Gulf of Alaska Climate Integrated Modeling (GOA-CLIM) Project

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The Gulf of Alaska Climate Integrated Modeling (GOA-CLIM) project is an integrated research program that is closely aligned with the Alaska Climate Integrated Modeling (ACLIM) project. This is a multiphase project where the first phase focused on (1) the development, calibration, and skill testing of an end-to-end Atlantis model for the GOA, (2) development of two Ecopath with Ecosim models splitting the GOA into eastern and western portions, (3) refinement of other multispecies models (e.g., Rceattle), (4) synthesizing datasets for the ensemble of models, (5) linking continuous Regional Ocean Modeling System (ROMS) simulations from the present to 2100 to ecosystem and stock assessment models, and (6) evaluating the performance of management strategies under different environmental scenarios (e.g., system level optimum yield). The main goals of the current phase, phase two, are to refine the ensemble of environment coupled models (e.g., refine modeling of top predators, refine the fleet structure in Atlantis) and develop a multispecies size spectrum model to include in the ensemble. The ensemble of models will be used to evaluate the performance of harvest control rules and ecosystem caps and will be linked to regional economic models to assess the impacts of environmental scenarios and fisheries management measures on GOA communities.

The purpose of this document is to provide a brief description of the ensemble of component models that have been developed or are under development, along with highlights of their model assumptions. The models include Atlantis, Ecopath with Ecosim/Rpath, Rceattle (as a multi-species model and as an extended single-species stock assessment model), a bioeconomics community impact model linked to Rceattle, and a multispecies size spectrum model. Though Rceattle has utility as a production assessment model in single-species form, the use of all of the GOA-CLIM models for projecting under environmental and harvest scenarios is intended for exploring long-term outcomes and corresponding uncertainty.

Atlantis is a deterministic ecosystem simulation model that comprises physical, food web, and fishery sub-models. The GOA Atlantis model spans the GOA shelf from 170W (NMFS area 610) to Northern BC, using 109 depth-stratified spatial polygons. The physical sub-model is forced using temperature, salinity, and currents output from ROMS for the Northeast Pacific, available for the historical period (1980-2020) and as three CO_2 emission scenarios through 2100. The food web sub-model captures 78 functional groups, including age-structured fish populations representing the FMP groundfish stocks and stock complexes, as well as key predators such as Steller sea lions and seabirds. Model functional groups are connected via trophic interactions, and recruitment of fish populations follow Beverton-Holt stock-recruit relationships. The fishery sub-model allows modeling species-specific fishing mortality, either as fixed rates or as determined dynamically by harvest control rules. Various harvest control rule forms can be reproduced, including the ramped fishing mortality (status quo) control rules used for GOA groundfish, as well as alternative formulations. A notable feature is the ability to model the Optimum Yield cap on FMP groundfish removals, allowing users to evaluate different cap values and species prioritization schemes when rescaling harvest specifications if aggregate projected catch exceeds the cap.

This functionality can be used in addition to the single-species harvest control rules. The key strengths of Atlantis are the explicit modeling of species interactions and the links between environmental variables and ecological processes. Owing to these features, Atlantis can be used to explore the ecosystem-level effects of management strategies under environmental variability in a simulation setting. Atlantis is a deterministic model capturing many species and processes; therefore, producing estimates of uncertaintyis difficult. Results from Atlantis GOA are best interpreted in a relative sense, for example when comparing between scenarios. Atlantis is not suitable for producing precise short-term forecasts.

The western and eastern GOA Ecopath models are climate-enhanced, mass-balanced, food web models that can be used to describe and project species interactions, biomass, fishing mortality, and annual catch quotas in the GOA under multiple climate and harvest scenarios. The GOA models describe the marine ecology found from 0-1000m, with an east/west divide at 147°W. The model is forced using temperature and primary production outputs from the NE Pacific ROMS (through 2020) and projections through 2100. The models include trophic dynamics of 86/87 (eastern/western GOA) species groups ranging from detritus and primary production up through the food web to seabirds and marine mammals, with a focus on groundfish and forage fish. Nine fish species have full age-structure accounting: Pacific herring, Pacific halibut, arrowtooth flounder, Pacific cod, walleye pollock, rex sole, flathead sole, Pacific ocean perch, and sablefish. For these species, monthly cohorts (numbers-at-age, weight-at-age, maturity, and therefore spawning biomass (SSB)) are tracked. Each monthly cohort is subject to density-dependent predation mortality, with the magnitude of density dependence set by its "vulnerability" parameter (vulnerability to predation) and density-dependent foraging (set by the vulnerability of its prey). The emergent result, for any given age above month-0 specified as the recruitment age, is a density-dependent relationship between spawning stock biomass and recruits of any given age. The remaining species do not have age-structure, so a Tier 5 HCR proxy is used with annual fishing mortality (F) as a function of natural mortality (M) , and total biomass (B) - i.e., surplus production modeling. Annual F is set from a measurement of annual B and the HCR, possibly including observation error. Annual B represents SSB for age-structured species and total biomass for other groups (i.e., "Tier 5" stocks). HCR analyses can inform the biomass and catch of managed species under varying management (and environment) scenarios, as well as the projected biomass of other species in the food web via resulting changes in predator-prey dynamics (prey availability and predation mortality). A resulting strength of the GOA Ecopath models is to inform the broader ecosystem implications of species-specific HCRs based on the models. Although the Ecopath models are not suitable for producing short-term forecasts, various network analyses can be used to describe the resulting community stability, resilience, productivity, balance of trophic guilds, and other ecosystem characteristics resulting from alternative HCRs or other system perturbations, in medium to long-term forecasts.

Rceattle is a single- and multi-species assessment modelling platform developed and applied to walleye pollock, Pacific cod, and arrowtooth flounder in the GOA (Adams et al., 2022). The model is an age-structured assessment model that links species through age- and time-varying predation mortality derived following the predation model underlying multi-species virtual population analysis. The model utilizes bioenergetics and diet information to parameterize climate-specific consumption and the prey preference of predators, respectively. Additionally, apart from time-varying predation mortality, the model is parameterized similarly or exactly the same as the single-species models used for tactical management. It can be run as a single-species model by “turning-off” time-varying predation mortality or as a multi-species model by “turning-on” time-varying predation mortality. The platform was written to be flexible and generalizable and includes code for projections under various harvest control rules, simulation, and management strategy evaluation (MSE). Environmental covariates can be linked to catchability, recruitment, bioenergetic consumption, and residual natural mortality (i.e. mortality not due to predation from species included in the model). Recruitment can be parameterized following either Ricker, Beverton-Holt, or stock-independent recruitment. Therefore, the model can be utilized to quickly evaluate various management frameworks with and without time-varying predation mortality under climate or density dependencies using MSE.

Multispecies size spectrum models (MSSMs) integrate ecological theory and a broad range of data (e.g., biomass estimates, life history parameters, and fishery selectivity) to explore various controls on marine food webs. More specifically, MSSMs relate individual body mass to population- and community-level processes to approximate steady states and simulate changes into the future. The GOA MSSM is based on the source code for the R package called "mizer." The focus of the work is on the demersal fish assemblage, which includes economically and ecologically important species such as arrowtooth flounder, Pacific cod, Pacific halibut, Pacific Ocean perch, sablefish, southern rock sole, and walleye pollock. The MSSM has been calibrated using stock assessment outputs, standardized survey data, and available scientific literature to quantify nonlinear and nonlocal effects on size-based metrics such as biomass density, trophic level, and predation mortality. The model will be used to simulate these metrics under different ecological and fishing scenarios to identify population- and community-level responses to perturbation in a highly variable ecosystem. Results from this work will be used to contextualize results from stock assessment models and inform long-term management of stocks in the Gulf of Alaska.

Economic modeling of the GOA region is an important aspect of the GOA-CLIM project. The goal is to better understand how exogenous shocks such as the environment and fishing impact regional economies. To that end, Rceattle has been linked to a dynamic, multi-regional computable generalized equilibrium (MRCGE) model to evaluate the potential consequences of various environmental and fishing scenarios from a combined social-ecological perspective. The CGE model overcomes the limitations of fixed-price models such as the input-output model and the social accounting matrix model. Catch is an important input of the MRCGE model. Projected catches of walleye pollock, Pacific cod, and arrowtooth flounder from Rceattle model runs are used as initial shocks to the MRCGE model, where the annual price per species is determined within the model. Alaska fisheries are characterized by a large leakage of the benefits from the fisheries through non-Alaska resident labor and fishing capital, as well as heavy reliance on other inputs (such as vessel insurance, vessel and engine repair/replacement) from non-Alaska states, which flow to other states. The MRCGE model accounts for this and includes 10 regions: an at-sea "region" (AT-SEA), six Southwest Alaska (SWAK) boroughs and census areas (BCAs), the rest of Alaska (RAK), the U.S. West Coast (WOC, Washington, Oregon, and California), and the rest of the U.S. (ROUS). The six SWAK BCAs are Aleutians West Census Area (AWCA), Aleutians East Borough (AEB), Lake and Peninsula Borough (LPB), Bristol Bay Borough (BBB), Dillingham Census Area (DCA), and Kodiak Island Borough (KIB). Given this parameterization, the MRCGE model can provide analyses of the impacts of the environmental and fishing scenarios on the economy of Southwest Alaska relative to other regions inside and outside of Alaska, with potential for linking to alternative multi-species models and refining inputs for the Bering Sea and Aleutian Islands region.