Multispecies model estimates of time-varying natural mortality

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Summary statement:

While warm water temperatures continue to drive high individual predator demand for prey, declines in groundfish biomass combined with increased recruitment has resulted in net declines in estimates of predation mortality for juvenile groundfish in recent years. This pattern indicates continued favorable top-down conditions for juvenile groundfish survival in 2023 through 2024 via predation release.

Description of indicator:

We report trends in age 1 total mortality for walleye pollock (*Gadus chalcogrammus*), P. cod (*Gadus macrocephalus*) and arrowtooth flounder (*Atheresthes stomias*), from the eastern Bering Sea (USA). Total mortality rates are based on residual mortality inputs (M1) and model estimates of annual predation mortality (M2) produced from the multi-species statistical catch-at-age assessment model (known as CEATTLE; Climate-Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics). See Appendix1 of the BSAI pollock stock assessment (Ianelli et al. 2024), Holsman et al. (2016), Holsman and Aydin (2015), Ianelli et al. (2016), and Jurado-Molina et al. (2005) for more information.

Status and trends:

The climate-enhanced multispecies model (CEATTLE) estimates of age 1 natural mortality (i.e., M1+M2) for walleye pollock (hereafter "pollock"), Pacific cod (hereafter "P. cod"), and arrowtooth flounder continue to decline from the 2016 peak mortality. For all three species, age 1 predation mortality rates have remained similar to 2023. At 1.42 yr^{-1}, age 1 mortality estimated by the model was greatest for pollock and lower for P. cod and arrowtooth, with total age 1 natural mortality at around 0.71 and 0.7 yr^{-1} for P. cod and arrowtooth, respectively. 2024 age 1 natural mortality across species is 12% to 38% lower than in 2016 and is near average for pollock (relative to the long-term mean) (Fig. 1). Similarly, P. cod and arrowtooth age 1 mortality are well below the long-term mean.

Patterns in the total biomass of each species consumed by all three predators in the model (typically 1-3 yr old fish) exhibit divergent trends from predation mortality in 2024. Pollock biomass consumed by all predators in the model is above the long-term mean (indicating more pollock were consumed in the last few years than on average), while P. cod consumed is approximately the mean, and arrowtooth consumed is trending downward (Fig. 2).

Factors influencing observed trends

Temporal patterns in natural mortality reflect annually varying changes in predation mortality that primarily impact age 1 fish (and to a lesser degree impact ages 2 and 3 fish in the model). Pollock are primarily consumed by older conspecifics, and pollock cannibalism accounts for 54% (on average) of total age 1 predation mortality, with the exception of the years 2006-2008 when predation by arrowtooth marginally exceeded cannibalism as the largest source of predation mortality of age 1 pollock (Fig. 3). The relative proportion

of age 1 pollock consumed by older pollock increased in 2024 relative to previous years, while the relative proportion consumed by P. cod and arrowtooth declined.

Combined annual predation demand (annual ration) of pollock, P. cod, and arrowtooth flounder in 2024 was 8.22 million tons, down slightly from the 10.68 million t annual average during the warm years and large maturing cohorts of 2014-2016. Walleye pollock represent approximately 76% of the model estimates of combined prey consumed with a long-term average of 5.98 million tons of pollock consumed annually by all three predators in the model. From 2015 - 2019,individual annual rations were above average for all three predator species, driven by anomalously warm water temperatures in the Bering Sea during during those years (Fig. 4). However, cooler temperatures in 2024 relative to the recent warm years has resulted in annual rations at or below the long-term average (Fig. 4).

Implications:

We find evidence of continued declines in predation mortality of age 1 pollock, P. cod and arrowtooth flounder relative to recent high predation years (2014 - 2016). While warm temperatures continue to lead to high metabolic (and energetic) demand of predators, declines in total predator biomass, in particular P. cod, are contributing to an net decrease in total consumption (relative to 2016) and therefore reduced predation rates and mortality in 2022-2024. This pattern indicates continued favorable top-down conditions for juvenile groundfish survival in 2023 through predator release due to declining biomass of groundfish.

Between 1980 and 1993, relatively high natural mortality rates for pollock reflect patterns in combined annual demand for pollock prey by all three predators that was high in the mid 1980's (collectively 9.87 million t per year). The peak in predation mortality of age 1 pollock in 2016 corresponds to warmer than average conditions and higher than average energetic demand of predators combined with the maturation of the large 2010-2012 year classes of pollock and P. cod (collectively with arrowtooth 10.62 million t per year).

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Figures:

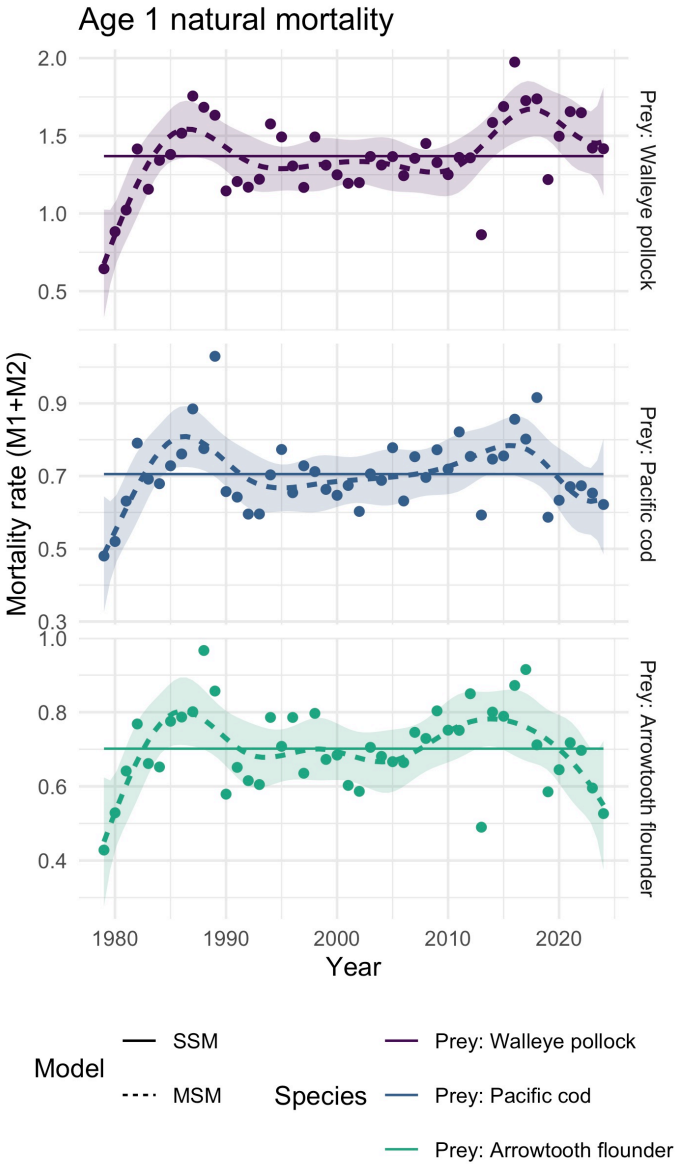

Figure 1: Annual variation in total mortality ($\mathbf{M1_{i1}}+\mathbf{M2_{i1,y}}$) of age 1 pollock (as prey) (a), age 1 P. cod (as prey) (b), and age 1 arrowtooth flounder (as prey) (c) from the single-species models (dashed), and the multi-species models with temperature (points and solid line). Updated from Holsman et al. 2016; more model detail can be found in Appendix1 of the BSAI pollock stock assessment (Ianelli et al. 2024). Solid lines are a 10 y (symmetric) loess polynomial smoother indicating trends in age 1 mortality over time.

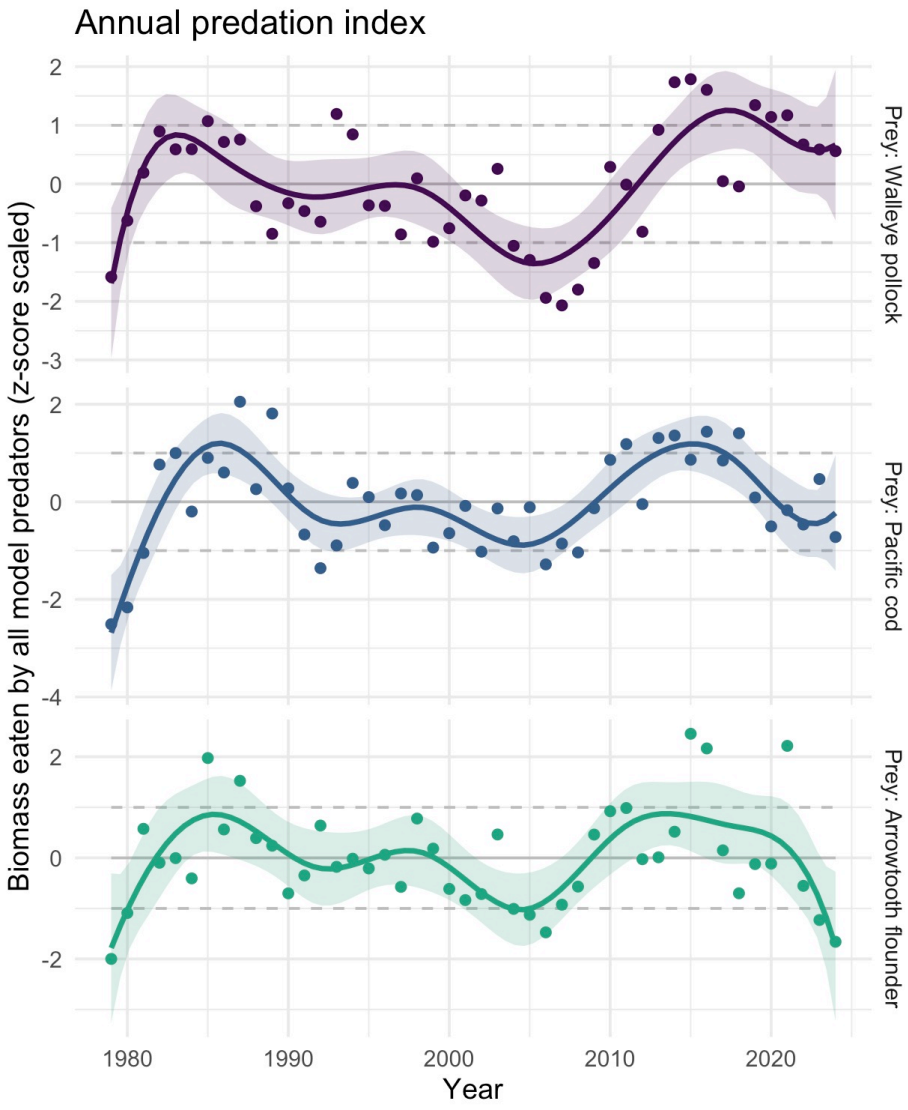

Figure 2: Multispecies estimates of prey species biomass consumed by all predators in the model (points) a) total biomass of walleye pollock consumed by predators annually b) total biomass of P. cod consumed by predators annually, c) total biomass of arrowtooth flounder consumed by predators annually. Gray lines indicate 1979-2024 mean estimates for each species; dashed lines represent 1 standard deviation of the mean. Solid lines are a 10 y (symmetric) loess polynomial smoother indicating trends in biomass consumed over time.

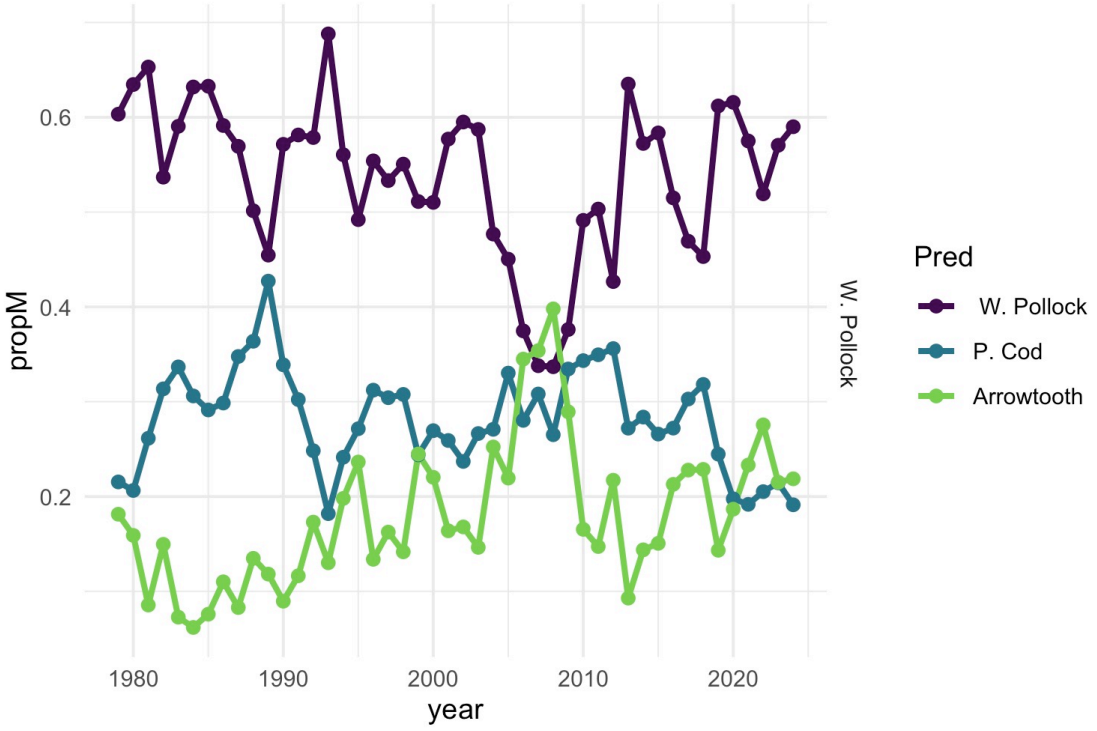

Figure 3: Proportion of total predation mortality for age 1 pollock from pollock (solid), P. cod (dashed), and arrowtooth flounder (dotted) predators across years. Updated from Holsman et al. 2016; more model detail can be found in Appendix1 of the BSAI pollock stock assessment (Ianelli et al. 2024).

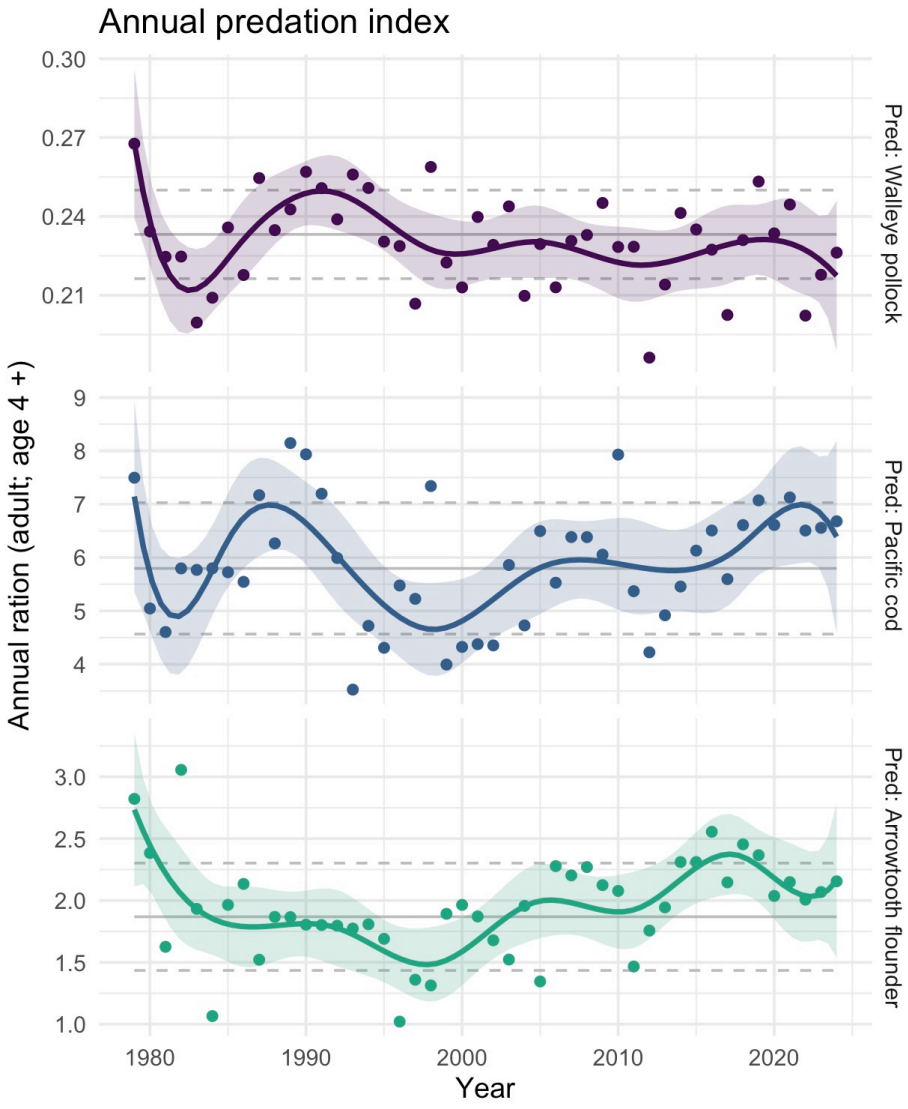

Figure 4: Multispecies estimates of annual ration (kg consumed per indiviudal per year) for adult (age 4 +) predators: a) pollock, b) P. cod, and c) arrowtooth flounder. Gray lines indicate 1979 -2024 mean estimates for each species; dashed lines represent 1 standard deviation of the mean. Solid lines are a 10 y (symmetric) loess polynomial smoother indicating trends in ration over time.