Large copepod abundance (sample-based and modeled) as an indicator of pollock recruitment to age-3 in the southeastern Bering Sea

**Contributed by**: Ellen Yasumiishi, Lisa Eisner, David Kimmel

**Contact**: Ellen Yasumiishi

**Address**: AFSC, 17109 Point Lena Loop Road, Juneau, AK 99801 ellen.yasumiishi@noaa.gov

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Body of contribution:

**Description of indicator**: Interannual variations in large copepod abundance during the age-0 life stage were compared to age-3 walleye pollock (*Gadus* *chalcogrammus*) abundance (billions of fish) for the 2002-2018 year classes on the southeastern Bering Sea shelf, south of 60°N, < 200 m bathymetry (Eisner et al. 2020). The large copepod index sums the abundances of *Calanus marshallae/glacialis* (copepodite stage 3 (C3)-adult), *Neocalanus* spp. (C3-adult), and *Metridia pacifica* (C4-adult), taxa typically important in age 0 pollock diets (Coyle et al. 2011). Zooplankton samples were collected with oblique bongo tows over the water column using 60 cm, 505 µm mesh nets for 2002-2011, and 20 cm, 153 µm mesh or 60 cm, 505 µm nets, depending on taxa and stage for 2012-2018. Data were collected on the Bering Arctic Subarctic Integrated Survey (BASIS) fishery oceanography surveys and along the 70 misobath during mid-August to late September, for four warm years (2002-2005) followed by one average (2006), six cold (2007-2012), four warm (2014-2016, 2018) and an average year (2017, 70 m isobath only) using methods in Eisner et al. (2014). Zooplankton data were not available for 2013. Age-3 pollock abundance was obtained from the stock assessment report for the 2002-2016 year classes (Ianelli et al., 2019). Two estimates of large copepod abundances were calculated, the first using means among stations (sample-based), and the second using the means estimated from the geostatistical model, Vector Autoregressive Spatial Temporal (VAST) package version 9.4.0 (Thorson et al., 2016a, b; Thorson and Barnett, 2017). We specified 30 knots, a log normal distribution, and the delta link function between probability or encounter and positive catch rate in VAST.

**Status and trends**: Positive significant linear relationships were found between BASIS sample-based mean abundances, BASIS VAST-modeled mean abundances, and sample-based mean abundances from the 70 m isobath surveys of large copepods collected during the age-0 stage of pollock and stock assessment estimates of age-3 pollock for the 2002-20155 year classes (Figure 1). For the BASIS survey stations, the stronger relationship of age-3 pollock with the large copepod index using the VAST model compared to observed means among stations (*R*2 = 0.720 vs *R*2= 0.43) appeared to be partially due to the VAST model filling in data for survey area missed in some years (e.g., 2008).

Fitted means and standard errors of the age 3 pollock abundances were estimated from the linear regression model using large copepod estimates from the BASIS VAST model and compared to the pollock stock assessment estimates from Ianelli et al. (2019) (Figure 2). Using the linear regression model relating copepods to age-3 pollock for the 2002-2016 year classes, the VAST copepod estimates in 2018 (5321 #/m2) predicts below average abundance of age-3 pollock in 2021 (3959 million, SE=642 million) for the 2018 year class. For data collected from the 70m isobath, the large copepod index from 2017 predicts relatively higher recruitment of Pollock to age-3 in 2020 than from the 2018 year class that will recruit to age-3 in 2021. However, the low values of the copepod indices predict relatively low recruitment to age-3 for the 2017 and 2018 year classes of pollock.

**Factors influencing observed trends**: Increases in sea ice extent and duration were associated with increases in large zooplankton abundances on the shelf (Eisner et al., 2014, 2015, 2020), increases in large copepods and euphausiids in pollock diets (Coyle et al., 2011) and increases in age-0 pollock lipid content (Heintz et al., 2013). The increases in sea ice and associated ice algae and phytoplankton may provide an early food source for large crustacean zooplankton reproduction and growth (Baer and Napp 2003; Hunt et al., 2011). These large zooplankton taxa contain high lipid concentrations (especially in cold, high ice years) which in turn increases the lipid content in their predators such as age-0 pollock and other fish that forage on these taxa. Increases in energy density (lipids) in age-0 pollock allow them to survive their first winter (a time of high mortality) and eventually recruit into the fishery. Accordingly, a strong relationship has been shown for energy density in age-0 fish and age-3 pollock abundance (Heintz et al., 2013).

**Implications**: Our results suggest low availability of large copepod prey for age-0 pollock during the first year of life in 2017 and 2018. These conditions may not be favorable for age-0 pollock overwinter survival and recruitment to age 3. Information from the 70 m isobaths survey may be useful in years of no BASIS survey in the southeast Bering Sea. If the relationship between large copepods and age 3 pollock remains significant in our analysis, the index can be used to predict the recruitment of pollock three years in advance of recruiting to age 3, from zooplankton data collected three years prior. This relationship also provides further support for the revised oscillating control hypothesis that suggests as the climate warms, reductions in the extent and duration of sea ice could be detrimental large crustacean zooplankton and subsequently to the pollock fishery in the southeastern Bering Sea (Hunt et al., 2011).

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Figure 1. Linear relationships between sample-based (top) from the BASIS and 70 m isobaths surveys and BASIS VAST-model (bottom) estimated mean abundance of large copepods (C+MN, sum of *Calanus marshallae/glacialis, Metridia pacifica* and *Neocalanus* spp.)during the age-0 life stage of pollock, and the estimated abundance (millions) of age-3 pollock from Ianelli et al. (2019) for 2002-2016 year classes. No zooplankton data were available for 2013. The orange dots represents the values for the large copepod index in 2018 and the blue dot for the 2017 year class.

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Figure 2. Fitted means and standard errors of the age-3 pollock abundance estimated from the linear regression models using VAST estimates of large copepods (orange), sample mean abundance of large copepods at the 70m isobaths stations (blue), and means from the pollock stock assessment estimates (black) from Ianelli et al. (2019). Predicted estimates of age-3 pollock (recruited into fishery as age 3’s in 2021) are shown for the 2017 and 2018 year classes.

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