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Reading the crystal ball: using multi-species stock-assessment models to predict climate-driven changes to recruitment, mortality, and biological reference points for Bering Sea (USA) fisheries.

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Summary
Climate change is expected to impact marine ecosystems globally, with largest changes anticipated for arctic and sub-arctic ecosystems. We used multi-species stock-assessment models to link climate-driven changes in physical and trophodynamic conditions to recruitment and mortality of three groundfish species (*Gadus chalcogrammus*, *G. macrocephalus*, and *Atheresthes stomias*, herafter pollock, P. cod, and arrowtooth, respectively) in order to distinguish harvest impacts on fish populations from large-scale climate pressures. When we compared model projections under climate scenarios to those under mean historical conditions, we generally found declines in estimated allowable biological catch (ABC) for pollock and P. cod. However, projected declines in ABC were sensitive to model specifications of trophic interactions, specifically the strength of bottom-up or top-down controls. Stock assessment models with predation had the largest projected declines in ABC, whereas single-species models without bottom-up controls on recruitment had the lowest projected changes in ABC. Our work emphasizes the need to evaluate multiple future scenarios and model structures when projecting climate effects on fishery species.

Introduction
Climate change has already begun to impact marine species and the fisheries that rely on them (IPCC 2014, Poloczanska et al. 2013, Cheung et al. 2011), emphasizing the need for fisheries management that is robust to potential climate-driven changes in the distribution and abundance of marine species. Biophysical models that link species behavior, growth, and/or survival to physical and trophic conditions can help evaluate hypotheses regarding climate change effects on species populations. Here we used a climate-specific multispecies stock-assessment model (MSMt; Holsman et al. *in review*) to link climate-driven changes in physical and trophodynamic conditions to recruitment and mortality and estimate recommended harvest rates under various future scenarios.

Materials and Methods
We statistically fit a temperature-specific multispecies stock-assessment model (MSMt) to historical catch, biomass, and food-web data for pollock, P. cod, and arrowtooth from the EBS. We also used a coupled ROMS-NPZ model to produce detailed hindcasts for the period 1970-2012. We then fit a modified Ricker recruit per spawner model to fit MSMt estimates of recruitment and biomass to hindcast-extracted time series from the ROMS-NPZ model. Finally, we used downscaled AR4 A1B IPCC scenario-driven ROMS-NPZ model estimates of temperature, circulation, and zooplankton abundance to project MSMt forward to 2040 to derive a proxy for future allowable biological catch (ABC) harvest recommendations under each scenario (i.e., catch given the fishing rate where fished spawning biomass in the projection period is equal to 40% of the corresponding unfished biomass). Various model configurations included those

where (A) predator and prey interactions were decoupled (i.e., single-species stock assessment) and future recruitment was a function of spawning biomass independent of future conditions, (B) predator and prey interactions influenced natural mortality (i.e., multi-species model), but future recruitment was independent of future conditions, (C) predator and prey interactions were decoupled (i.e., single-species stock assessment) but variability in the spawner-recruit relationship was a function of physical and biological future conditions, (D) predator and prey interactions influenced natural mortality and variability in the spawner-recruit relationship was a function of physical and biological future conditions.

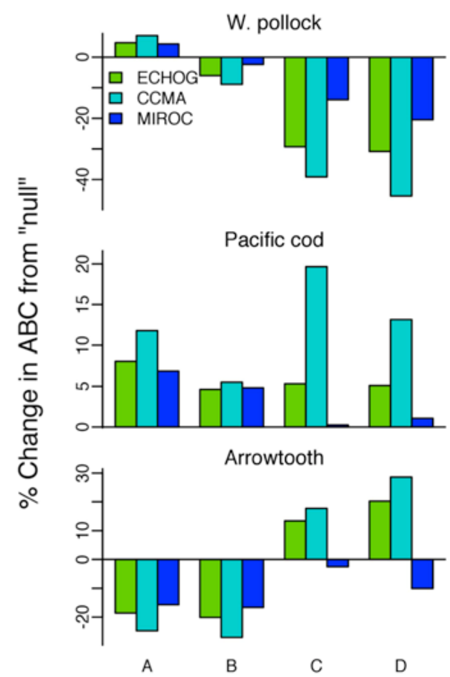

Figure 1. Percent change in recommended harvest (ABC) relative to a "null" future scenario. Projected ABC for the 3 species were evaluated under future projections of the ROMS-NPZ-MSMt models forced by downscaled projections from 3 global climate models including the ECHO-Gv4 GCM (ECHOG; green), the CCMA GCM (light blue), and the MIROC-ESM (MIROC; dark blue). Four MSMt model configurations were used to compare harvest recommendations: models A, B, C, and D.

Results and Discussion

We predict declines in pollock and Pacific cod recruitment under future climate conditions (relative to a "null" future scenario), whereas we predict increases in future arrowtooth recruitment. This pattern is consistent across climate models (i.e., ECHOG, CCMA, MIROC) and configurations of the multi-species model (i.e., both coupled and decoupled predator-prey interactions). That said, including predator and prey interactions in model projections further amplified climate driven declines in recruitment for pollock and pacific cod. Pollock ABC declined 27% and 32% in the single- and multi-species projections of the model when climate conditions were included in recruitment projections (C and D, respectively; Figure 1). This is in contrast to minimal changes in ABC when temperature effects on predation and growth alone were included model projections (A and B, respectively). Unlike the recruitment projections, we project increases in Pacific cod ABC under future conditions, but results are variable and highly dependent on the specific climate scenario. Arrowtooth flounder ABC may increase 9%-12% according to our model projections. Our results emphasize the importance of including predator-prey interactions in analyses of climate driven changes to species abundance and harvest.

References

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