

Multispecies model estimates of time-varying natural mortality

Kirstin K. Holsman, Jim Ianelli, Kerim Aydin, Kalei Shotwell, Kelly Kearney, Ingrid Spies, Steve Barbeaux, and Grant Adams

kirstin.holsman@noaa.gov

Alaska Fisheries Science Center, NOAA, 7600 Sand Point Way N.E., Bld. 4, Seattle, Washington 98115

Last Updated: Nov. 2023

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 2022 through 2023 via predation release.

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 2022. At 1.2 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 0.65 and 0.66 yr^{-1} for P. cod and arrowtooth, respectively. 2023 age 1 natural mortality across species is 11% to 39% 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 2023. Pollock and P. cod biomass consumed by all predators in the model is trending upward (indicated more pollock and P. cod were consumed this year than in previous years), while 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 59% (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 ~~and arrowtooth~~ increased ~~again~~ in 2023 relative to previous years, while the relative proportion consumed by P. cod and arrowtooth declined ~~slightly~~.

Combined annual predation demand (annual ration) of pollock, P. cod, and arrowtooth flounder in 2023 was 9.26 million tons, down slightly from the 9.99 million t annual average during the warm years and large maturing cohorts of 2014-2016. Walleye pollock represent approximately 77% of the model estimates of combined prey consumed with a long-term average of 5.73 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 2023 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 2021-2023. This pattern indicates continued favorable top-down conditions for juvenile groundfish survival in 2022 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 highest in the mid 1980's (collectively 9.24 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 10.07 million t per year).

Description of index:

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 Appendix 1 of the BSAI pollock stock assessment (Ianelli et al. 2023), Holsman et al. (2016), Holsman and Aydin (2015), Ianelli et al. (2016), and Jurado-Molina et al. (2005) for more information.

Literature Cited

- Hermann et al., 2021 A.J. Hermann, K. Kearney, W. Cheng, D. Pilcher, K. Aydin, K.K. Holsman, et al. Coupled modes of projected regional change in the Bering Sea from a dynamically downscaling model under CMIP6 forcing Deep-Sea Res. II (2021), 10.1016/j.dsr2.2021.104974 194 104974.
- Hollowed, K. K. Holsman, A. C. Haynie, A. J. Hermann, A. E. Punt, K. Y. Aydin, J. N. Ianelli, S. Kasperski, W. Cheng, A. Faig, K. Kearney, J. C. P. Reum, P. D. Spencer, I. Spies, W. J. Stockhausen, C. S. Szuwalski, G. Whitehouse, and T. K. Wilderbuer. Integrated modeling to evaluate climate change impacts on coupled social-ecological systems in Alaska. *Frontiers in Marine Science*, 6(January):1–18, 2020. DOI: 10.3389/fmars.2019.00775.
- Holsman, KK, J Ianelli, K Aydin, AE Punt, EA Moffitt (2016). Comparative biological reference points estimated from temperature-specific multispecies and single species stock assessment models. *Deep Sea Res II* 134:360-378.
- Holsman, KK and K Aydin. (2015). Comparative methods for evaluating climate change impacts on the foraging ecology of Alaskan groundfish. *Mar Ecol Prog Ser* 521:217-235 10.3354/meps11102
- Ianelli, J KK Holsman, AE Punt, K Aydin (2016). Multi-model inference for incorporating trophic and climate uncertainty into stock assessment estimates of fishery biological reference points. *Deep Sea Res II*. 134: 379-389 DOI: 10.1016/j.dsr2.2015.04.002
- Holsman, K.K., A. Haynie, A. Hollowed, J. Reum, K. Aydin, A. Hermann, W. Cheng, A. Faig, J. Ianelli, K. Kearney, A. Punt. (2020) Ecosystem-based fisheries management forestalls climate-driven collapse. *Nature Communications*. DOI:10.1038/s41467-020-18300-3
- Ianelli, J. N., et al.. Chapter 1: (2023) Assessment of the walleye pollock stock in the Eastern Bering Sea. In *Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions*, Alaska Fisheries Science Center, National Marine Fisheries Service, Anchorage, AK.

Jurado-Molina, J, P Livingston, J Ianelli (2005) Incorporating predation interactions in a statistical catch-at-age model for a predator-prey system in the eastern Bering Sea. *Can J Fish Aquat Sci* 62(8):1865–1873.

Kearney, K, A. Hermann, W. Cheng, I. Ortiz, and K. Aydin. A coupled pelagic benthic-sympagic biogeochemical model for the Bering Sea: documentation and validation of the BESTNPZ model (v2019.08.23) within a high resolution regional ocean model. *Geoscientific Model Development*, 13 (2):597–650, 2020. DOI: 10.5194/gmd13-597-2020.

Spencer, P., Holsman, K, Zador, S., Bond, N., Mueter, F., Hollowed, A., Ianelli, J. (2016). Modelling spatially dependent predation mortality of eastern Bering Sea walleye pollock, and its implications for stock dynamics under future climate scenarios. *ICES Journal of Marine Science*.

Zador, S, Aydin, K. and Cope, J. 2011. Fine-scale analysis of arrowtooth flounder (*Atheresthes stomias*) catch-per-unit-effort reveals spatial trends in abundance. *Marine Ecology Progress Series*, 438:229–239.

Figures:

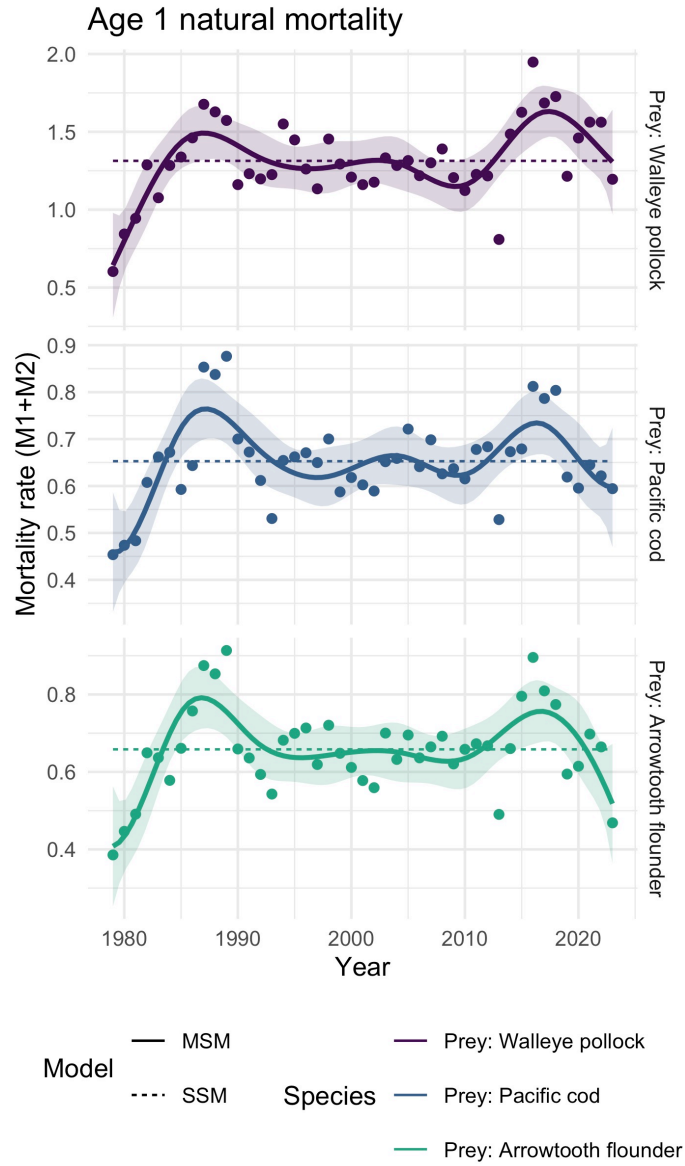


Figure 1: Annual variation in total mortality ($M_{1,i1} + M_{2,i1,y}$) of age 1 pollock (as prey) (a), age 1 P. cod (as prey) (b), and age 1 arrowtooth flounder (as prey) (c) from the single-species models (dashed), and the multi-species models with temperature (points). Updated from Holsman et al. 2016; more model detail can be found in Appendix1 of the BSAI pollock stock assessment (Ianelli et al. 2023). Solid lines are a 10 y (symmetric) loess polynomial smoother indicating trends in age 1 mortality over time.

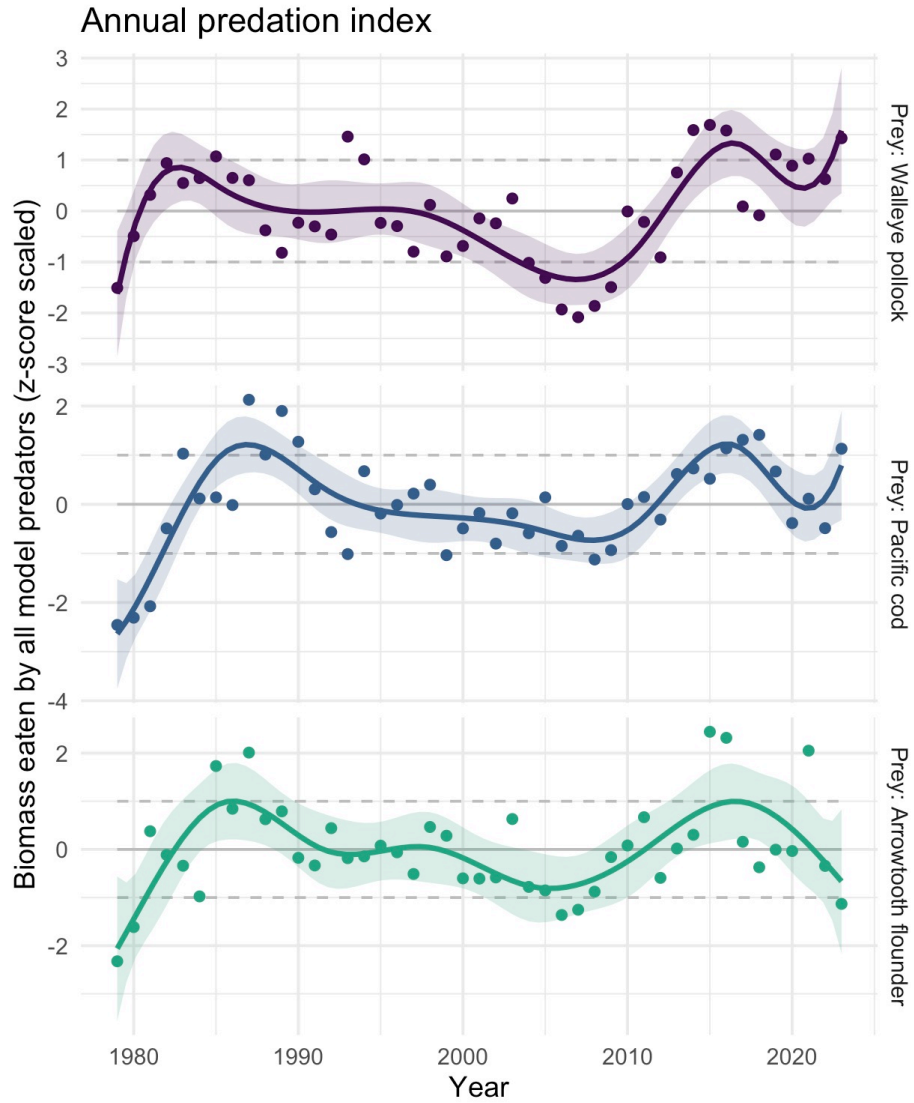


Figure 2: Multispecies estimates of prey species biomass consumed by all predators in the model (points) a) total biomass of walleye pollock consumed by predators annually b) total biomass of P. cod consumed by predators annually, c) total biomass of arrowtooth flounder consumed by predators annually. Gray lines indicate 1979-2023 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.

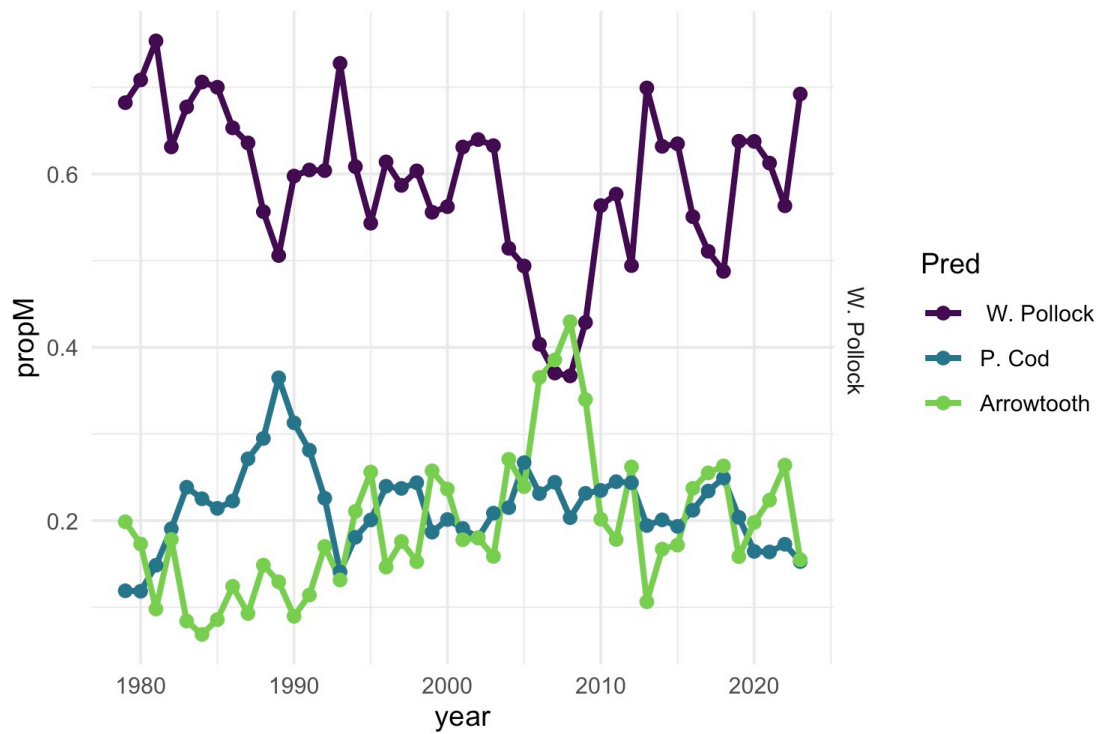


Figure 3: Proportion of total predation mortality for age 1 pollock from pollock (solid), P. cod (dashed), and arrowtooth flounder (dotted) predators across years. Updated from Holsman et al. 2016; more model detail can be found in Appendix1 of the BSAI pollock stock assessment (Ianelli et al. 2023).

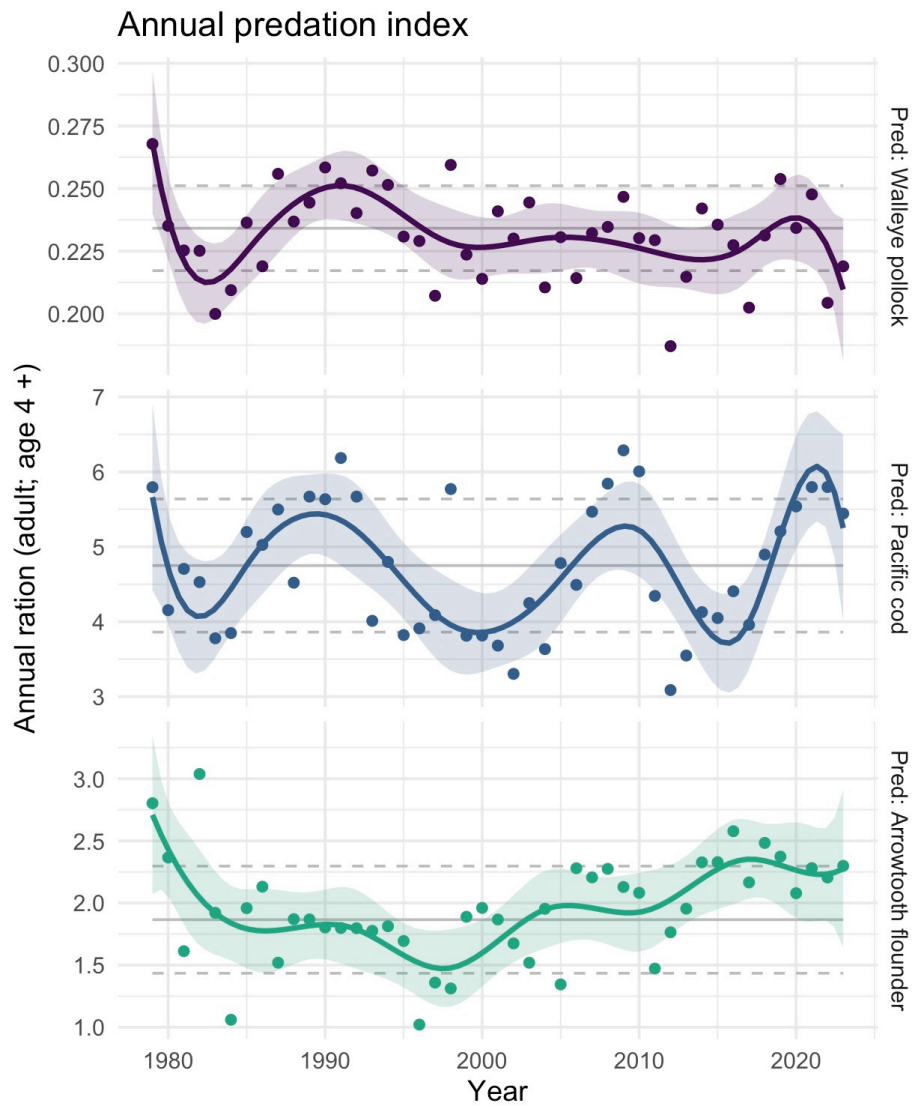


Figure 4: Multispecies estimates of annual ration (kg consumed per individual per year) for adult (age 4 +) predators: a) pollock, b) P. cod, and c) arrowtooth flounder. Gray lines indicate 1979 -2023 mean estimates for each species; dashed lines represent 1 standard deviation of the mean. Solid lines are a 10 y (symmetric) loess polynomial smoother indicating trends in ration over time.