Advances in linking data to models to understand ecosystem dynamics under climate change in the California Current

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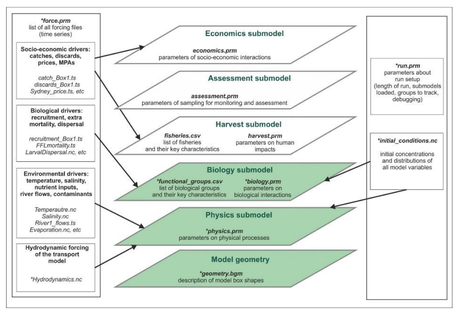
An Atlantis Ecosystem Model for the California Current

Atlantis is an end-to-end ecosystem model that considers the physical, biological, socio-economic components of marine social-ecological systems. It is designed to assist in Management Strategy Evaluation (MSE) and to assess approaches to Ecosystem-Based Fishery Management (EBFM). However, given their complexity, Atlantis models can be difficult to parameterize. In the California Current implementation of Atlantis, we have made several improvements in how the model represents the reality of the California Current Ecosystem by informing model parameters with data.



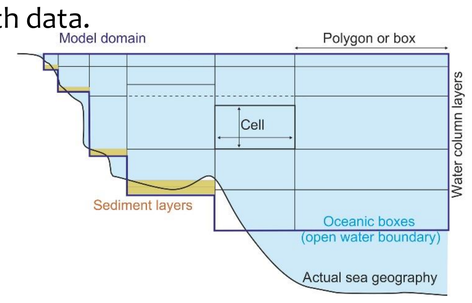


Figure 1. (left) A schematic representation of how different input parameters and files interact in Atlantis. (right) A cross-sectional representation of Atlantis' box-model setup, where the study region is partitioned into polygons with multiple depth layers. Simulated biophysical and socioeconomic process occur among and between these multi-layered polygons. Figures reprinted from Audzijonyte et al. 2019.

Objectives

The goal of this version of the California Current Atlantis Ecosystem Model is to **understand the effect of future climate change (and climate-adaptive management) on California Current species and fisheries.** To accomplish this, we want to:

- Improve biological representation of California Current species through translation of a comprehensive diet database
- Use globally-available oceanographic products to simulate the California Current under projected climate change
- Improve realism in the geographical and behavioral representation of fishing fleets through incorporation of observed spatial fishing dynamics for key California Current fisheries

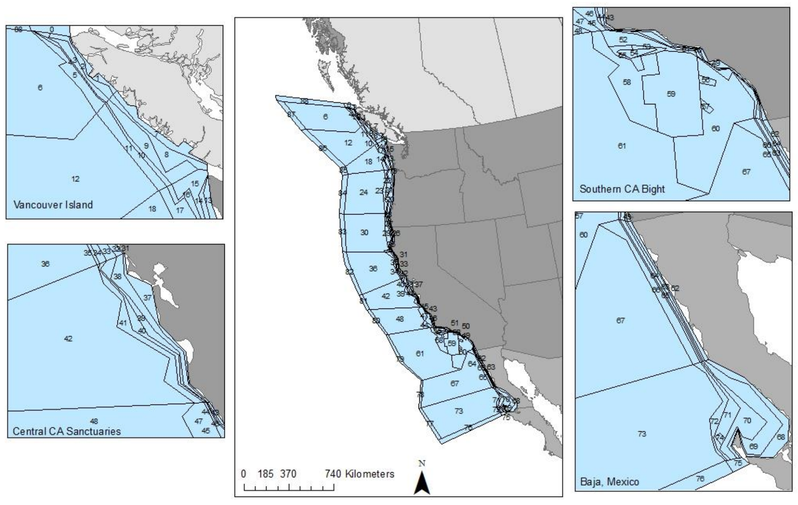
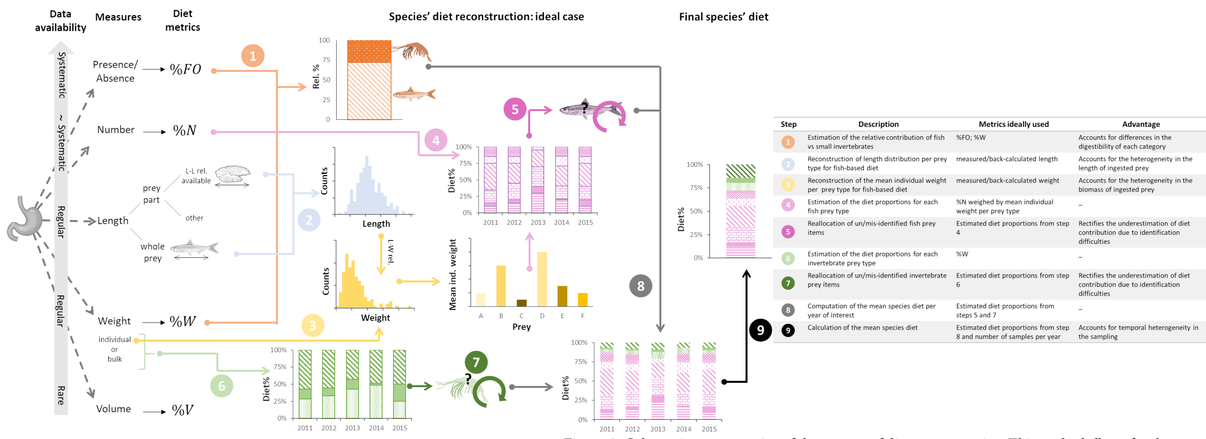


Figure 2. Map of the California Current Atlantis model. The box geometry includes waters out to 200 nautical miles, but was specifically designed to capture higher resolution dynamics along the continental shelf and slope, which is why there is a much higher density of boxes along the coast. Figure from Marshall et al. (2017).

Who eats Whom? A California Current Diet Database

One of the most difficult biological processes to represent in ecosystem models is a realistic trophic web. In Atlantis, trophic interactions are partially driven by a diet network (or, availability) matrix that defines who eats whom and at what intensity. Our new parameterization notably incorporates a newly developed California Current Trophic Database (Bizzarro et al. 2022).



Step	Description	Metrics ideally used	Advantage
1	Estimation of the relative contribution of fish vs small invertebrates	%FO; %W	Accounts for differences in the digestibility of each category
2	Reconstruction of length distribution per prey type for fish-based diet	measured/back-calculated length	Accounts for the heterogeneity in the length of ingested prey
3	Reconstruction of the mean individual weight per prey type for fish-based diet	measured/back-calculated weight	Accounts for the heterogeneity in the biomass of ingested prey
4	Estimation of the diet proportions for each fish prey type	%N weighed by mean individual weight per prey type	–
5	Reallocation of un/mis-identified fish prey items	Estimated diet proportions from step 4	Rectifies the underestimation of diet contribution due to identification difficulties
6	Estimation of the diet proportions for each invertebrate prey type	%W	–
7	Reallocation of un/mis-identified invertebrate prey items	Estimated diet proportions from step 6	Rectifies the underestimation of diet contribution due to identification difficulties
8	Computation of the mean species diet per year of interest	Estimated diet proportions from steps 5 and 7	–
9	Calculation of the mean species diet	Estimated diet proportions from step 8 and number of samples per year	Accounts for temporal heterogeneity in the sampling

Figure 4. Schematic representation of the process of diet reconstruction. This method allows for the translation of observed diet data (e.g., stomach contents) into parameterized diets for Atlantis functional groups. More information on the California Current Trophic Database can be found here: https://oceanview.pfeg.noaa.gov/cctd/.

Spatial Fishing Data Informs Atlantis Fishing Fleets

Atlantis allows for fishing fleets with limited spatial ranges. For the California Current model, we used observed spatial fishing data to define port-specific fishing fleets.

Fishing "footprints" were derived from logbook data that record spatially-explicit catch information, which we represent as kernel density surfaces. To translate these onto the Atlantis geometry, we:

- *Overlay* footprints on Atlantis polygons (see figure)
- *Extract* the area of each Atlantis polygon that overlaps with the footprint
- *Calculate* the proportion of the Atlantis polygon covered by the footprint

This calculation constitutes the value Atlantis needs (i.e., *the proportion of Atlantis polygon X that is accessible to fleet Y*), and allows us to accurately represent the extent of real-world fishing footprints within Atlantis.

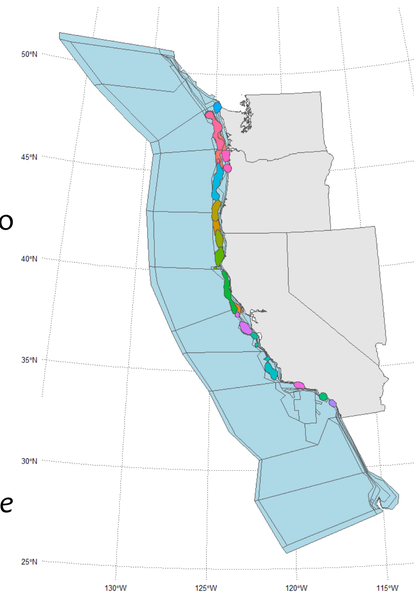
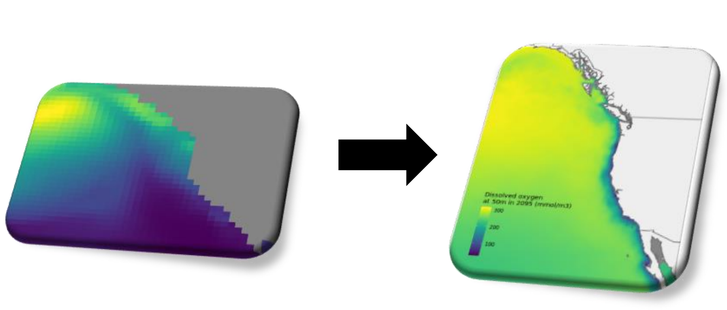


Figure 5. Overlap between Atlantis polygons and port-specific fishing footprints. Fishing footprints are derived from logbook data and represent fishing zones averaged over the period 2011-2019. The footprints shown here are for groundfish fisheries, but we adopted a similar approach for coastal pelagic fisheries.

Climate Models Drive Species Distributions

Atlantis is forced by hydrodynamics, ocean temperature, and salinity time series. To represent climate change in the California Current, we use a statistical downscaling approach to translate coarse-scale Earth System Model projections from the Coupled Model Intercomparison Project Phase 5 (CMIP5) ensemble on to a finer-scale grid based on the GLobal Ocean ReanalYsis and Simulation (GLORYS) grid from Copernicus Marine Environment Monitoring Service (CMEMS). The downscaled oceanography is then translated into Atlantis time series of temperature, salinity, and hydrodynamics in three dimensions (time step, Atlantis polygon, and depth layer).



We also use this downscaled oceanography to fit and project species distribution models (SDMs) based on observed species' occurrences from fisheries-independent surveys.

SDMs are translated to Atlantis' polygon geometry to allow species distributions to evolve in time in response to projected climate change.

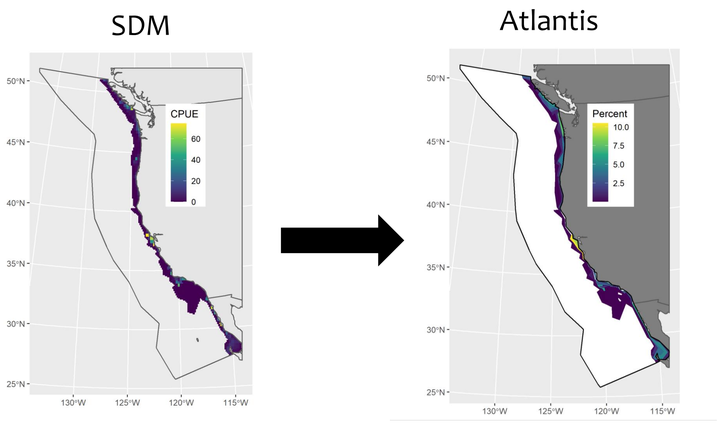
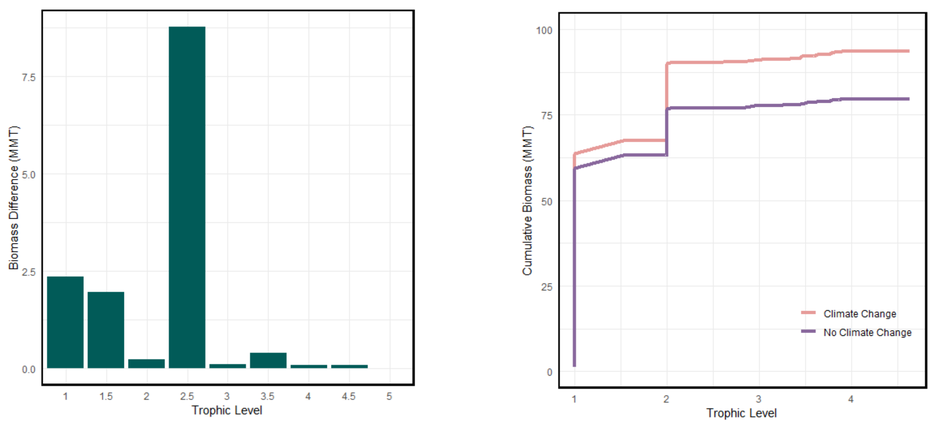


Figure 3. To parameterize species distributions in Atlantis, we translate from spatial maps in species distribution model outputs (left) to proportional distributions of biomass per box (right).

Effect of Climate Change on California Current Species

These data-driven updates to the California Current Atlantis Ecosystem Model allow us to explore the implications of projected climate change for key species and fishing communities within a fully resolved and interconnected ecosystem model. As an initial test of these updates, we compared a scenario that include climate change in forcing files and SDMs to a scenario with static species distributions and mean climate.

- **63 out of 87 Atlantis species groups had greater biomass at the end of the projection under climate change than in a non-climate change scenario**
- **The climate change scenario resulted in approximately 18 percent greater overall production**
- **Groups with the greatest gain under climate change included phytoplankton, zooplankton, and planktivorous fish**



These are preliminary results as we continue to calibrate the Atlantis model.

Future work will further refine bioenergetic and thermal niche constraints, explore the effect of climate change on projected fisheries catch, and test the efficacy of a variety of fisheries management strategies. For more information about the effects of climate change in the California Current ecosystem model, make sure to attend Sessions 8 and 15 on 20 April.

Figure 6. Contrasting final biomass by trophic level across all 87 functional groups in the California Current Atlantis model, under scenarios with and without climate change, shown as (left) difference in biomass at each trophic level and (right) cumulatively across trophic levels.

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