing the annual predation mortality of herring in which the stock crashed after about 10 y. It is not anticipated that annual estimates of M calculated from Atlantis will be useful to inform single species stock assessments.

e) Formal Management Strategy Evaluation to 'simulation test' new methods of stock assessment, data collection, and decision making.   Examples: 1) identifying ecological indicators to be tracked by Fishery Council "State of California Current"; 2) evaluating performance of harvest policies that account for spatial impacts of ocean acidification, in context of strategic environmental impact analyses.

Recent research involving simulation testing with Atlantis of new methods and metrics for ecological indicators and an assessment of their performance across local and coast-wide scales was reviewed. The Atlantis model was used to simulate both the state of various ecosystem attributes and the sampling of proposed indicators for screening of proposed indicators. Whether or not different attribute-indicator pairs were needed for each scale (i.e. local and coast-wide) and the determination of whether or not local (coast-wide) indicators provide meaningful information about coast-wide (local) attributes, with the former considered representative of upscaling and the latter downscaling were discussed. The local attributes (e.g. ecosystem health and groundfish productivity) and indicators (e.g. species abundance and catch, population condition, feeding guilds, functional group ratios) focused on marine protected areas, fishing hotspots, or coastal boxes. In general it was found that downscaling was unsuccessful for both attributes, however upscaling was successful for groundfish attributes, particularly with indicators related to species groups that had strong, synchronous coast-wide trends. A consideration of the spatial scale of the underlying processes is essential when selecting indicators and new, statistical based methods are being pursued for indicator selection in the near future which is an approach that will likely be an improvement over past assessments of indicator performance based on correlations between indicators and attributes.

2. TOR 2. Reviewers will be asked to comment on the technical merits and/or deficiencies of the methodology and recommendations for remedies.

a) What are the data requirements of the methodology?

The chosen functional group structure was as follows: 4 primary producers, 18 invertebrates, 26 fish, 3 seabirds and 6 mammal groups. Data inputs for each species or functional group include: initial abundance per area, initial size-at-age and numbers-at-age (vertebrates only), consumption rate parameters, length-weight conversions, maximum age and age at maturity, habitat preferences, daily, seasonal, and annual migration patterns and timing (if applied), diets (matrix of interaction strength parameters) and gape, and recruitment parameters (e.g. Beverton and Holt, Ricker). The main data sources used to guide the model calibration for the primary producers was obtained from selected years of CalCOFI and GLOBEC cruises, NMFS Essential Fish Habitat mapping, and growth rates from an Ecopath model by Field (2004).

Some potentially informative data sources were not used and should be used in the future (e.g. satellite color imagery and associated data products). Zooplankton data were available from only a few sources and growth and consumption estimates were obtained from Field (2004). It was recommended that other data sources be pursued to increase the spatio-temporal and species/functional group resolution, notably through the incorporation of CalCOFI zooplankton data. Data for other lower trophic levels, mainly macroinvertebrates, was available from a variety of sources including scuba transect surveys (PISCO), targeted benthic sampling and landings data for squid and crab. Consumption and growth rate data were obtained from Field (2004).

The most highly resolved functional group was fish with several species level designations (hake, sable fish, chinook salmon, albacore, dover sole, canary rockfish, shortbell y rockfish, yelloweye and cowcod), many of which are routinely assessed by the Pacific Fisheries Management Council. The remaining fish species were aggregated into functional groups determined by similarity in diets and behavior. As expected data availability was high for fish species and fish functional groups as a result of the availability of annual trawl surveys and/or model output from stock assessments. In turn, this information provided initial conditions and rate parameters involving abundance, length-weight and vonBertalanffy growth parameters, natural mortality and R_0 (steepness of the stock-recruit relationship). Additionally, trawl survey data provided details of species/functional group spatial distributions whereas migrations were forced in either an onshore-offshore orientation or south of the model domain. Lower trophic level fish were all combined into functional groups based on body size and geographic location despite the existence of detailed data and stock assessments for some of the species (e.g. sardine and Pacific mackerel). Myctophidae were part of a functional group designated as deep vertical migrators and is composed of an unknown, but presumably large number of species. Sharks and skates were also included in the model and supported with details provided by data from stock assessments, trawl surveys and mass balance estimates from Field (2004).

Seabird species were grouped into planktivores (3 species), piscivores (13 species) and migratory birds (2 species). Several data sources were available that provided information on abundance, spatial distribution, life history parameters, bioenergetics and diets. While it known the seabirds generally exhibited high spatial aggregation in colonies/rookeries, this spatial detail was not included in the model. Six functional groups of marine mammals were included in the model but similar to seabirds no spatial structure was included in the model for any of the groups. Several data sources were available ranging from surveys to stock assessments although it was noted that additional data sources for abundance of many of the mammal species exist.

A key requirement of any food web model involves detailed knowledge of diets. Since there has been no systematic, coast-wide diet analysis initiative within the California Current marine ecosystem, a synthesis of the published literature was undertaken by the NWFSC and summarized by predator species and/or predator functional groups. Seventy-five published studies provided detailed diet information that was subjected to hierarchical cluster analyses to objectively partition species into feeding groups or guilds and to calculate diet overlaps based on a percent similarity index (Dufault 2009). Functional groups were highly significant in explaining the percent similarity index difference between species suggesting that the functional groups retain feeding interactions within the ecosystem. However, given the existence of annual trawl surveys within the California Current model domain consideration should be given to the development of a standardized, sub-sampling protocol of fish stomachs for subsequent diet analysis. Most individual fish species and functional groups of fish fed primarily on large zooplankton (euphausiids) based on their high percentage contribution to the total diet indicating that euphausiids play a key role in the California Current food web. Questions were raised concerning how the diet information was incorporated into the model with the suggesting that the predicted versus the observed diet composition needed to be checked for each species/functional group.

Habitat associations were defined on the basis of bottom types and geographic features such as canyon and seamounts which serve to set limits on where some species/functional groups occur. No consideration was given to impacts of trawling on benthic habitats.

b) What are the situations, management uses, and spatial scales for which the methodology is applicable, if not discussed in TOR 1?

The geographic domain of the Atlantis model ranges from Point Conception in the south to Cape Flattery in the north just short of the Canadian border within which 82 polygons across several depth zones were devised. There existed boundary boxes to the north, south and western edges of the domain that allow for exchange of water and nutrients to the main model domain but no other processes are modeled in these areas. For example, myctophid biomass may be exceedingly high along the western boundary boxes. Central California was a region of high interest and greater spatial resolution initially because of the goal to evaluate and rank management strategies there – particularly the National Marine Sanctuaries program. Within this geographic domain the extensively documented and widely used Regional Ocean Modeling System (ROMS) provided outputs of ocean circulation, salinity, and temperature fluxes that distributes nutrients and controls their availability to primary producers. Temperature fields from the model influence biological processes such as respiration and spawning. The model is forced with freshwater inputs, modeled heat flux and regional winds and linked with physical sub-models at 10km scale of resolution.

Several concerns were raised concerning the geographic domain of the model in relation to some of the key fish species under consideration and the non-dynamic character of the boundary boxes. Conversely, there was limited discussion of the hydrographic sub-model model development due largely to the lack of expertise within the review panel although ROMS was probably a good choice for the California Current large marine ecosystem given its limited shelf area that is, instead, strongly influenced by deep ocean processes.

c) What are the assumptions of the methodology?

The Atlantis model is a set of two-way coupled, differential equations that are spatially resolved linking processes occurring in 3D between a hydrographic, ecology and human impacts sub-models solved on a 12 h time step with a user defined reporting interval typically set at a quarterly or annual time scales. The modeled processes occur in each polygon and depth layer. A 50 y model run takes about 16 hours. There are no equilibrium assumptions in the model and for vertebrates weight at age is a dynamic property. Density dependence is expressed through fitted stock and recruitment relationships (e.g. Beverton-Holt) although age 0 is not modeled. Closure terms exist in the model in the form linear and quadratic mortality terms. The ecology sub-model features the determination of primary production, consumption, reproduction, movement, mortality and habitat with generally increasing levels of detail associated with higher trophic levels species or functional group. Primary producers are modeled as aggregate biomass pools limited by both abiotic (space, nutrients, light) and biotic (grazing) processes and includes phytoplankton (small and large), macroalgae and seagrass. Coupling to zooplankton (small and large, euphausiids) and nutrients is achieved through a modification of the North Pacific Ecosystem Model for Understanding Regional Oceanography (NEMURO) model. Invertebrate consumers resident in the water column, sediment, and epi-benthos are also treated as simple biomass pools per spatial box limited by food availability, predation, diseases and oxygen limitation. Nitrogen is the common currency used throughout the model with biomass back calculated from the output. Plankton are advected throughout the model domain by currents, with temperature dependent metabolic rates driven by model output from ROMS.

The vertebrate consumers are modeled in much greater detail than most other components in the ecology sub-model of Atlantis so that for most fish species and functional groups, numbers at age per age class and dynamic weights at age can be obtained. Ages classes were generally set to 10 but flexibility exists to modify it. Predation depends on prey availability (based on overlap in 3D) and gape limitation with a modified Type II functional response determining the prey consumption per predator. As with most food web models, several questions and requests for clarification were directed at the development and parameterization of the functional response equations. Fish reproduction was modeled utilizing the Beverton and Holt or Ricker stock and recruitment relationship whereas for marine mammals, seabirds and sharks, recruitment was modeled as proportional to adult abundance. Fish recruits enter the model at a stage equivalent to juveniles after about 60-90 days. A larval dispersal code exists in the model but was not yet used and instead spatial distributions were assumed proportional to juvenile abundance. Simulation of adult movement ranged from diel to seasonal migrations within the model domain to larger migratory events involving fish, marine mammals and seabirds where the species or functional groups temporally reside outside of the model domain.

The sub-model involving human impacts was intended to simulate fishery effects and responses due to various management options. The human impacts sub-model handles catch in three general ways: forced time series of catch, fixed fishing mortality rates, and age-specific catch. Age specificity was derived from parameterizations of selectivity, effort, availability, and catchability with several gear or age-specific selectivity options available in the model. Options also exist for the incorporation of dynamic or forced fleet dynamic models. Fisheries management involved options for inclusion of quotas and harvest strategies or control rules. Non-fishing pressures that can influence or interfere with fishing may also be a future application, for example, the effects of proliferation of wind farms at sea.

d) Is the methodology correct from a technical perspective?

The methodology was correct from a technical perspective but with most ecosystem models several simplifying assumption must be made to accommodate a lack of knowledge about processes and/or the absence of relevant data.

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

The Atlantis model makes several simplifying assumptions, departures from which could not be assessed in some cases due to the lack of source code within the model. For example, recruitment is driven by a theoretical stock and recruitment relationship (Beverton and Holt) within the model and some alternative formulations cannot be accommodated due to lack of coding within the model. The review panel recommended development of a code allowing for forced time series of recruitment deviations to more realistically account for inter-annual, frequently highly episodic variation that generally typifies the reproductive success of most commercially exploited fish species.

Diet data were assembled from the published literature over many years from a variety of studies. The data are treated as though no temporal variability exists and this assumption should be evaluated since the California Current ecosystem has undergone regime shifts in past forced by decadal scale, oceanographic variability.

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

Treatment of uncertainty in the Atlantis model for the California Current was based on using two bounded scenarios involving uncertainty in biomass estimates and uncertainty in rate parameters. An example was presented illustrating the robustness of food web impacts of euphausiid depletion to uncertainty in hake biomass. Complete depletion of euphausiids (large zooplankton) led to declines in many predators. Altering Pacific hake abundance did little to vary the magnitude or direction of effects that euphausiid depletion has on other food web components. When euphausiids were fully depleted, varying Pacific hake generally changed food web effects by <5%. The discussion about uncertainty in rate parameters suggested that the Atlantis base model can be incremented and decremented to capture productivities implied by stock assessment R_0, h, and M. Bounded parameterizations of productivity suggests that these same three metrics (R_0, h, and M) show strong responses in High and Low Productivity scenarios, that the piscivores index shows very strong declines under 'worst mismatch' of Low Productivity and High Catch, and the response of piscivores and other metrics were due to direct fishing impacts on groundfish stocks.

A sensitivity analysis of initial conditions and some key rate parameters using 50 year runs of the status quo model (projected from 2008) revealed that with the exception for species that exhibit long recovery times, the sensitivity to initial conditions was low based on proportional effects on biomass of the various functional groups. Conversely, the model was highly sensitive to rate parameters associated with interaction strengths and trophic linkages. The model was also sensitive to non-predation mortality, particularly for upper trophic level species where these terms are commonly added during calibration. In terms of bioenergetic rate parameters such as growth rates and assimilation efficiencies, sensitivity changed in a linear manner, i.e. a 20% change in assimilation efficiency led to a similar changes functional group biomasses. As the Atlantis model for the California Current continues to be developed, a variety of ways to handle parameter uncertainty will be explored including setting tolerances based on fits to survey data, diets, phytoplankton distributions, etc. It is also the intention of the research team to incorporate natural variability in recruitment and to consider exploring multi-model inferences using other food web models.

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

One of the goals for calibration of the Atlantis model was for the calibrated model productivity to be biologically plausible when forced without fishing, with constant fishing and historical fishing pressure. Tuning the model to reproduce reasonable dynamics and fits to historical observations was achieved through an iterative process by adjusting the initial parameters used at the beginning of a simulation. Tuning of the model involved adjustments to the recruitment and consumption parameters, the interaction coefficients between predator and prey, and both the linear and quadratic mortality terms. Avoiding extinction of species or functional groups was an obvious goal of the initial calibration. Inter-comparisons between 1950 biomass levels and unfished biomass levels from stock assessments provided another check on model performance. Model outputs for each species or functional group include: time series of abundance per area, time series of size-at-age and numbers-at-age, per area (vertebrates only), diets and predation mortality rates, time series of recruits or young of the year.

In the first calibration phase 19 out of 22 fish functional groups qualitatively matched B_0 estimates. B_0 was the year (1950) assumed to be representative of each species unfished biomass. Groups that did not perform well included toothed whales, baleen whales and yelloweye rockfish + cowcod as none of them reached a steady state during the 85 year run. This was likely due to a lack of predation and the relative longevity of these groups. Numbers and weights at age for the majority of functional groups demonstrated a reasonable age structure based on a tolerance limit set at 0.5 to 1.5 times the initial values for weight at age. Lower trophic level groups, primarily primary producers and invertebrates, were difficult to tune reflecting a lack of data as calibration targets for these groups in comparison to the higher trophic levels. For example, macroalgae, benthic filter feeders and benthic grazers rapidly went extinct while other groups such as large phytoplankton, microzooplankton, large carnivorous zooplankton, and shrimp exhibited large, but bounded fluctuations.

The second calibration involved applying a range of fishing mortalities to evaluate the biomass responses to fishing. When fishing mortality exceed natural mortality (F > M), 16 of 24 fish species were heavily depleted with F_{msy} occurring at a level of 1/3 or less of M which is substantially less than literature estimates of M. Only large pelagic predators, which reside outside of the model domain for most of the year, could sustain a level of F > M.

In the third phase of calibration the simulation was first spun up without fishing for 18 groups having historical biomass time series data to obtain an unfished state resembling 1950 biomass levels and then historical catches were applied in order to replicate the 1950 to 2007 biomass time series for each group. For all but four groups, a matching with the historical record was considered reasonable based on the magnitude and similarity of trends across the entire time series or a portion of it. However, substantial differences existed between the model output and the historical series for sardine, mackerel, hake and lingcod. The poor performance of the sardine and hake population dynamics within the model is problematic given that hake is key predator in the system and sardine is an important forage component. These discrepancies, in part, stem from the inability of the Atlantis model to handle variable recruitment as each of these species produce irregular, highly episodic recruitment not captured by output from a theoretical stock and recruitment relationships. The need to enlarge the model domain to cover the entire stock distribution of sardine and hake may also be contributing to these large predicted differences.

h) Will the new methodology or data set result in improved stock or ecosystem assessments or management advice, beyond what is discussed in TOR1?

The new version of the Atlantis model that is currently under development should certainly result in improved ecosystem assessments and strategic management advice. The ocean acidification goals for the new Atlantis model will be expanded upon significantly over the previous analyses conducted by Kaplan et al. (2010). Utilizing the regional ocean modeling systems (ROMS), 50 – 100 year spatial projections of ocean acidification will be linked to a broad suite of calcifying organisms with varying sensitivities to reductions in pH within the Atlantis modeling framework to simulate impacts on harvested and protected stocks. ROMS will be coupled to global circulation models and IPCC CO_2 scenarios. Stock productivity, fishery management reference points and consequences of harvest policies will be investigated. Coupling with an economic model and testing management strategy performance is also anticipated. These strategies will range from current single-species fishery management rules to harvest control rules that respond to simple metrics of ecosystem productivity and susceptibility. Finally, the intention is to provide managers with information regarding potential impacts and vulnerability of species, marine areas, and fishing economies through engagement with the Pacific Fishery Management Council and NOAA's Integrated Ecosystem Assessment.

Future goals have also been established for the forage fish component in the new Atlantis model. Several new species have been isolated from being previously aggregated within functional groups and the geographic domain of the model has been greatly expanded resulting in a reduction in the number of species residing outside of the model domain during an annual cycle. These changes overcome some serious shortcomings of earlier Atlantis models particularly with respect to sardine and hake.

Invertebrate data quality and resolution has also increased especially for hard corals, pteropods, mega-zoobenthos, benthic herbivorous grazers, and the isolation of Dungeness crab which was formally imbedded with a functional group. Fish groups have also been vastly revised with an increase to 29 functional groups or species. Upward, and in some cases substantially higher revisions to abundance estimates for anchovy, herring, Jack mackerel and mesopelagics have also occurred. These changes are expected to result in large impacts on the dynamics and interactions of these forage species within the food web. In addition, literally dozens of new stock assessments, with many conducted as recently as 2013, have been incorporated into the model and improvements to spatial distributions has occurred as well, based on species-specific data from the 2011 NWFSC bottom trawl survey and from research supporting the development of Essential Fish Habitat analyses. Marine mammals have also been improved upon and updated with the inclusion of 10 functional groups along with the incorporation of data from recent stocks assessments and other published reports. Seabird functional groups have been expanded to three and better spatial and temporal resolution now exists for both breeding and migratory birds. Few changes have been made to the diet database.

The review panel was presented with some preliminary runs of the new Atlantis model which illustrated somewhat better behavior for species such as cowcod and yelloweye rockfish which were highly problematic in runs of previous versions of the Atlantis model. Improvements were also evident in the simulation of hake biomass dynamics. Problems remained for myctophids and some of the shallow large rockfish whose dynamics are not well captured in the simulations. Lower trophic level dynamics showed some remarkable improvements, notably for large and small phytoplankton and seagrass. Simulation results were also shown for size and numbers at age for some species and improvements were noted while some problem species/functional groups remained poorly resolved. Initial estimates of natural mortality were provided for most of the upper trophic level species/functional groups with only very few displaying excessively high levels such as shallow small rockfish and small planktivorous fish. Overall, the new version of the Atlantis model is showing encouraging preliminary results.

The Kaplan research team intends to make substantial improvements to the oceanography subcomponent of the model by forcing the ROMS model with various climate change scenarios. The intention is also to develop a synthesis of how various organisms respond to pH changes through meta-analysis of a compilation of experimental studies from the California Current region that now includes over 600 studies. This base of literature provides the rationale for considering larger numbers of options for biological effects in the Atlantis model attributable to reduction in pH. Options such as changing recruitment due to reduce larval survival, reduced foraging success, changes in the thermal tolerances of species and several other effects will be considered in future model runs. It is also intended to build fleet structure into future projections of Atlantis and to match fleet structure to the IOPAC model by setting up initial fishing mortality rates per fleet.

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

There were no stated areas of disagreement regarding panel recommendations among panel members or between the panel and proponents.

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

There does not appear to be any major unresolved problems and major uncertainties that would preclude the use of the methodology. Application of the model does, however, require careful consideration and at present the model is tailored for strategic planning instead of short-term management advice.

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

A large base of biophysical, human use and other data types exists for the California Current region. Clearly it can be considered a very data rich area. However, securing, quality checking, database development, and so on is a great challenge. The first objective of obtaining the necessary data was met and is an on-going initiative as not all potentially useful data sources have been secured. Several data issues were raised and these are highlighted in the **ToR** 2.**l** below in terms of recommendation for future data collection.

l) Prioritized recommendations for future research and data collection.

There has been no systematic, coast-wide diet sampling initiative within the California Current marine ecosystem. Given the existence of annual trawl surveys within the California Current model domain consideration should be given to the development of a standardized, sub-sampling protocol of fish stomachs for subsequent diet analysis.

Potentially informative data sources were not used for the lower trophic level invertebrate groups in the model such as synoptic satellite color imagery and associated data products for primary producers and zooplankton data collected during the long-term, coast-wide monitoring of lower trophic levels by CalCOFI. Collectively, these are excellent sources of lower trophic level data and may help to overcome the difficulty in tuning these groups during the calibration process.

Atlantis did not predict strong declines in marine mammals or seabirds due to forage fish depletion. The model did capture the interaction between forage and their prey in the simulations but was unresponsive to the depletion of forage groups on higher trophic levels. Either because of the poor parameterization of the lower trophic levels or the structure of the model itself, Atlantis is largely a top-down driven (consumer driven) model. Not capturing this bottom-up process is considered a major limitation of Atlantis given the strong environmental forcing that characterizes the California Current large marine ecosystem.

The divergent results between Ecosim and Atlantis are problematic and in need of further investigation.

The inability of the Atlantis model to handle variable recruitment, particularly for lower trophic level fish species which often exhibit irregular, highly episodic recruitment needs to be corrected.

Myctophidae were part of a functional group designated as deep vertical migrators and is composed of an unknown, but presumably large number of abundant species. Improved estimates of species diversity, abundance and spatial distribution are needed given their perceived role as a highly important component in the California Current large marine ecosystem.

The primary CO_2 problem is ocean warming and it was recommended that future scenarios based on such changes be evaluated.

The lack of any compensatory increases among other functional groups that should have occurred as a result of the decline in shell-forming species sensitive to ocean acidification needs to be explored. In addition, the processes and resultant dynamics of the groups represented in the benthic boxes of the model are among the least reliable. It was also noted the acidification effects can act directly on the fish themselves and this effect should be explored in future simulations.

Lower trophic level fish and some macro-invertebrates should be more highly resolved as many species were combined into functional groups based on body size and geographic location despite the existence of detailed data and stock assessments for some of them.

As the Atlantis model for the California Current continues to be developed, a variety of ways to handle parameter uncertainty needs to be explored such as setting tolerances based on fits to survey data, diets, phytoplankton distributions, etc. Inferences derived from the development, execution, and inter-comparison with other food web models is also recommended. In addition, the complexity of the Atlantis model and slow run time makes it difficult to conduct formal sensitivity analyses or to fit parameters in a statistical manner.

The poor performance of the sardine and hake population dynamics within the model is problematic given that hake is key predator in the system and sardine is an important forage component. The model domain does not cover the entire stock distribution of sardine and hake which may be contributing to these large predicted differences, needs to be enlarged.

Scenarios devised at small spatial scales, such as for Monterey Bay, may be less reliable as some processes become more important at these scales such a local movements and fluxes that are not adequately resolved in the model. The minimum scale of geographic resolution should be resolved.

Conclusions and Recommendations

Atlantis is a simulation model intended for use as a strategic management tool and is therefore not designed for tactical decision making such as setting annual quotas, replacing annuals stock assessments, or the sighting of marine protected areas. Such a modeling framework can help to synthesize and integrate large volumes of unconsolidated biophysical, human use and other data types that accumulate over time. Adopting the Atlantis model was viewed by the NWFSC as a testing ground for exploring model complexity, improving ecological and whole ecosystem understanding, and for exploration of both fishing and non-fishing effects such as oceanographic variability, ocean acidification and nutrient loading on species spatial distributions and productivity. The California Current Atlantis model, its potential applications and uncertainties were carefully and concisely documented in the literature provided prior to the review, in the PowerPoint presentations delivered by the research team led by Dr. Kaplan during the review meeting, and in responses by the team to questioning during the review. The review process itself was extremely thorough with the possible exception of an in-depth evaluation of the hydrographic sub-model and its coupling to the other sub-models within Atlantis. This deficiency was due to lack of expertise in the subject area within the review panel. Development and implementation of end to end models such as Atlantis demands a very high level of knowledge of computer programming, mathematics, ecological modeling and a fundamental understanding of marine ecosystem dynamics ranging from physics to fish. Meeting this challenge as successfully as Dr. Kaplan and his research team demonstrated during the review is a strong endorsement for a continuation of this line of research for addressing strategic management issues within the California Current large marine ecosystem.

Continued development/revision of the Atlantis model for the California Current ecosystem is strongly encouraged as is the exploration of alternative models that can yield inter-comparisons of their performance. The lower trophic levels within Atlantis are not very well modeled because of lack of data, but it should be possible to correct this problem given the existence of spatially and temporally resolved lower trophic level data from the CalCOFI monitoring program. Readily available remote sensing data also exists which can provide many data products to parameterize primary production and associated attributes. It is expected that the incorporation of this information will resolve the poor parameterization of the lower trophic levels in the model and provide a better representation of bottom-up processes that are known to influence the California Current large marine ecosystem. A continuation of the application of the Atlantis model to examine the system wide effects of climate change is strongly supported as well.

Many of the concerns and criticisms expressed during the first days of the review had been anticipated by the research team and substantial progress has been made toward their completion. It was evident during the review that the body of research presented by Isaac Kaplan and his team is of an extremely high standard and can be considered at the cutting edge of ecosystem model development and application within the California Current large marine ecosystem. The provision of integrated as opposed to piecemeal solutions to complex fisheries problems is most definitely the way forward and it certainly appears that the Atlantis model has this potential. Fisheries managers and councils are by their very nature highly traditional and movement towards more integrative approaches will take time requiring greater exposure to ecosystem modelers, their methodologies and capacities to provide alternative solutions to the many issues currently facing management of the global oceans.

Recommendations are listed in **ToR 2.l** and are therefore not repeated here.

Appendix 1: Bibliography of materials provided for review

Primary peer-reviewed documents

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4. Peterman, R. M. 2004. Possible solutions to some challenges facing fisheries scientists and managers. ICES Journal of Marine Science, 61: 1331-1343.

5. Plagányi, É. E. 2007. Models for an ecosystem approach to fisheries. FAO Fisheries Technical Paper. No. 477. Rome, FAO. 108 p.

Appendix 2: A copy of this Statement of Work

Attachment A: Statement of Work for Dr. Kenneth Frank

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 California Current Large Marine Ecosystem

BACKGROUND

The National Marine Fisheries Service's (NMFS) Office of Science and Technology coordinates and manages a contract providing external expertise through the Center for Independent Experts (CIE) to conduct independent peer reviews of NMFS scientific projects. The Statement of Work (SoW) described herein was established by the NMFS Project Contact and Contracting Officer's Representative (COR), and reviewed by CIE for compliance with their policy for providing independent expertise that can provide impartial and independent peer review without conflicts of interest. CIE reviewers are selected by the CIE Steering Committee and CIE Coordination Team to conduct the independent peer review of NMFS science in compliance the predetermined Terms of Reference (ToRs) of the peer review. Each CIE reviewer is contracted to deliver an independent peer review report to be approved by the CIE Steering Committee and the report is to be formatted with content requirements as specified in **Annex 1**. This SoW describes the work tasks and deliverables of the CIE reviewer for conducting an independent peer review of the following NMFS project. Further information on the CIE process can be obtained from www.ciereviews.org.

SCOPE

Project Description: The purpose of this review is to evaluate the performance characteristics and to identify appropriate management applications of an Atlantis ecosystem model, employed at NWFSC as an operating model in support of the development of Ecosystem-Based Fishery Management (EBFM) strategies for the California Current Large Marine Ecosystem. This review is being undertaken based on recommendations by the Scientific and Statistical Committee (SSC) of the Pacific Fishery Management Council (PFMC), who will chair the review panel.

NMFS strongly endorsed the concept of Ecosystem-Based Management and the related need for the development of Integrated Ecosystem Assessment in support of EBFM. Although this review is directed at efforts in the NWFSC, and more specifically the PFMC, the findings will be more broadly applicable on the West Coast and throughout the agency.

The objectives of the methodology review meeting are to evaluate the performance characteristics of this application of the Atlantis model, and to identify the extent to which this Atlantis ecosystem model is suitable as an operating model to provide strategic guidance related to NOAA management needs on the West Coast. Specific objectives of the SSC are to identify the strengths, weaknesses, and applicability of the model to particular questions and needs in order to facilitate use of Atlantis-generated products in the future.

These needs include evaluation of cumulative impacts of groundfish and pelagic fisheries, evaluation of risks of climate change and ocean acidification, ranking of potential fishery management strategies, and formal Management Strategy Evaluation to ‘simulation test’ new methods of stock assessment, data collection, and decision making. The review will not focus on the Atlantis C++ 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**.

OBJECTIVES

Requirements for the reviewers: Three reviewers shall conduct an impartial and independent peer review of the Atlantis ecosystem model provided, and this review should be in accordance with this SoW and the methodology review ToRs herein.

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, meaning direct senior level policy applications or recommendations in addition to scientific publications.

PERIOD OF PERFORMANCE

The reviewers shall conduct the tasks according to the schedule of milestones and deliverables as specified in this statement of work (SoW). Each reviewer’s duties shall not exceed a maximum of 14 days to complete all work tasks of the peer review described herein. The tentative schedule of milestones and deliverables is provided herein.

PLACE OF PERFORMANCE AND TRAVEL

Each reviewer shall conduct an independent peer review during the panel review meeting tentatively scheduled during June 30 – July 2, 2014 in Seattle, Washington.

STATEMENT OF TASKS

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

Tasks prior to the meeting: The contractor shall independently select qualified reviewers that do not have conflicts of interest to conduct an independent scientific peer review in accordance with the tasks and ToRs within the SoW. Upon completion of the independent reviewer selection by the contractor's technical team, the contractor shall provide the reviewer information (full name, title, affiliation, country, address, email, and FAX number) to the contractor officer's representative (COR), who will forward this information to the NMFS Project Contact no later than the date specified in the Schedule of Milestones and Deliverables. The contractor shall be responsible for providing the SoW and stock assessment ToRs to each reviewer. The NMFS Project Contact will be responsible for providing the reviewers with the background documents, reports, foreign national security clearance, and other information concerning pertinent meeting arrangements. The NMFS Project Contact will also be responsible for providing the Chair a copy of the SoW in advance of the panel review meeting. Any changes to the SoW or ToRs must be made through the COR prior to the commencement of the peer review.

<u>Foreign National Security Clearance</u>: The reviewers shall participate during a panel review meeting at a government facility, and the NMFS Project Contact will be responsible for obtaining the Foreign National Security Clearance approval for the reviewers who are non-US citizens. For this reason, the reviewers shall provide by FAX (not by email) the 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 before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations available at the Deemed Exports NAO website: http://deemedexports.noaa.gov/.

<u>Pre-review Background Documents</u>: Approximately two weeks before the peer review, the NMFS Project Contact will send (by electronic mail or make available at an FTP site) to the COR the necessary background information and reports (i.e., working papers) for the reviewers to conduct the peer review, and the COR will forward these to the contractor. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the COR on where to send documents. The reviewers are responsible only for the pre-review documents that are delivered to the contractor in accordance to the SoW scheduled deadlines specified herein. The reviewers shall read all documents deemed as necessary in preparation for the peer review.

Tasks during the panel review meeting: Each reviewer shall conduct the independent peer review in accordance with the SoW and stock assessment ToRs, and shall not serve in any other role unless specified herein. **Modifications to the SoW and ToRs shall not be made during the peer review, and any SoW or ToRs modifications prior to the peer review shall be approved by the COR and contractor.** Each reviewer shall actively participate in a professional and respectful manner as a member of the meeting review panel, and their peer review tasks shall be focused on the methodology review ToRs as specified herein. The NMFS Project Contact will be responsible for any facility arrangements (e.g., conference room for panel review meetings or teleconference arrangements). The NMFS Project Contact will also be responsible for ensuring that the Chair understands the contractual role of the reviewers as specified herein. The contractor can contact the COR and NMFS Project Contact to confirm any peer review arrangements, including the meeting facility arrangements.

Specific Tasks for CIE Reviewers: The following chronological list of tasks shall be completed by each CIE reviewer in a timely manner as specified in the **Schedule of Milestones and Deliverables**.

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review.
2) Participate during the panel review meeting tentatively scheduled in Seattle, Washington during June 30 through July 2, 2014.
3) During the panel review, conduct an independent peer review in accordance with the ToRs (**Annex 2**).
4) No later than 16 July 2014, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Mr. Manoj Shivlani, CIE Lead Coordinator, via email to shivlanim@bellsouth.net, and CIE Regional Coordinator, via email to Dr. David Die ddie@rsmas.miami.edu. Each CIE report shall be written using the format and content requirements specified in Annex 1, and address each ToR in **Annex 2**.

DELIVERY

Each reviewer shall complete an independent peer review report in accordance with the SoW. 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 SoW in accordance with the following schedule.

26 May 2014	Contractor sends reviewer contact information to the COR, who then sends this to the NMFS Project Contact
16 June 2014	NMFS Project Contact provides reviewers the pre-review documents
30 June – 2 July 2014	Each reviewer participates and conducts an independent peer review during the panel review meeting in Seattle, WA
16 July 2014	Reviewers submit draft independent peer review reports to the contractor's technical team for independent review
30 July 2014	Contractor submits independent peer review reports to the COR who reviews for compliance with the contract requirements
6 August 2014	The COR distributes the final reports to the NMFS Project Contact and regional Center Director

Modifications to the Statement of Work: Requests to modify this SoW must be approved by the Contracting Officer at least 15 working days prior to making any permanent substitutions. The Contracting Officer will notify the COR within 10 working days after receipt of all required information of the decision on substitutions. The COR can approve changes to the milestone dates, list of pre-review documents, and ToRs within the SoW as long as the role and ability of the reviewers to complete the deliverable in accordance with the SoW is not adversely impacted. The SoW and ToRs shall not be changed once the peer review has begun.

Acceptance of Deliverables: The deliverables shall be the final peer review report from each reviewer that satisfies the requirements and terms of reference of this SoW. The contract shall be successfully completed upon the acceptance of the contract deliverables by the COR based on three performance standards:

(1) each report shall be completed with the format and content in accordance with **Annex 1**,
(2) each report shall address each stock assessment ToR listed in **Annex 2**,
(3) each report shall be delivered in a timely manner as specified in the schedule of milestones and deliverables.

Upon the acceptance of each independent peer review report by the COR, the reports will be distributed to the NMFS Project Contact and pertinent NMFS science director, at which time the reports will be made publicly available through the government's website.

The contractor shall send the final reports in PDF format to the COR, designated to be William Michaels, via email William.Michaels@noaa.gov

Support Personnel:

William Michaels, Program Manager, COR
NMFS Office of Science and Technology
1315 East West Hwy, SSMC3, F/ST4, Silver Spring, MD 20910
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Annex 1: Format and Contents of Independent Peer Review Report

1. The independent peer review report shall be prefaced with an Executive Summary providing a concise summary of whether they accept or reject the work that they reviewed, with an explanation of their decision (strengths, weaknesses of the analyses, etc.).

2. The main body of the report shall consist of a Background, Description of the Individual Reviewer's Role in the Review Activities, Findings of whether they accept or reject the work that they reviewed, and an explanation of their decisions (strengths, weaknesses of the analyses, etc.) for each ToR, and Conclusions and Recommendations in accordance with the ToRs. For each assessment reviewed, the report should address whether each ToR of the SAW was completed successfully. For each ToR, the Independent Review Report should state why that ToR was or was not completed successfully. To make this determination, the SARC chair and reviewers should consider whether the work provides a scientifically credible basis for developing fishery management advice.

   a. Reviewers should describe in their own words the review activities completed during the panel review meeting, including a concise summary of whether they accept or reject the work that they reviewed, and explain their decisions (strengths, weaknesses of the analyses, etc.), conclusions, and recommendations.

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

   c. Reviewers should elaborate on any points raised in the SARC Summary Report that they feel 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 independent report shall be a stand-alone document for others to understand the proceedings and findings of the meeting, regardless of whether or not others read the SARC Summary Report. The independent report shall be an independent peer review of each ToR, and shall not simply repeat the contents of the summary report.

3. The reviewer report shall include the following appendices:

   Appendix 1: Bibliography of materials provided for review
   Appendix 2: A copy of this Statement of Work
   Appendix 3: Panel Membership or other pertinent information from the panel review meeting.

Annex 2: Terms of Reference

Review of the Atlantis Ecosystem Model in Support of Ecosystem-Based Fishery Management in the California Current Large Marine Ecosystem

BACKGROUND

Atlantis (http://atlantis.cmar.csiro.au/) was developed at CSIRO (Australia) as an 'end-to-end' simulation modeling approach for marine ecosystems that includes oceanographic, chemical (nutrient cycling), ecological (competition and predation), and anthropogenic processes in a three-dimensional, spatially explicit domain (Fulton 2004a,b; Fulton *et al.* 2007, 2011). The simulation approach allows projections through time, and forecasting of system response to specific management actions, physical drivers, or climate change. Atlantis is intended as a strategic management tool to evaluate hypotheses about ecosystem response, to understand cumulative impacts of human activities, and to rank broad categories of management options. It is not intended for tactical decision making, such as precisely setting quotas or siting of marine reserves. Fulton et al. (2011) summarize thirteen recent applications of the Atlantis framework, and discuss the appropriate role and strengths and weaknesses of the approach.

OBJECTIVES

The objective of the methodology review meeting is to:

Evaluate the performance characteristics and appropriate uses of two Atlantis ecosystem models for the California Current.

Previous Atlantis models of the California Current have been published in the peer reviewed literature and technical documents (Horne *et al.* 2010; Kaplan *et al.* 2012a,b, 2013). A new version of the Atlantis model is in development, but includes finer resolution of some forage fish and calcifier (shell forming) species, and an expanded geography that matches the full extent of the California Current. Documentation for this new model will be provided to the reviewers.

The review panel will be chaired by a member of the Pacific Fishery Management Council's Scientific and Statistical Committee (SSC), and the panel will include SSC members as well as Center for Independent Experts (CIE) reviewers. The review will follow the Methodology Review Process established by the Fishery Management Council, and the Terms of Reference below, in part, reflect the Terms of Reference of the Methodology Review Process.
The methodology review Terms of Reference will identify the models' strengths, weaknesses, applicability, and potential areas of improvement with respect to specific management needs on the US West Coast.

The review will not focus on the Atlantis C++ code base, nor will it focus on data quality except as it pertains to model performance.

TERMS OF REFERENCE
All panel reviewers, including CIE reviewers, SSC members, and others, will document the meeting discussions and contribute to a summary panel report that addresses the following terms of reference:

1. **TOR 1. Reviewers will be asked to consider the strengths, weaknesses, appropriate uses, and potential areas of improvement for the Atlantis models with respect to these management needs, in the context of ecosystem-based management.**

    a. Food web impacts of groundfish fisheries, pelagic fisheries, and other anthropogenic impacts. Policy example: evaluating trophic impacts of forage fish harvest policies on abundance and yield of other species.
    b. Ranking of potential fishery management strategies, including spatial management, harvest rates, quota systems. This expands beyond trophic impacts to include habitat, bycatch, and economic indicators. Discussion may differentiate between pelagic vs groundfish fisheries. Potential policy context: Tier 1 Environmental Impact Statements (10 year strategic planning) .
    c. Evaluation of risks of climate change and ocean acidification. Example: cumulative impacts analysis under National Environmental Policy Act (NEPA), which may consider the impact of actions (e.g. fishing) in the context of global change.
    d. Informing parameters within single species assessments, e.g. M.
    e. Formal Management Strategy Evaluation to 'simulation test' new methods of stock assessment, data collection, and decision making. Examples: 1) identifying ecological indicators to be tracked by Fishery Council "State of California Current"; 2) evaluating performance of harvest policies that account for spatial impacts of ocean acidification, in context of strategic environmental impact analyses.

2. **TOR 2. Reviewers will be asked to comment on the technical merits and/or deficiencies of the methodology and recommendations for remedies.**
    a. What are the data requirements of the methodology?
    b. What are the situations, management uses, and spatial scales for which the methodology is applicable, if not discussed in TOR 1?
    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.** Will the new methodology or data set result in improved stock or ecosystem assessments or management advice, beyond what is discussed in TOR1?
- **i.** Areas of disagreement regarding panel recommendations: among panel members; and between the panel and proponents.
- **j.** Unresolved problems and major uncertainties, e.g., any issues that could preclude use of the methodology.
- **k.** Management, data or fishery issues raised during the panel review.
- **l.** Prioritized recommendations for future research and data collection.

CITATIONS

Fulton, E. (2004a) Biogeochemical marine ecosystem models II: the effect of physiological detail on model performance. *Ecological Modelling* **173**, 371–406.

Fulton, E. (2004b) Effects of spatial resolution on the performance and interpretation of marine ecosystem models. *Ecological Modelling* **176**, 27–42.

Fulton, E.A., Link, J.S., Kaplan, I.C., et al. (2011) Lessons in modelling and management of marine ecosystems: the Atlantis experience. *Fish and Fisheries* **12**, 171–188.

Fulton, E.A., Smith, A.D.M. and Smith, D.C. (2007) Alternative management strategies for southeast Australian Commonwealth Fisheries: stage 2: quantitative management strategy evaluation. *Australian Fisheries Management Authority Report*.

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., 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.

Annex 3: Agenda

Review of the Atlantis Ecosystem Model in Support of Ecosystem-Based Fishery Management in the California Current Large Marine Ecosystem

June 30th – July 2nd, 2014
NOAA Northwest Fisheries Science Center
Auditorium
2725 Montlake Blvd. E.
Seattle WA 98112
Phone: (206) 860-3428

Relevant Terms of Reference (TOR) are noted below.

Monday, June 30th

9:00 - 9:10 Call to Order (*Martin Dorn*)

- Introductions
- Approval of Agenda

9:10 - 9:30 Introduction to the role of Atlantis ecosystem model at the Northwest Fisheries Science Center (*Phil Levin*)

9:30 - 9:50 History, goals, and evolution of Atlantis model development at NWFSC and CSIRO (*Isaac Kaplan*)

9:50 - 10:10 Current and potential role of Atlantis ecosystem models for the California Current Integrated Ecosystem Assessment (*Chris Harvey*)

Break

10:30 - 12:00 Overview of mechanics, assumptions, and functional relationships of Atlantis (*Isaac Kaplan*) [TOR2.a-d]

Lunch

1:00 - 2:00 Continued: Overview of mechanics, assumptions, and functional relationships of Atlantis (*Isaac Kaplan*) [TOR2.a-d]

Break

CURRENT ATLANTIS MODEL
Isaac Kaplan

2:15 - 3:00 Geography and functional groups (Isaac Kaplan) [TOR2.a-d]

3:00 - 4:30 Panel discussion (Martin Dorn)

Tuesday, July 1st

9:00 - 11:00 Data (*Isaac Kaplan and Kristin Marshall*) [TOR2.a-d]

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

Break

11:00 - 12:00 Model calibration and fits to history (*Isaac Kaplan*) [TOR2.e-g]

- Estimates of unfished biomass
- Sensitivity to fixed fishing mortalities, estimates of MSY and FMSY
- Fits to historical data
- Sensitivity to initial conditions

Lunch

1:00 - 2:30 Example applications and recent publications (*Isaac Kaplan*)

a. Food web impacts of forage fish fisheries (e.g. *Kaplan et al. 2013 Environmental Conservation, Marshall et al. submitted*) [TOR1.a]
b. Ranking of potential fishery management strategies, including spatial management, harvest rates, quota systems. (e.g. Kaplan et al. 2012 *Progress in Oceanography*, Kaplan and Leonard 2012 *Marine Policy*, Kaplan et al. 2013 *ICES Journal of Marine Science**). [TOR1.b]
c. Evaluation of risks of climate change, acidification, and cumulative impacts (e.g. Kaplan et al. 2010 *Canadian J. Fish. Aquatic Sciences**, Kaplan et al. *2013 Fish and Fisheries*) [TOR1.c]
d. Informing parameters within single species assessments, e.g. M. (brief discussion of relevant examples from Northeast US) [TOR1.d]
e. Simulation testing new methods and metrics for ecological indicators (Testing of spatial indicators within the Integrated Ecosystem Assessment) [TOR1.e]

*Note the two articles marked with * use an earlier version of the Atlantis California Current model.*

2:30 - 3:30 Treatment of uncertainty [TOR2.f]

- Bounded scenarios – uncertainty in biomass estimates
- Bounded scenarios – uncertainty in rate parameters

Break

3:30 - 5:00 Panel discussion on potential uses of Atlantis to support Council decision-making identified in TOR 1 (*Martin Dorn*)

Wednesday, July 2nd

NEW VERSION OF ATLANTIS MODEL UNDER DEVELOPMENT
Isaac Kaplan and Kristin Marshall

9:00 - 9:30 Goals and applications [TOR 1.a-c,1.e,2.b]

9:30 - 10:00 Geography and functional groups [TOR2.a]

10:30 - 11:00 Data

Break

11:00 - 11:30 Oceanography and global change projections (Al Hermann) [TOR2.a]

11:30 - 12:00 Model calibration and sensitivity tests [TOR2.e-g]

Lunch

1:00- as needed Panel discussion and writing assignments (Martin Dorn)

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

Methodology Review Panel Members:
Kerim Aydin, AFSC
Kenneth Frank, CIE, Fisheries and Oceans Canada
Martin Dorn (Chair), SSC, AFSC
Daniel Howell, CIE, Institute of Marine Research
Galen Johnson, SSC, Northwest Indian Fisheries Commission
Pete Lawson SSC, NWFSC
Andre Punt, SSC, University of Washington
Will Satterthwaite, SSC, SWFSC
Tien-Shui Tsou, SSC, Washington Department of Fish and Wildlife
Cindy Thomson, SSC, SWFSC
Reg Watson, CIE, University of Tasmania

Pacific Fishery Management Council (Council) Representatives:
Kit Dahl, Council Staff

Atlantis Technical Team:
Isaac Kaplan, NWFSC
Kristin Marshall, National Research Council, NWFSC, University of Washington
Chris Harvey, NWFSC
Phil Levin, NWFSC
Al Hermann, University of Washington