Atlantis Model for the California Current

Report of Methodology Review Panel Meeting

National Marine Fisheries Service (NMFS)
Northwest Fisheries Science Center (NWFSC)
Seattle, Washington
30 June – 2 July 2014

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1. OVERVIEW

A review of an Atlantis model of the California Current ecosystem, developed by the Northwest Fisheries Science Center (NWFSC), was conducted by a Methodology Review Panel (Panel) at the NWFSC in Seattle, Washington, during 30 June – 2 July 2014. The Panel followed the Terms of Reference for the Methodology Review Process for Groundfish and Coastal Pelagic Species (June 2012).

The review meeting began with overview presentations by Phil Levin (NWFSC) and Chris Harvey (NWFSC), who discussed the goals of the Ecosystem Science Program at the NWFSC concerning the Atlantis model, both in regard to its potential utility in supporting fisheries management decision-making, and in the ongoing California Current Integrated Ecosystem Assessment (IEA) process. Isaac Kaplan and Kristin Marshall then gave several presentations on the details of model structure and dynamics, data inputs, model calibration, and uncertainty evaluation. Applications of the Atlantis model for the California Current were also presented. These presentations extended over the rest of the three-day meeting. At the end of the first day of review, the Panel made a small number of requests to the technical team for additional information. However, it was not practical to request model sensitivity runs during the review meeting because the Atlantis model requires a day (or longer) to run.

This report summarizes the Panel's discussions on the model, provides recommendations on the potential applications of the California Current Atlantis model in the Council setting, and summarizes the Panel's requests to the Atlantis technical team. The report concludes with a list of research recommendations. Appendix 1 lists the participants and their affiliations. Appendix 2 includes a list of the primary and background documents that were provided to the Panel in advance of the meeting on an ftp site. These documents included technical descriptions of the Atlantis model; applications of the California Current Atlantis model published in the peer-reviewed literature; and other supporting documents. Appendix 3 contains the terms of reference for the panel review, and the meeting agenda is included as Appendix 4.

Two implementations of Atlantis were reviewed. One was an established model that was documented in a 2010 technical memorandum (Horne et al. 2010). This model was the basis for several of the publications evaluating cumulative fishing impacts on the California Current ecosystem. The Panel also reviewed a new implementation of the Atlantis model that is under development. Some of the deficiencies that the Panel identified in the current model will be addressed in the new model. The Panel did not review an earlier Atlantis model for the California Current (Brand et. al 2007), although some of the applications of the model were discussed.

The emphasis of the Panel's review was on the potential use of the Atlantis model to support Council decision-making, rather than as an independent research activity. Atlantis should be regarded as a tool for addressing strategic issues, such as evaluating the trade-offs among management objectives achieved by various harvest policies, rather than tactical issues such as setting annual ABCs and OFLs. It is not intended to replace single species stock assessments. Prior to the review, five potential applications of the California Current Atlantis model were identified:

a. food web impacts of fisheries, such as evaluating trophic impacts of forage fish harvest policies on abundance and yield of other species;

b. ranking of potential fishery management strategies;
c. evaluation of risks of climate change and ocean acidification;
d. informing parameters within single species assessments, e.g. natural mortality; and
e. Management Strategy Evaluation to 'simulation test' new methods of stock assessment, data collection, and metrics for indicators of ecosystem attributes.

The Panel supports continued development of the Atlantis model as a tool to assist the Council in evaluating ecosystem impacts of fisheries management actions. Atlantis could be used to address several of the EBFM initiatives listed in the Appendix to the Council's Fishery Ecosystem Plan (e.g., protection for unfished forage fish, cross-FMP socio-economic effects of fisheries management, cross-FMP effects of climate shifts, and indicators for analyses of Council actions). Atlantis may be uniquely suited to address cross-FMP issues of concern to the Council.

The Panel recommends that Atlantis results be presented and interpreted qualitatively rather than quantitatively. This report provides suggestions on qualitative interpretation of results for potential applications of Atlantis in the Council setting. While the Panel encourages further development of Atlantis, this Panel cannot endorse any particular application that might be presented to the Council in the future. The utility of a particular model depends on the intended application, and this will need to be evaluated on a case-by-case basis. New applications of Atlantis should be reviewed by the SSC, or through a STAR-panel process.

The Panel identified a need for ecosystem modelers to more fully engage with the Council and its advisory bodies, both to improve understanding of ecosystem modeling within the Council family, and to identify relevant management scenarios. Many of the management scenarios in the Atlantis applications published to date are too stylized to be directly useful to the Council. Consideration should be given to the establishment of a routine process by which new ecosystem science is reviewed and brought before the Council.

Many of the applications presented to Panel relied on a single configuration of the ecosystem model. The Panel recommends a stronger emphasis on evaluation of the uncertainty of Atlantis output. Given that Monte Carlo approaches are not yet possible for Atlantis due to lengthy run times, uncertainty evaluation should take the form of a set of carefully selected scenarios. These scenarios could reflect alternative plausible hypotheses of ecosystem productivity (as in the cumulative impact analysis for the Tier 1 EIS), some aspect of ecosystem function, such as the strength of species interactions, or different combinations of parameters which reproduce the observations about equally well.

The Panel appreciated the extensive documentation provided by technical team. Atlantis is described in several peer-reviewed publications, but formal documentation is not available. An informal user's manual is available by request and the source code (also available by request) is extensively commented. The Panel expressed concern about using a model for management applications unless full and formal documentation was freely available.

The California Current Atlantis model was carefully developed, and the process of model calibration was described in technical documents. Nevertheless, the Panel was concerned by several instances of unrealistic model behavior. Some benthic invertebrate species groups did not persist in the absence of fishing, and biomass trends from stock assessments were not well matched when historical catches were used to project the ecosystem forward from unfished status to the present. While the technical team was aware of all these issues, they did not view them with the same level of concern. The Panel acknowledges that standards for the performance of ecosystem models are not well established (FAO, 2008). One possibility would be to establish minimal standards for model performance prior to undertaking a model calibration. Establishing these standards could be a task for the SSC or another methodology review panel, which could also provide guidance on the steps to take during the calibration phase.

The Chair thanked the NWFSC for hosting the meeting and the participants for the excellent and constructive atmosphere during the review, the results of which should help inform the Council and its advisory bodies determine the best available science for ecosystem-based fisheries management.

2. SUMMARY COMMMENTS ON THE TECHNICAL MERITS AND/OR DEFICIENCIES OF THE METHODOLOGY AND RECOMMENDATIONS FOR REMEDIES

2.1 History, goals, and evolution of ecosystem modeling at NWFSC

The California Current Atlantis Model (CCAM) is a spatially explicit, coupled physical-biological oceanographic model developed and maintained by the Integrative Marine Ecology Team at NOAA's Northwest Fisheries Science Center, based on the framework developed by Dr. Elizabeth Fulton (CSIRO, Ocean and Atmosphere Flagship). The principal goal of the CCAM is to simulate the California Current ecosystem to explore the impacts of natural and anthropogenic disturbances. Work on the CCAM began in 2006, focusing on the synthesis of needed data and recreating expected population patterns in the absence of fishing (Brand et al. 2007). The second version of the model (Horne et al. 2010) built on this framework to enable the evaluation and ranking of management strategies by including fisheries, incorporating new and updated data, and increasing the spatial resolution along the coast of California. The team is working currently on the third version of a model of the California Current Ecosystem, increasing the detail in lower trophic levels to examine issues relating to ocean acidification and management of forage fish. The new model will also link to the IO-PAC input-output model (Leonard and Watson 2011) that examines the economic impacts of fisheries landings on the economy to quantify spatial economic impacts of ocean acidification. The Panel notes that IO-PAC is designed for use on much shorter time scales than Atlantis, and that such linking should be done with caution.

Phil Levin and Isaac Kaplan explained and emphasized the utility of the model for strategic rather than tactical planning, and the Panel agrees that Atlantis should be used for management strategy evaluation and other broad questions, rather than for more technical use, such as setting quotas, selecting stock assessment parameters, or the precise placement of a marine protected area. Chris Harvey gave an overview of the Integrated Ecosystem Assessment (IEA) process, which utilizes Atlantis to test scenarios for examination of alternative futures and tradeoffs. The first two versions of the Atlantis model have been used in IEAs to examine climate change effects, compare strategies for targeting forage fish, investigate the ecological and economic effects of ITQs, and to compare how fisheries management actions at different spatial scales may cause local or coast-wide effects. The IEA is not fisheries-centric, but is meant to examine trade-offs among conservation, fisheries, and other interests or aspects of the ecosystem. Review of the IEA itself by the SSC is ongoing and is separate from this methodology review of the CCAM.

2.2 Mechanics, assumptions, and functional forms of Atlantis

The Central California Atlantis Model (CCAM) is based on the Atlantis code base first developed at CSIRO. While the Panel reviewed applications based on multiple iterations of CCAM, this section focuses on the version described in Horne et al. (2010) as this is the most recent version, used in published work. A new version of the model is in development (see Section 2.9) and may address some of the concerns expressed in this section. However, all of these concerns apply to analyses published to date.

Atlantis is a spatially-explicit, deterministic ecosystem model based on mass (nitrogen) balance governed by a set of differential equations. Space is modeled in three dimensions (see also Section 2.3). Simulated oceanographic processes are provided by the Regional Ocean Modeling System (ROMS, http://www.myroms.org). There are separate submodels for hydrography, ecology, and management/human activities. Here we highlight model assumptions and implementation issues that received particular attention from the Panel, and do not attempt to provide a full description of Atlantis.

<u>Age structure:</u> Atlantis incorporates age structure using a user-defined number of equal-sized bins (each bin represents an equal fraction of the organism's life span). Annual cohorts are tracked within bins (i.e., only the oldest individuals can move to the next bin) but are assumed to be otherwise ecologically equivalent. For the California Current implementation, 10 equal-sized bins are used, spanning from "recruitment" (recruits enter the model when they start feeding "similarly" to juveniles) to the maximum observed age. The Panel noted that this may result in the initial bin of long-lived species being inappropriately wide and lumping together ecologically dissimilar life stages. A move to more bins for longer-lived species may address this concern, at the cost of some increase in computation time. Making bin widths unequal would allow for a more efficient solution, but does not seem possible given the current code base. Similarly, the current code does not allow for a "plus" age group, which could be more efficient than providing bins that extend to the maximum observed age.

<u>Natural mortality:</u> Natural mortality in Atlantis results from the combined effects of predation (described later), disease (not implemented for the CC applications), oxygen limitation (not implemented for the CC applications), starvation (not implemented for the CC applications) a linear (density-independent) mortality term, and a quadratic (density-dependent) mortality term. The linear and quadratic mortality terms are typically applied only if needed (see Section 2.6 on calibration) in cases when predation mortality alone does not sufficiently constrain population growth, or for functional groups without predators in the model. Thus, comparison between natural mortality in Atlantis and estimates of natural mortality from stock assessments is not straightforward. In addition, there is no mortality from starvation in the CC application, which may predispose the model toward strong top-down effects and weak bottom-up effects.

<u>Recruitment:</u> Recruitment in CCAM is driven by a Beverton-Holt stock recruitment curve, with spawning biomass calculated over the entire model domain (with potential for response to local temperature) and recruits subsequently distributed spatially throughout the model domain in proportion to local juvenile abundance. Many options for recruitment exist in the Atlantis code base, including a forced time series of recruitments and a forced time series of recruitment

deviations. The Panel recommends using forced time series of recruitment deviations, with any stochastic implementations accounting for temporal autocorrelation. In the current code, the Beverton-Holt is parameterized in terms of α and β, but for interpretability and consistency with the inputs used at the start of the calibration process, the Panel recommends reparameterizing in terms of R_0 and steepness.

Functional response of predators: While the Atlantis code base allows for a variety of functional responses, almost all applications to date use a multispecies Holling type 2 functional response, which incorporates saturation but does not reflect prey switching. Consumption rates of different functional groups depend on preference coefficients specified for each pair of functional groups. Separate preferences can be specified for juveniles versus adults, but finer-scale effects of age or size on preferences are not incorporated except through gape limitation. Gape limitation is modeled with a step function, with both minimum and maximum acceptable size of prey specified as a percentage of predator length. There is a new option in the model to "smooth" the feeding window. The Panel expressed concern that the simple juvenile versus adult distinction in specifying preferences may be too coarse (especially for long-lived functional groups where the first age bin is wide and incorporates a large amount of growth). It was also suggested that gape limitation may vary by prey type rather than (or in addition to) by predator; for example the same predator may be able to consume different sizes of fish with a "pelagic shape" compared to a "flatfish shape". Expressing gape limitation as a percentage of predator length may not be appropriate over the full range of predator sizes; for example it does not seem appropriate that minimum prey size would continuously increase with growth for an organism as large as a whale. Prey quality is not directly incorporated in the model although E_{ij} (assimilation efficiency) may be able to serve as a surrogate.

Density dependence: Density-dependence enters the model in multiple ways: through the stock-recruitment relationship, through depletion of prey, and through the quadratic mortality term when implemented. The Panel noted that this mix of prescribed and emergent density dependence requires careful thought about proper implementation in a model which does not explicitly model the youngest recruits, with consideration given to the timing of density-dependence and whether any density-dependent processes are being "double-counted".

Movement and behavior: Predators in the model move within the model domain in pursuit of better growth potential or during prescribed seasonal migrations. Some functional groups also undergo forced migration outside of the model domain, experiencing pre-specified growth and mortality during their absence. The Panel noted that modeled impacts of environmental change (e.g. ocean acidification) are not extended outside the model domain during simulations, but they would in reality.

Fishery: Fishery aspects of Atlantis are discussed in more detail in Section 2.5. Fisheries can be implemented many ways in the Atlantis framework. The Panel noted that applications to date which considered spatial closures did not attempt to model effort displacement, and that it was not clear how to allocate catch seasonally or even among 12-hour model time steps when total catch was specified as a model input. The Panel notes the difficulty in portraying technical interactions or modeling multispecies fisheries where weak stocks may constrain fisheries well before allowable catch of abundant species has been obtained. Numerous current applications of

CCAM use the year 1950 as a proxy for "unfished" conditions (see also the discussion of calibration in Section 2.6), but the Panel noted that there were substantial fisheries before that time for some species in the model. The Panel also noted that many simulations require a "burn-in" period to generate a quasi-equilibrium state before different scenarios are compared in further projection. Saving this unfished ecosystem state rather than regenerating it anew for each scenario would substantially improve computational efficiency.

2.3 Model domain and functional groups

The domain of CCAM is bounded by the U.S.-Canada border to the north, Point Conception to the south, the U.S. shoreline to the east, and the 2400m isobath to the west. The domain is divided into polygons formed by latitudinal breaks that follow biogeographic and management boundaries and longitudinal breaks that follow bathymetric contours. These polygons are stratified into 1-7 vertical water column layers, depending on their offshore extent, plus an additional sediment layer. The ecosystem is represented by submodels that simulate phenomena such as physical oceanography, nutrient exchange, primary production, and food web relationships in a spatially dynamic way.

The model includes 61 functional groups: 5 bacteria/detritus, 4 phytoplankton/algae, 17 invertebrate, and 35 vertebrate (26 fish, 3 bird, 6 mammal). The CCAM includes forced seasonal movement within the domain for five of the vertebrate groups and larger migratory movements into and out of the domain for nine vertebrate groups. Primary producers and invertebrates are modeled as aggregate biomass pools, while vertebrate groups are represented by ten age classes, each age class representing 10% of the life span of that group. Physical habitat is characterized in terms of substrate (soft, hard) and geographic features (canyons, seamounts); biogenic habitat types include kelp, seagrass and benthic filter feeders. Habitat associations are defined for each functional group.

The Panel spent considerable time discussing the challenges posed by imposing arbitrary boundaries to define the spatial domain of a model when real ecosystems are highly connected. The Panel agreed that a reasonable approach was to set boundaries on the basis of data availability and management concerns, and then ask what questions a model with that spatial domain is or is not appropriate for addressing. In the present application of the California Current IEA, the Panel expressed concern that the spatial scale was too restricted to answer questions about some migratory taxa of high interest, particularly hake and sardine. Highly migratory species such as whales and tuna may be modeled well enough to capture their predation impacts on other species of interest, but their own biology is not well captured. Nine vertebrate groups are characterized as migrating into and out of the model domain. CCAM is better suited for characterizing ecosystem effects for functional groups that stay within the domain than those that leave the domain.

Similar concerns apply to the taxonomic resolution and number of functional groups. The Panel considered the appropriateness of using a single "generic" ecosystem model for multiple applications. The Panel was informed it would be very difficult to increase the taxonomic resolution of certain functional groups on a case-by-case basis in response to particular questions. Geographic expansion was also challenging, since defining the base map is one of the most time consuming parts of model development. The Panel noted that nevertheless Atlantis provides a generally useful tool and the CCAM as developed, and being further developed, could often be an appropriate and readily available tool. However, other existing models such as that of Ruzicka et al. (2012) may be more suited to specific questions, or the development of new models (e.g., Plagányi et al. 2014) may be required. The Panel suggests careful consideration of the benefits relative to the expense of developing entirely new models in pursuit of incremental improvements.

The Panel identified several functional groups of particular concern in the current model implementation. Some concern was expressed about uncertainty in the appropriate scale of primary producer biomass (see Section 2.4), although the scale may not be crucial to calibrated dynamics of higher trophic levels (see Section 2.6). The inability of kelp to persist was troubling from a calibration perspective (see Section 2.6) and due to the importance of kelp as habitat. Among invertebrates, Dungeness crabs are of high economic interest, but are not resolved into their own functional group. Market squid dynamics are not well captured. Among fish, particular concern was expressed regarding hake, for which modeled dynamics did not seem realistic but could have substantial impacts on ecosystem dynamics due to high biomass and predation rates. The flexible life history and localized spawning stocks of salmon are not captured. The small planktivore and large planktivore groups both contain multiple species of independent fishery interest and in some cases distinct ecologies (e.g. sardine versus anchovy).

The Panel noted that seabirds are typically colony-based central place foragers with intense and localized impacts and needs, but the current model models their behavior like fish resulting in diffuse impacts. The model in development (Section 2.9) should perform better in terms of constraining seabird impacts within the appropriate spatial polygon, but some polygons are quite large and in the real world impacts would be highly concentrated in only part of the area. Similar concerns apply to colony-based marine mammals. For both birds and marine mammals, concerns were expressed that some functional groups contained a mix of migratory and foraging strategies.

Additional troubling functional groups included benthic filter feeders and benthic grazers, which both went extinct in the model, as well as shallow benthic filter feeders and large megazoobenthos, which appeared to increase indefinitely for the duration of model runs.

2.4 Data used to configure the model

Isaac Kaplan and Kristin Marshall presented the data sources for trophic groups (including primary producers) and habitat used in the current (Horne et al. 2010) and proposed (Kaplan et al. 2014) versions of the CCAM. For each species or species group, the model input can include initial abundance by area, size at age and numbers at age, maximum age, age at maturity, length-weight conversion, consumption rate parameters, habitat preference, daily, seasonal and annual migration patterns, diets, gape, and recruitment parameters. Detailed information on species (or species groups) and data sources is presented in Brand et al. (2007), Horne et al. (2010), and Kaplan et al. (2014.) Diet information sources are primarily detailed in Default et al. (2009). The Panel found the data sources appropriate and many of the concerns regarding the current data are being addressed in the update. The Panel supports using the biomass and catch time series output of stock assessments, but suggests matching trends rather than specific numbers and referring to this information as stock assessment output rather than "data." The Panel also noted that if stock assessment output is used as input and to tune the CCAM, then using the CCAM to inform stock assessments becomes problematic.

The analyses conducted as part of the Essential Fish Habitat (EFH) designation process (NMFS 2004) were used to assign the percentage of area covered by rock, soft sediment, canyon and seamount in each polygon. In addition, kelp and seagrass cover from the same report is used in the model as an initial condition. Faunal association with habitat was assigned according to the EFH for groundfish and the California Department of Fish and Wildlife for invertebrates.

The Panel had the following recommendations on the topic of data sources and presentation:

- Provide a table listing possible options for terms and functions in the Atlantis model and which options are applied in the CCAM (see Panel Requests in Section 1).
- Obtain recent data on whale populations and diet to replace the outdated information from the large review sources.
- Summarize the diet information detailed in Dufault et al. (2009) in a table that presents sample size as well as temporal and spatial coverage of diet studies.
- Continue, and expand if possible, the current diet sampling programs. Comprehensive diet sampling and analysis is crucial to capturing functional relationships that allow the Atlantis model to accurately reflect diet changes that result from variation in absolute or relative prey populations.

2.5 Fisheries and management representation

One simple representation of fisheries is described in Kaplan, Horne, and Levin (2012), and applied in that publication as well as in Kaplan and Leonard (2012), Kaplan, Gray, and Levin (2012), and Kaplan et al. (2013). In this representation, the model includes 20 fishing fleets, defined by gear type and fish group. Harvest is modeled by applying a constant fishing mortality rate F to all fish groups harvested by a given fleet across all years (this differs from the constant F applied by biologists to an entire stock). F is constant across space as well as time; that is, each fleet's catch is distributed among the polygons that are open to that fleet in proportion to the areas of those polygons. In cases where part of a polygon is closed (as an RCA, MPA or EFH), the catch associated with that polygon is decreased proportionately. In other words, the model assumes that catch foregone when an area is closed is not made up elsewhere. The combination of exploitation rates and spatial closures is set so that total catch per fleet and fish group approximates 2007 catch levels.

The CCAM forces catches per fleet with constant Fs that are invariant over time and space. The Panel recommends that the model base catches on harvest control rules (ACLs) rather than constant Fs. Combining harvest control rules with fleet dynamics would be a next logical step but would be challenging, as ACLs for a given species often affect the behavior of multiple fleets that catch the species in different proportions. Nevertheless, a fine-scale fishing model that incorporates regulations, fleet behavior, and economics would better capture the dynamics at the scale the Council is interested in, and would be a worthwhile objective.

The spatial capabilities of the CCAM provide considerable opportunity for modeling movement of functional groups and fleets and evaluating effects of spatial management. The extent to which these capabilities can be realized depends on the availability of relevant spatial data and the scale(s) at which ecosystem processes and functional group and fleet behavior can be understood. Spatial behavior is generally more uncertain at smaller than larger spatial scales. In evaluating spatial management scenarios, it would be helpful to determine the sensitivity of results to the CCAM assumption of zero effort displacement.

2.6 Model calibration and fits to history

An Atlantis model is not fitted to data, unlike the stock assessment models provided to the Council. Rather, a subset of the parameters of the model are tuned or calibrated to achieve a set of model outputs which are considered sufficiently biologically plausible and which match available data qualitatively. The only sources of process error in an Atlantis model are due to impact of oceanographic conditions on primary productivity and predation. The parameters which are adjusted differ between the upper and lower trophic levels of the model. For lower trophic levels the adjusted parameters are typically: maximum consumption rates, interaction parameters and mortality closure terms. For upper trophic levels the adjusted parameters are typically: unfished recruitment, maximum consumption rates, interaction parameters and mortality closure terms. Linear and quadratic mortality closure terms are used, when needed, to bring modeled abundances and dynamics of individual species into a plausible range. In principle they represent sources of mortality that are not otherwise captured in the model.

The model building / calibration phase involves three phases:

- Phase 1. Projecting the model forward from the initial conditions (which roughly match the situation in 2007) under zero fishing mortality.
- Phase 2. Projecting the model forward from the initial conditions under different levels of fishing mortality (either setting the fishing mortalities for all species to the same value or changing the fishing mortality for each species in turn keeping the fishing mortalities for the remaining species at their 2007 levels).
- Phase 3. Projecting the model from the unfished level under historical catches.

The analysts examined time-trajectories of biomass relative to estimates of unfished biomass from stock assessments for phase 1, values of F_{MSY} from Atlantis versus those from stock assessments for phase 2, and time-trajectories of biomass from Atlantis versus those from stock assessments for phase 3.

The Panel agreed that the three phase approach to model calibration was generally appropriate. It noted that phases 1 and 3 are standard diagnostics when fitting end-to-end models, while phase 2 is somewhat unique to the CCAM. However, it had several concerns regarding the final calibrated model: a) several species do not persist in phase 1 and other species are extirpated before the present in phase 3, b) several of time-trajectories of biomass from Atlantis are markedly different from the results from stock assessments, and c) the time-trajectories of biomass for hake and small pelagics species (a combination of sardine and several other species) do not match the historical data well. These components are a substantial fraction of the fish biomass subject to fishery mortality. The hake component of the model appears to be more productive than would be expected based on the stock assessment – in particular, there is little evidence that fishing has had an impact on population biomass according to the Atlantis model.

The analysts noted that there were no standards for how well an end-to-end model should mimic assessment outputs when the current model was developed. They noted that achieving persistence of all groups in an Atlantis model can be very difficult and that the aim of an Atlantis model was to obtain broad trends in multiple groups. The Panel suggested that one approach to handling situations in which some groups did not persist under zero fishing mortality is to drop those groups from the model, though obviously this is not an ideal solution. The analysts agreed that this might be an appropriate way to handle cases in which it is impossible to find a parameterization so that all groups persist. If groups are removed from a model, the implications of this for the questions which the model can be used to address need to be clearly articulated.

The Panel has several recommendations related to model calibration.

- The model needs to be run for more than 80 years for phases 1 and 2 because there is evidence that it has not reached a stable state (or cyclic behavior) after 80 or fewer years.
- The analysts should specify their definition for satisfactory model calibration. In particular, the analysts should identify a set of species for which it is necessary to replicate the magnitude and trend of biomass as well as changes in population age-structure from independent sources (e.g., hake and sardine). If necessary, recruitment or the deviations in recruitment about the stock-recruitment relationship should be set to ensure that model matches the independent data.
- Data should be obtained (e.g. from CalCOFI, Santa Cruz juvenile rockfish survey) which could better characterize the inter-annual variation in the abundance of lower trophic level species. Consideration should be given to adding an additional calibration step to compare spatial and seasonal patterns of lower trophic level dynamics with available information on those dynamics.
- Ideally, all groups should persist in the model if it is projected forward under zero fishing mortality. If management advice is to be based on a model in which some groups do not persist, there is a need to provide a convincing argument why not having these functional groups can still lead to results which are useful to management.
- Plot natural mortality (M) as a function of age over time – in principle M should decrease with age.
- Consider validating to the model to (a) stock assessment estimates of total and mature biomass, and (b) estimates of abundance and age-structure from surveys.
- Compare the model-predicted diets with observed data on diets. Also, compare the model predicted and observed age-structure of the diets for key species.
- Show the confidence intervals for stock assessment output and the data used to evaluate fit.
- Consider the implications of leaving predator species out of model to investigate whether model behaves as expected.

The Panel had the following technical recommendations for changes to Atlantis.

- Add the ability to pre-specify weight-at-age rather than allowing it to change dynamically – conducting runs in which weight-at-age is pre-specified might help understand model behavior and assist with model calibration.
- Add the ability to turn off the dynamics of the structural vs the non-structural aspects of weight - conducting runs without this aspect of the model might help understand model behavior and assist with model calibration.

- Allow the age-bins to have different numbers of age-classes in each.
- Add the ability to run the model in which a predator does not consume prey (but obtains the fixed ration needed to persist).

2.7 Evaluation of uncertainty

Atlantis is not fitted formally to data so many standard methods of quantifying uncertainty such as bootstrapping, Bayesian and asymptotic methods cannot be applied. The analysts outlined a "bounded scenarios" approach for characterising uncertainty. This involves setting the values for some of the parameters of the model based on confidence intervals on unfished recruitment from assessment outputs or the scenarios used in assessments to construct decision tables. The Panel considered this a useful approach, but noted that it would be hard to assign relative probabilities to such scenarios.

The analysts indicated that they planned to characterise uncertainty using a small group of sets of model parameters, each of which reproduce the observations about equally well. This approach to characterizing uncertainty has been used in implementations of Atlantis in Australia. The Panel supported this approach. The analysts also noted they intended to explore multiple models and summarize the results of projections using multi-model inference. The Panel supported development of multiple models to explore structural uncertainty, but noted that integrating the results from multiple models will be difficult given there is no statistical basis to evaluate model fit.

2.8 Applications of Atlantis in the California Current to inform Council decision-making

a. Food web impacts of forage fish fisheries

Impacts of depleting forage fish (Kaplan et al. 2013) were modeled using both the current version of Atlantis and the Northern California Current Ecopath/Ecosim model. Overall results were similar between the two models, but there were important differences that reflect different model configurations and assumptions about diet in the two models. For example, Ecosim included sardines separate from other forage fish, while Atlantis did not. With a reduction in forage fish both models showed increases in euphausiids, cephalopods, mesopelagics, and mackerel. The models diverged in modeled responses of micro-zooplankton and copepods, salmon, and sharks. Ecosim showed strong responses of some rockfish, while Atlantis showed little change.

A common metric of ecosystem impacts of fisheries on forage fish is a count of the number of species and species groups that decline by greater than some percentage (typically 20% or 40%) at different levels of fishing mortality on forage fish. There are several limitations of the current version of Atlantis to make accurate predictions of this kind. In the current model setup, species groups do not experience mortality due to starvation, limiting the impact of reductions in prey on a predator population. For vertebrates in the Atlantis model, changes in mortality due to prey limitation occur indirectly, through changes in growth and size-dependent predation. For seabird and marine mammal groups, predation is modeled as a diffuse impact throughout the ecosystem, but most of these species are central place foragers with intense and localized foraging needs and impacts. The Panel is concerned that these assumptions may tend to underestimate the importance of forage fish to top predators, and does not regard Atlantis predictions of the percent of species impacted by forage fish declines to be reliable model outputs. Substantial improvements to the Atlantis model that are being considered, including better representation of different forage fish species, improved geographic coverage, and more realistic foraging patterns of seabirds and marine mammals, will go a long way to improving its performance in this regard. The Panel supports further development of Atlantis to address forage fish issues, but recommends greater use of alternative model scenarios to understand sensitivity to model structure and assumptions. Analyses of this kind are necessary to ensure that the policy decisions made by the Council are robust to uncertainty.

b. Ranking of potential fishery management strategies, including spatial management, harvest rates, quota systems.

The CCAM was used to compare fishing mortality, gear switching and spatial management scenarios at two spatial scales: (1) the Monterey Bay National Marine Sanctuary (MBNMS), which covers 12% of the model domain, and (2) the entire West Coast (Kaplan et al. 2012). For each of the 20 fleets in the model, status quo harvest was simulated by applying a constant fishing mortality rate F to all relevant fish groups harvested by the fleet over a 20-year projection period. Each fleet's harvest was distributed uniformly across all polygon areas that were open to that fleet in 2007 (considering the RCAs, MPAs and EFH in effect at that time). In addition to the status quo, other scenarios considered included (1) increasing status quo fishing mortality rates for all fleets by 0%, 50%, 150% and 200% and applying to all polygons coastwide, including areas closed as RCAs or EFH under the status quo, (2) gear switching, modeled separately for the MBNMS and West Coast as reductions in fishing mortality rate for groundfish trawlers and increases in fishing mortality rate for fixed gear vessels, (3) prohibiting bottom contact gear (fixed gear as well as trawl) in all RCAs, modeled separately for the MBNMS, Central California (including the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries), and the West Coast, and (4) changing the status quo spatial distribution of effort within EFH by allowing bottom contact gear (trawl and fixed gear) outside 550m but banning those gears inside 550m. Management scenarios were compared using five environmental metrics (gear impact on habitat, mature rockfish as proportion of total rockfish population, total rockfish biomass, biomass of marine mammals and birds, bycatch of rebuilding rockfish species) and a sixth economic metric (landed value of catch). Results for each metric were expressed in relative terms, that is, by comparing each alternative relative to the status quo.

In a related application (Kaplan and Leonard, 2012), the CCAM was used to compare some of the same management scenarios developed by Kaplan et al. (2012) – using the same five environmental metrics and expanding the sixth (economic) metric to include not only ex-vessel revenue but also wholesaler and processor revenue and regional income and employment impacts derived from a regional input-output (I-O) model.

Catches were modeled by applying a constant fishing mortality rate F to all fish groups harvested by each fleet across all years and fishing polygons for the fishing mortality, gear switching and spatial management scenarios developed by Kaplan et al. (2012). As indicated earlier, catches are better represented by harvest control rules rather than constant Fs. Homogeneous distribution of each fleet's catch across all polygons open to that fleet is a simplistic and unrealistic assumption but difficult to remedy, given the lack of spatial data for fleets other than groundfish trawl. Despite these reservations, this application demonstrates the potential utility of the CCAM for providing qualitative insights into the relative effects of broadly defined management scenarios.

Kaplan and Leonard (2012) expressed the environmental outcomes of each scenario in terms of how each environmental metric performed relative to the best performing scenario. However, the economic metrics were expressed for each scenario as absolute effects (jobs and dollars). This disparate treatment suggests a higher level of certainty regarding the economic metrics that is not warranted. Moreover, regional I-O models of the type used in this application are intended to estimate short-term economic impacts, not long-term effects such as those for which the CCAM was designed. The Panel does not consider this to be a suitable pairing of models.

An augmented version of an earlier version of the California Current Atlantis model (Brand et al. 2007) was used to compare the environmental and economic effects of three management regimes – cumulative landings limits, a competitive TAC, and ITQs (Kaplan et al. 2013). The comparison was based on a model of fleet dynamics developed for 95 vessels active in the non-whiting groundfish trawl fishery in 2004. These 95 vessels were divided into 12 fleets, each affiliated with a major port area on the West Coast. Effort was modeled at the fleet level, with each fleet consisting of 2-25 vessels. For each fleet, a utility score was assigned to each of 62 polygons, based on potential revenue per unit effort (with zero revenue in RCAs) and available towing time in the polygon based on an assumed three-day trip. Effort was distributed among polygons in proportion to their relative utility scores. The model was based on fixed quotas (species-specific TACs for limited entry trawl in 2005) and average ex-vessel prices during 2004-2005, and calibrated to the level of effort and the spatial distribution and species composition of catch in 2004. Each management scenario was simulated in monthly time steps for 30 years.

For the cumulative landings limits scenario, each fleet's landing limits are calculated by multiplying the number of vessels per fleet by a per-vessel quota for each species. Fleets cease operation once their limits are reached until the next bimonthly period. For the ITQ scenario, ex-vessel prices are adjusted by quota lease prices for harvested species, scarce quota lease prices for rebuilding species, and over-quota penalties for catches that exceed quotas. Several versions of this scenario were developed to reflect varying combinations of quota lease prices, scarce quota lease prices and over-quota penalties. For the competitive TAC scenario, each fleet can land each species until the coastwide TAC for that species is reached. Fleets can continue to fish in areas where over-quota species occur, but must discard those species when encountered (no over-quota penalties). This scenario would not be legal in the U.S., but was provided as a useful contrast to some features of the ITQ scenario. Simulation results for each management scenario were compared on the basis of fishing effort, rockfish catch and biomass, fishery revenues, and indirect trophic effects.

While highly stylized, the scenarios developed in this application illustrate the potential of the CCAM for comparing environmental and economic effects of broadly defined, alternative groundfish management approaches. The issues addressed in this application – the importance of over-quota penalties in managing effort and bycatch, how port location and quota trading affect economic opportunities under ITQs, and the importance of TACs (regardless of details of the ITQ system) for achieving biological objectives – would be of potential interest to the Council.

Scenario outcomes described include absolute catches and fishing effort for the first five years of the simulation, absolute gross and net revenues for the entire 30 years of the simulation, biomass relative to initial biomass for each of the 30 years, and indirect trophic effects expressed as percentage changes in various forage groups, birds, and marine mammals. It is not clear why environmental effects are expressed in relative terms while fishery effects are expressed in absolute terms. This disparate treatment suggests a higher level of certainty regarding fishery effects that is not warranted. In characterizing such results to the Council, it would be important to emphasize that the fishery outcomes represent simulated results that provide qualitative insights under simplifying assumptions (e.g., constant quotas) and should not be interpreted as projections.

c. Evaluation of risks of climate change, acidification, and cumulative impacts

Kaplan et al. (2010) evaluated the implications of ocean acidification on the performance of four harvest policies. Ocean acidification was represented by linear trends in mortality for benthic groups. The Panel agreed that Atlantis was a way to explore the implications of climate change-related impacts such as ocean acidification. It should be noted that the lower trophic levels, which are likely to most directly impacts by ocean acidification, are modeled in less detail than higher trophic levels (fish, mammals and seabirds). Consequently the results of modeling studies involving ocean acidification may be less detailed and/or accurate than for questions focusing on higher trophic levels.

Results are shown in Kaplan et al. (2010) in the form of a decision table. Decision tables are used frequently in Council stock assessments to summarize the outputs from model projections. The Panel noted that presenting results as decision tables should be undertaken with care because this way of summarizing results may suggest a level of precision which is not justifiable. In general, the results of projections should be summarized qualitatively and in a relative sense, using, for example, a radar plot.

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

Isaac Kaplan presented several studies from other regions, such as the Gulf of Alaska, Gulf of Maine, and Georges Bank, in which results from multispecies or ecosystem models were used to inform single species stock assessments. The Panel was not supportive of the idea of using Atlantis mortality estimates directly in single species assessments. Nevertheless, comparison of mortality estimates between Atlantis and single species models was considered valuable both from an ecosystem modeling and from a single species stock assessment perspective. It is important to recognize that there is some unavoidable circularity in these comparisons if single species biomass trends are used to tune the ecosystem model. Mortality in ecosystem models, at least for the adult population, should be roughly commensurate with the natural mortality implied by the longevity of the species. For a hypothetical example, a canary rockfish population with a natural mortality of $0.5yr^{-1}$ no longer has population dynamics of a canary rockfish. From a single species perspective, the age-specific pattern of mortality in the ecosystem model will be of interest, as will the pattern of temporal changes in mortality as the abundance of prey, predators, and competitors varies in the ecosystem.

e. Simulation testing new methods and metrics for ecological indicators

Fulton et al. (2005) and the California Current IEA Report describe the use of Atlantis as an operating model for the generation of pseudo-data with which to test proposed ecological indicators. The Atlantis model simulates the true state of various ecosystem attributes (factors that are of interest to managers, but difficult or impossible to observe directly) and simulates the sampling of proposed indicators (factors that are easier to measure, and hoped to correlate with ecosystem factors of interest). The Panel supports this use of Atlantis.

The Panel notes, however, that this approach is useful for screening out proposed indicators (or management strategies) which perform poorly even in simulation, but indicators (or strategies) which perform successfully in simulation will not necessarily perform successfully in reality, since the correspondence between an indicator and attribute in a simulation may depend on biological assumptions which are not met in reality. The converse is possible as well, but the Panel deemed this much less likely.

Previous assessments of indicator performance have focused on simple correlations between indicator and attribute. The Panel supports the move toward methods that account for the time series nature of the simulated data and allow for explicit consideration of observation error, for example multivariate autoregressive state-space modeling.

2.9 New version of model under development

A new implementation of the Atlantis model is under development. The new model is designed to address forage fish issues, ocean acidification, and human impacts on the California Current ecosystem. The new model includes a wider geographic area, from Baja California to the northern Vancouver Island, and includes the Southern California Bight.

Effects of ocean acidification (OA) are expected to result from reductions in shell-forming molluscs and plankton which are important prey to many species. Patterns of OA are responsive to oceanographic conditions on a scale finer than the polygons in the Atlantis model. Downscaling of the ROMS oceanographic model will allow simulation of pH, nutrients, currents, temperature and other factors on a 10km grid, with trend projections to the year 2065. These projections will define the physical environment in the revised model.

The larger geographic area allows the model to encompass the annual migratory cycle of both Pacific sardine and Pacific hake. Forage species will be modeled with higher species resolution, with Pacific sardine, northern anchovy, Pacific herring, Pacific mackerel, jack mackerel, and Pacific hake all being modeled as individual species. Mesopelagics will continue to be modeled as an aggregate group. The revised Atlantis model incorporates new information on habitat distribution and species habitat preferences from the EFH review process. Updated stock assessments including data-moderate assessments will be used to calibrate the model. The Panel was generally supportive of the changes being implemented in the new model.

Human impacts will be modeled in economic terms by linking an input-output economic model (IOPAC) to the harvest simulations. There was concern among the Panel, acknowledged by the model development team, that the intended use of IOPAC is for short-term analysis, while Atlantis is more useful for long-term projections.

Overall, the revised Atlantis model will encompass a greater area, more species, and more processes, than has previously been attempted with a model of this sort. This increased complexity will require extra effort, and care in specifying and tuning the model to produce realistic system behavior. Continued and increased support for the modeling team will enable them to produce a more reliable and generally useful ecosystem model to inform science and management over the next decades.

3. AREAS OF DISAGREEMENT REGARDING PANEL RECOMMENDATIONS

There were no major disagreements between the Panel and the Team or among Panel members.

4. UNRESOLVED PROBLEMS AND MAJOR UNCERTAINTIES

There were several instances of unrealistic model behavior even after model calibration. Some benthic invertebrate species groups did not persist even in the absence of fishing, and biomass trends from stock assessments were not well matched when historical catches were used to project the ecosystem forward from unfished status to the present. The Panel recommends that a more rigorous approach to model calibration be adopted.

There was inadequate evaluation of uncertainty in many of the applications of the CCAM reviewed by the Panel. Methods of characterizing uncertainty in ecosystem models are not well developed, and long run times preclude the use of Monte Carlo techniques. For the time being, the Panel recommends greater use of scenarios to reflect alternative ecosystem states or dynamics as a way to characterize uncertainty, but other approaches may be possible in the future with the development of new techniques and faster computers.

The Panel identified a need for ecosystem modelers to more fully engage with the Council and its advisory bodies, both to improve understanding of ecosystem modeling, and in developing relevant management scenarios. Many of the management scenarios in the Atlantis applications published to date were too stylized to be directly useful to the Council. Consideration should be given to the establishment of a routine process by which new ecosystem science is reviewed and brought before the Council.

5. MANAGEMENT, DATA OR FISHERY ISSUES RAISED BY THE PUBLIC

There was no public comment.

6. DISCUSSION AND REQUESTS MADE TO THE TECHNICAL TEAM DURING THE MEETING

Request 1: Find out the order of calculations for solving the sets of differential equations, if it is not simultaneously. For example, does growth occur first or natural mortality?

Rationale: The order of calculation may have impacts on the results.

Response (provided by Beth Fulton [CSIRO]):

- Step 1—Copy final biomasses from the 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 (to 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 is consistent with advection of plankton etc happening with the physics time step which happens between each biological time step).
- Step 3—Rest of the 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). Flux terms are then determined based on the biomasses at the end of the previous time step, with everything responding to those values (i.e. no incremental update). The final flux is then all done together so the order of operations is not important (i.e., the issue of mortality depleting population before growth is avoided).

For everything except plankton and bacteria the time step is as defined in input files (12 hours for California Current models). An adaptive time step is used so as to avoid numerical artefacts for the fast growing groups (small plankton and bacteria and their primary predators). This means that the fastest turnover group (typically small phytoplankton) dictates the time step based on their flux / standing stock. This sub-time step is squeezed so that no flux can exceed a specific proportion of their standing biomass. The model fails to execute and basically gives an error message as it means there is likely a parameterisation problem if that means that the effective time step they would experience is very small (<< 1 sec). 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 hrs) before Atlantis continues. There is no loss in mass conservation (i.e. fish can't be eating biomass that doesn't actually exist) as buffering groups (medium and large zooplankton) sit between the most volatile "fast" groups and "slow" groups.

Request 2: Clarify how Atlantis tracks a recruitment event through the age bins?
Rationale: An "age" group in Atlantis includes more than one cohort. It is unclear how the model deals with periodical high recruitment events, such as for rockfish.
Response (provided by Beth Fulton [CSIRO]): 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. 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 can be 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?
Rationale: Fishing selectivity patterns determine which portions of the fish population will be taken by the fisheries.
Response: The forced catch can be allocated to specific age classes. If the specified age classes are not present in sufficient abundance, the catch shifts to the existing age classes. Since this method roughly mimics a fisheries selectivity pattern, the panel recommends that this approach be used in future models used to support PFMC management, rather than applying fishing mortality to all age classes equally.

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.
Rationale: To have a better understanding of current CCE model.
Response: Two tables were provided, a table showing the basic parameterization of invertebrate and primary producer functional groups (Table 1), and second table for vertebrate functional groups (Table 2).

Request 5: Distribute the internal user guide to the Panel.
Rationale: To have better understanding of input data requirements, formats, tuning, and possible options.
Response: An internal working manual "HowToBuildAnAtlantisModel.doc" was provided to the Panel. There is no official Atlantis documentation from CSIRO. The Panel recommends that a formal user manual be prepared for the future.

Request 6: Provide all presentation Powerpoint files to the Panel.
Rationale: To facilitate review and note taking.
Response: All files were uploaded to \Presentations directory on the Council's FTP site.

Day 2 Requests
Request 7: Clarify sources for pre-1981 pelagic catch data.
Rationale: Earlier catch data are not available in PacFIN
Response: This information came from NMFS annual catch reports

Request 8: Clarify whether black rockfish is included in the model.
Rationale: Black rockfish is the dominant nearshore rockfish species. It is unclear in the documents and in the presentation if black rockfish is included.
Response: Black rockfish is included in the model.

Request 9: Clarify whether the hagfish fishery is included in the new model.
Rationale: There are active hagfish fisheries in Washington and Oregon. Overfishing may be a concern for this species.
Response: Hagfish are not well represented in the new model. They are part of an aggregated 'deep demersal fish' functional group that is dominated by eelpouts, grenadiers, and California slickhead. Fisheries (of all types) are not yet implemented in this model, but detailed representation of the hagfish fishery in this new model would require addition of a hagfish group.

7. RECOMMENDATIONS FOR FUTURE FOR FUTURE RESEARCH AND DATA COLLECTIONS

Recommendations for the next iteration of the California Current Atlantis model

- Summarize the diet information detailed in Dufault et al. (2009) in a table that presents sample size as well as temporal and spatial coverage of diet studies.
- Atlantis-predicted diet compositions should be compared to observed diets. Provide a measure of the precision of the diet composition estimates to aid in the interpretation of results and fine-tuning of the model. Estimating preferences directly from data is difficult and probably not worthwhile due to effects of spatial overlap and gape limitation.
- Continue, and expand if possible, the current diet sampling programs. Comprehensive diet sampling and analysis is crucial to capturing functional relationships that allow the Atlantis model to accurately reflect diet changes that result from variation in absolute or relative prey populations.
- 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 (see Panel Requests Section 6).

- Obtain recent data on whale populations and diet to replace the outdated information from the large review sources.
- Data should be obtained (e.g. from CalCOFI, Santa Cruz juvenile rockfish survey) which could better characterize the seasonal and inter-annual variation in the abundance of lower trophic level species. Consider adding an additional calibration step to compare spatial and seasonal patterns of lower trophic level dynamics with available information on those patterns.
- The model needs to be run for more than 80 years for calibration phases 1 and 2 because there is evidence that it has not reached a stable state (or cyclic behavior) after 80 or fewer years.
- The analysts should more explicitly specify their definition for satisfactory model calibration. In particular, the analysts should identify a set of species for which it is necessary to replicate the magnitude and trend of biomass as well as changes in population age-structure from independent sources (e.g., hake and sardine). If necessary, recruitment or the deviations in recruitment about the stock-recruitment relationship should be set to ensure that model matches the independent data.
- Ideally, all groups should persist in the model if it is projected forward under zero fishing mortality. If management advice is to be based on a model in which some groups do not persist, there is a need to provide a convincing argument why not having these functional groups can still lead to results which are useful to management.
- Compare cumulative mortality estimates from all sources in Atlantis to the natural mortality rate used in the stock assessment. Also plot natural mortality (M) as a function of age over time – in most cases M should decrease with age.
- When calibrating the model by adjusting the stock recruit parameters, use the R_0 and steepness parameterization, and then convert these into α and β. Turning should focus on adjusting R_0 rather than steepness. R_0 scales the entire population higher or lower, and is likely to be different in an ecosystem model compared to a stock assessment model. Steepness values in single species stock assessments will have been carefully chosen to be representative of the stock, or estimated using an informative prior.
- Consider validating to the model to (a) stock assessment estimates of total and mature biomass, and (b) estimates of abundance and age-structure from surveys. Comparisons of mature biomass are likely to be most relevant. Juvenile biomass from an ecosystem model is may be much higher than from stock assessments, depending on whether realistic values are used for juvenile M in the stock assessment.
- Show the confidence intervals for stock assessment output and the data used to evaluate fit. Consider using a goodness of fit measure to evaluate where the model is sufficiently calibrated.
- Consider the implications of leaving predator species out of model to investigate whether model behaves as expected.

Technical recommendations for Atlantis model code

- Develop a formal user manual and documentation of the model.
- Allow the age-bins to have different numbers of age-classes in each. Include an option to make the final age bin a plus group.

- Add the ability to run the model in which a predator does not consume prey (but obtains the fixed ration needed to persist)
- Parameterize Beverton-Holt stock recruit relationship with R_0 and steepness to facilitate model tuning.
- Add the ability to pre-specify weight-at-age rather than allowing it to change dynamically – conducting runs in which weight-at-age is pre-specified might help understand model behavior and assist with model calibration.
- Add the ability to turn off the dynamics of the structural vs the non-structural aspects of weight - conducting runs without this aspect of the model might help understand model behavior and assist with model calibration.

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Table 1. California Current Atlantis model invertebrate and primary producer functional groups and basic parameterization.

Code	Group	Species	Initial Concentration (Max, mg N/m^3)	Max Growth Rate (mgN / day)	Clearance (mg^3 / mgN / day)	Linear Mortality (/day)	Quadratic Mortality (/day)	Space Limitation	Oxygen Limitation
BC	Carnivorous Infauna	Polychetes, nematodes, burrowing crustacea, peanut worms, flatworms	786.91	0.07	0.09312	0.0001	0	No	No
BD	Deposit Feeders	Amphipods, isopods, small crustacea, snails, ghost shrimp, sea cucumber, worms, sea mouse, sea slug, barnacles,	103.66	0.6	0.0744	0	0	Yes	No
BFD	Deep Benthic Filter Feeders	Anemones, deep corals, lampshells, reticulate sea anemone, rough purple sea anemone, swimming sea anemone, giagntic sea anemone, corals, sponges	108.71	0.0012	0.001485	0	0	Yes	No
BFF	Other Benthic Feeders	Goeducks, barnacles, razor clams, littleneck, Manila clams, miscellaneous bivalves, Vancouver scallop, glass scallop, green urchin, red urchin	929.18	1.1	0.23814	0	0	Yes	No
BFS	Shallow Benthic Filter Feeder	Barnacles, seafan, soft corals, Gorgonian corals, black coral, green colonial tunicate, sea pens, sea whips, sea potato, vase sponge, mussels, scallops	112.61	0.24	0.0222	0	0	Yes	No
BG	Benthic Grazers	Snails, abalone, nudibranchs, sand dollars, make solarelle, Dorid nudibranchs, limpets, heart sea urchin, spot prawns, pandalid shrimp	840.14	0.03	0.036	0	0	Yes	No
BMD	Deep Megazoobenthos	Sea stars, moonsnail, whelk, leather sea star, bat star, sunflower sea star, common mud star, crinoids, brittle sea star, basket star	59.99	0.0326	0.03	0.0001	0	No	No
BML	Large Megazoobenthos	Dungeness crab, tanner crab, spiny lobster, pinchbug crab, red rock crab, graceful rock crab, spider crab, grooved tanner crab, Bairdi, scarlet king crab, California king crab	0.1	0.175	0.01713	0.0001	1.00E-06	No	No
BMS	Small Megazoobenthos	Giant, bigeye, yellowring, and smoothskin octopi, flapjack devilfish	34.04	0.1	0.201	0.0001	0	No	No
BO	Meiobenthos	Flagellates, cilliates, nematodes	95.81144	0.00688	0.00237		0	Yes	No
CEP	Jumbo Squid	Jumbo Squid	0.1	0.02	0.006	0.001	0	No	No
jCEP	Market Squid	Market Squid	0.04827	0.15	0.0003	0.001	0	No	No
jPWN	Juvenial Shrimp	Crangon and mysid shrimp	0.036204	0.388	0.13032	0.001	1.00E-13	No	No
PWN	Adult Shrimp	Crangon and mysid shrimp	0.01206	0.5068	0.054096	0.001	1.00E-13	No	No
ZG	Gelatinous Zooplankton	Salps, jellyfish, ctenophores, comb jellies	0.04449	0.03	0.045	0	1.00E-06	No	No
ZL	Large Carnivorous Zooplankto	Euphausiids, chaetognaths, pelagic shrimp, pelagic polychaetes, crimson pasiphaed	8.563443	0.45	0.2301	0	1.00E-06	No	No
ZM	Mesozooplankton	Copepods, cladocera	0.309387	1.8	0.18	0	1.00E-06	No	No
ZS	Microzooplankton	Ciliates, dinoflagellates, nanoflagellates, gymnodioids, protozoa	3.02	0.5	0.6249	0	1.00E-06	No	No
PL	Large phytoplankton	Diatoms	17.1	0.68	na	0	na	No	na
PS	Small phytoplankton	Picophytoplankton	5.7	0.4	na	0	na	No	na
MA	Macroalgae	Kelp	5281 mg N/m^2	0.45	na	0	na	Yes	na
SG	Seagrass	Seagrass	893 mg N/m^2	0.6	na	0	na	Yes	na

Table 2. California Current Atlantis model vertebrate functional groups and basic parameterization.

(For vertebrate migrations, see Table 7 in Horne et al. 2010)

Code	Group	Initial Biomass (mt)	Natural Mortality (/year)	k	*Linf*	Max Age (Years)	a	b	Age at Maturity (Years)	Age at Recruitment (Days)	Beverton-Holt Alpha	Beverton-Holt Beta	Fixed Recruitment (Recruits/Adult)	Adult Linear Mortality (/day)	Juv. Linear Mortality (/day)	Adult Quadratic Mortality (/day)	Juv. Quadratic Mortality (/day)	Oxygen Limitation	Habitat assoc
FDP	Dover Sole	423049	0.0900	0.08	50	53	0.0041	3.2495	5.0	360	9.50E+07	1.35E+09	NA	0.00003	0.000009	0	0	NO	YES
FPO	Canary	21088	0.0600	0.16	56	75	0.0155	3.0300	8.0	90	1.80E+06	4.85E+08	NA	0.000035	0.000035	1.00E-17	1.00E-16	NO	YES
FVV	Shortbelly	64000	0.3500	0.20	28	17	0.0095	3.0650	2.0	30	1.00E+08	4.38E+08	NA	0	0	1.00E-12	0	NO	YES
SHC	Yellow eye and Cow cod	595	0.0473	0.05	69	110	0.0193	2.9852	16.1	53	8.00E+04	1.54E+08	NA	0	0	3.00E-11	7.00E-18	NO	YES
FBP	Deep Vertical Migrators	244363	0.4582	0.35	25	8	0.0030	2.9980	2.2	30	1.00E+10	1.07E+13	NA	0.000289	0.000289	0	0	NO	NO
FDD	Deep Demersal Fish	179207	0.0819	0.10	97	65	0.0640	3.0692	25.1	90	1.00E+06	8.05E+12	NA	0.0001	0.0001	0	0	NO	YES
FDC	Deep Small Rockfish	489619	0.0628	0.11	31	77	0.0075	3.2383	12.7	45	6.00E+08	1.17E+09	NA	0.00015	0.00015	0	0	NO	YES
FDO	Deep Large Rockfish	172271	0.0675	0.09	61	90	0.0092	3.2310	12.8	45	2.09E+07	1.84E+09	NA	0.00018	0.0002	0	0	NO	YES
FDF	Small Flatfish	314932	0.3507	0.23	47	19	0.0066	3.1410	3.8	195	9.25E+07	9.88E+08	NA	0.0001	0.0001	0	0	NO	YES
FDE	Shallow Piscivorous Fish	60181	0.6221	0.06	56	18	0.0105	3.0267	3.2	35	3.91E+11	2.42E+15	NA	0.0002	0.0002	8.00E-11	8.00E-11	NO	NO
FDM	Nearshore Fish	685808	0.3200	0.24	35	13	0.0030	3.0739	2.2	30	1.00E+10	4.85E+13	NA	0.0001	0.0001	1.00E-19	1.00E-19	NO	NO
FDS	Midw ater Rockfish	252991	0.1384	0.19	50	59	0.0195	2.9276	18.6	141	2.37E+07	3.83E+09	NA	0	0.00002	0	0	NO	YES
FDB	Small Shallow Rockfish	48221	0.1659	0.13	28	45	0.0108	3.1108	4.6	73	7.25E+07	1.82E+10	NA	0.000001	0.000001	1.00E-12	0	NO	YES
SHR	Shallow Large Rockfish	62044	0.2018	0.14	47	41	0.0245	2.7311	6.3	58	1.00E+07	2.63E+08	NA	0.000015	0.000015	0	0	NO	YES
FMM	Hake	3698000	0.2300	0.33	91	23	0.0204	2.7376	3.5	70	3.00E+08	2.11E+10	NA	0.000001	0.000001	0	0	NO	NO
FMN	Sablefish	156676	0.0700	0.23	78	85	0.0024	3.3469	5.0	360	2.50E+06	9.42E+09	NA	0.000001	0.000001	1.00E-10	1.00E-14	NO	YES
FVD	Large Piscivorous Flatfish	113779	0.2068	0.14	92	29	0.0044	3.2478	7.0	180	1.00E+07	2.82E+08	NA	0.000175	0.000175	0	0	NO	YES
FVS	Large Demersal Predators	34744	0.2505	0.14	108	20	0.0031	3.3021	3.9	90	5.50E+06	1.17E+08	NA	0.000001	0.000001	1.00E-10	1.00E-12	NO	YES
FVT	Albacore	1310	0.3000	0.10	140	10	0.0453	2.7900	5.0	30	1.90E+05	1.98E+08	NA	0.00015	0.00015	1.00E-10	1.00E-10	NO	NO
FPL	Large Planktivores	1259290	0.5000	0.29	41	14	0.0035	3.3657	1.5	60	5.00E+09	2.20E+13	NA	0.0002	0.00017	0	0	NO	NO
FPS	Small Planktivores	3736609	0.7546	0.52	20	9	0.0086	2.9982	1.7	60	1.00E+10	5.90E+11	NA	0.0001	0.0001	0	0	NO	NO
FVB	Salmon	37534	0.2700	0.15	153	7	0.0133	3.0000	4.0	350	7.50E+07	1.23E+13	NA	0.00016	0.00016	1.00E-10	1.00E-10	NO	NO
SHD	Large Demersal Sharks	936	0.2000	0.25	202	49	0.0135	3.0000	10.0	360	2.00E+03	6.51E+10	NA	0.00018	0.00018	1.00E-14	1.00E-14	NO	YES
SHB	Small Demersal Sharks	117835	0.1512	0.13	98	49	0.0045	3.0276	31.2	360	2.10E+07	5.04E+12	NA	0.0002	0.0002	1.00E-14	1.00E-14	NO	YES
SHP	Pelagic Sharks	3742	0.1850	0.13	200	15	0.0068	2.9400	9.0	360	5.00E+05	4.77E+11	NA	0.00015	0.00015	1.00E-18	1.00E-18	NO	YES
SSK	Skates and Rays	96239	0.2000	0.05	194	20	0.0044	3.0547	7.5	60	2.00E+07	4.69E+08	NA	0.00017	0.00017	0	0	NO	YES
PIN	Pinnipeds	34587	NA	0.95	350	17	0.0015	3.3745	4.5	330	NA	NA	0.57	0.000001	0.000001	7.00E-09	7.00E-09	NO	NO
REP	Transient orcas	194	NA	0.40	915	50	0.1430	2.4070	13.0	480	NA	NA	0.175	0.0001	0.0001	5.00E-06	7.00E-06	NO	NO
WHB	Baleen w hales	49789	NA	0.22	2007	86	0.5980	2.3380	7.7	375	NA	NA	0.2375	0	0	5.00E-20	5.00E-19	NO	NO
WHT	Toothed Whales	3493	NA	0.11	1343	67	0.4775	2.3561	9.8	448	NA	NA	0.175	0.000002	0.000002	1.00E-06	1.00E-06	NO	NO
WHS	Dolphins/Porpoise	5199	NA	0.59	225	20	0.1430	2.4070	5.8	329	NA	NA	0.2375	0.00005	0.00005	3.00E-08	3.00E-08	NO	NO
WDG	Sea Otter	101	NA	0.71	133	15	1.0000	2.1000	4.0	150	NA	NA	0.475	0.0001	0.0001	6.50E-07	6.50E-07	NO	NO
FVO	Migratory Birds	1534	NA	NA	45	34	12.4650	1.1228	6.2	53	NA	NA	0.2622	0.000005	0.000005	9.00E-10	9.00E-10	NO	NO
SB	Planktivorous Seabirds	41	NA	NA	23	6	7.5982	1.0000	3.0	39	NA	NA	0.3125	0.0001	0.0001	3.00E-08	3.00E-08	NO	NO
SP	Piscivorous Seabirds	1072	NA	NA	67	22	11.8728	1.0380	4.5	32	NA	NA	0.475	0.00001	0.00001	2.00E-08	2.50E-08	NO	NO

Note: 'k' and '*Linf*' are von Bertalanffy grow th parameters, 'a' and 'b' are length-w eight relationship parameters.

Appendix 1: List of Participants

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
André 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) Representative:
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

Others in Attendance
Mike Burner, PFMC
Yvonne deReynier, NMFS West Coast Region
Emma Hodgson, University of Washington
Corey Niles, Washington Department of Fish and Wildlife
Corey Ridings, Ocean Conservancy
Mindi Sheer, NWFSC
John Stein, NWFSC

Appendix 2: Documents reviewed

Primary peer-reviewed documents

1. Fulton, E. A., Link, J. S., Kaplan, I. C., Savina-Rolland, M., Johnson, P., Ainsworth, C., Horne, P., et al. 2011. Lessons in modelling and management of marine ecosystems: the Atlantis experience. Fish and Fisheries, 12: 171–188.

2. Kaplan, I. C., Brown, C. J., Fulton, E. A., Gray, I. A., Field, J. C., and Smith, A. D. 2013. Impacts of depleting forage species in the California Current. Environmental Conservation 40(04): 380 – 393.

3. Kaplan, I.C. and Leonard, J. 2012. From krill to convenience stores: forecasting the economic and ecological effects of fisheries management on the US West Coast. Marine Policy 36: 947–954.

4. Kaplan, I.C., Horne, P.J. and Levin, P.S. 2012. Screening California Current fishery management scenarios using the Atlantis end-to-end ecosystem model. Progress In Oceanography 102: 5–18.

5. Isaac C. Kaplan, Daniel S. Holland, and Elizabeth A. Fulton. 2014. Finding the accelerator and brake in an individual quota fishery: linking ecology, economics, and fleet dynamics of US West Coast trawl fisheries. ICES Journal of Marine Science, 71(2), 308–319.

6. Kaplan, I.C., Levin, P.S., Burden, M. and Fulton, E.A. 2010. Fishing catch shares in the face of global change: a framework for integrating cumulative impacts and single species management. Can. J. Fish. and Aquat. Sci. 67, 1968–1982.

7. Kaplan, I. C. Gray, I. A. and P. S. Levin. 2012. Cumulative impacts of fisheries in the California Current. Fish and Fisheries, 14: 515–527.

Primary technical documents

1. Horne, P., Kaplan, I.C., Marshall, K., Levin, P. S., and Fulton, E.A., 2010. Central California Atlantis Model (CCAM): Design and Parameterization. US Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-104.

2. Kaplan I.C, K.N. Marshall, E. Hodgson, L. Koehn. Update for 2014 Methodology Review: Ongoing Revisions to the Spatially Explicit Atlantis Ecosystem Model of the California Current (Document developed for Methodology review)

3. Dufault, A., Marshall, K.M., and Kaplan, I.C. 2009. A Synthesis of Diets and Trophic Overlap of Marine Species in the California Current. U.S. Dept. Commer., NOAA Technical Memorandum NMFSNWFSC-103.

Additional Atlantis documents

1. Brand, E. J., I. C. Kaplan, C. J. Harvey, P. S. Levin, E. A. Fulton, A. J. Hermann, and J. C. Field. 2007. A spatially explicit ecosystem model of the California Current's food web and oceanography. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-84.

2. Fulton, E. A. 2004. Biogeochemical marine ecosystem models II: The effect of physiological detail on model performance. Ecol. Model. 173:371–406.

3. Fulton, E.A., Smith A.D.M., Smith D.C., Johnson P. 2014. An Integrated Approach Is Needed for Ecosystem Based Fisheries Management: Insights from Ecosystem-Level Management Strategy Evaluation. PLoSONE9(1):e84242. doi:10.1371/journal.pone.0084242

Background on ecosystem modeling

1. FAO. 2008. Best practices in ecosystem modelling for informing an ecosystem approach to fisheries. FAO Fisheries Technical Guidelines for Responsible Fisheries. No. 4, Suppl. 2, Add. 1. Rome, FAO. 78p.

2. Levin P.S., Fogarty M.J., Murawski S.A., Fluharty D. 2009. Integrated ecosystem assessments: Developing the scientific basis for ecosystem-based management of the ocean. PLoS Biol 7(1): e1000014. doi:10.1371/journal.pbio.1000014.

3. Link J. S., T.F. Ihde, C.J. Harvey, S.K. Gaichas, J.C. Field, J.K.T. Brodziak, H.M. Townsend, R.M. Peterman. 2012. Progress in Oceanography 102 (2012) 102–114.

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 3: 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.

APPENDIX 3 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.

Appendix 4: 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)