Prey Over Temperature: A Multi-Decadal Assessment of How Euphausiid Availability Buffers Juvenile Pollock Against Marine Heatwaves

Presenter: Jesse F. Lamb, David G. Kimmel, and Lauren A. Rogers

EcoFOCI Program, RACE Division, Alaska Fisheries Science Center, NMFS/NOAA
Contact: jesse.f.lamb@noaa.gov



INTRO

- **High-Value Fishery with Variable Recruitment:** Walleye pollock (*Gadus chalcogrammus*) supports a $1.42B fishery in the North Pacific (2020), with recruitment in the Western Gulf of Alaska (WGOA) heavily tied to early life history survival and oceanographic advection.
- **First Multi-Decadal WGOA Study (2003–2019):** This study evaluates **8 years** of juvenile pollock diet and size data to identify how fish size, sampling time (diel), temperature, and prey availability shape feeding ecology across environmental regimes.

Three Hypotheses:

- **H1 (Fish Size Drivers):** Individual fish size increases with day of year (reflecting age) and high prior sea-surface temperatures, accelerating metabolic growth rates
- **H2 (Prey Quality Drivers):** Consumption of energy-rich prey increases with larger fish size, warmer sea-surface temperatures, and nocturnal foraging
- **H3 (Thermal & Metabolic Demands):** Warmer water elevates metabolism, necessitating increased foraging of lipid-rich prey to sustain juvenile growth and survival during warm anomaly periods

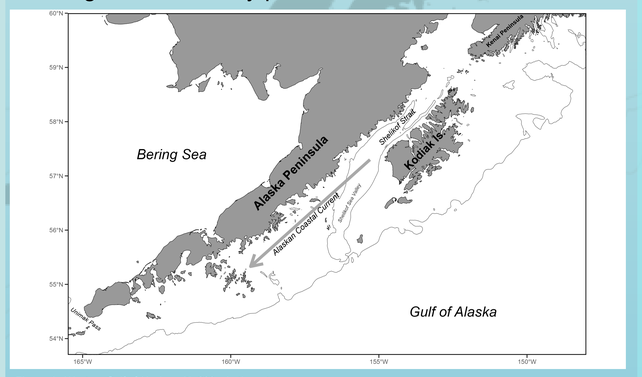
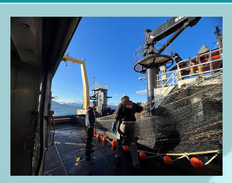


Figure 1. Western Gulf of Alaska, with 200m bathymetry.

METHODS

- **Field Sampling & Data Collection (2003–2019):** Midwater trawling (anchovy net) and zooplankton sampling (Tucker/Bongo nets) were conducted across the WGOA shelf (Unimak Pass to Kodiak Island), paired with in situ CTD profiles and satellite sea surface temperature (SST) metrics.
- **Laboratory Processing & Condition Metrics:** Age-0 pollock (**n = 3,533**) were measured, weighed, and evaluated for body condition (length-weight residuals); stomach contents were identified, enumerated, weighed, and evaluated using Percent Prey-Specific Index of Relative Importance (% PSIRI) and total prey energy content (kJ).
- **Statistical Modeling (LMMs):** Linear mixed-effects models (with random year effects) controlled for sample timing (day of year) and tested how prior 3-month SST, fish lengths and weights, and diel timing (day vs. night) influenced juvenile pollock growth (**model 1**) and diet energy density (**model 2**).











RESULTS

Figure 1. A) Three-month rolling mean satellite sea surface temperature, with the grand mean SST across all years (10.79ºC). B) Mean Seabird Electronics (SBE) sea surface temperature anomaly (B). C) mean SBE bottom temperature anomalies, all in (ºC) for all study years. Error bars represent standard error of the mean.

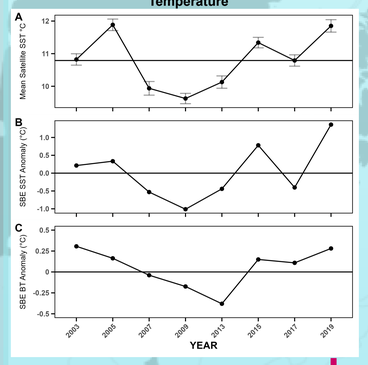


Figure 2. Pollock diet composition expressed as the proportion of total stomach contents (Y-axis, ranging from 0 to 1.0 in 0.25 intervals) across 10 mm size bins (X-axis) by year. Infrequently consumed prey taxa (occurring in <5% of stomachs) were consolidated into the "other" category. Numbers above each bar indicate the number of stomachs examined in that bin.

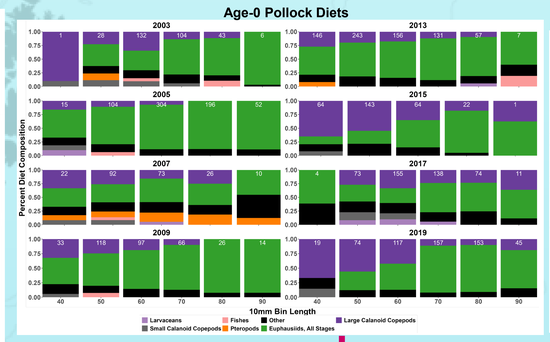
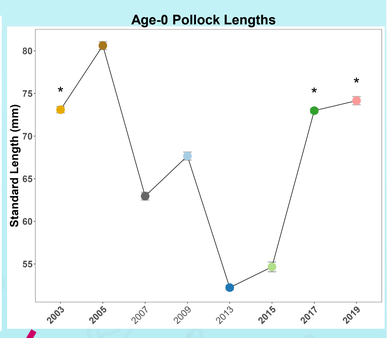


Figure 3. Age-0 pollock yearly mean standard length (mm), with warmer water temperature years represented in bold (x-axis). Error bars represent standard error of the mean. Asterisks denote years that were found not significantly different in mean length from each other.



Year	Thermal Regime	Prey Field	Primary Diet (% PSIRI)	Somatic Growth	Body Condition
2003	Warm	Positive	LCC	Large	Positive
2005	Warm	Positive	Euphausiids	Large	Poor
2007	Cold	Neutral	LCC	Small	Positive
2009	Cold	Positive	Euphausiids	Small	Positive
2013	Cold	Positive	Euphausiids	Very Small	Neutral
2015	MHW	Poor	LCC	Very Small	Poor
2017	Warm	Poor	LCC	Large	Poor
2019	MHW	Positive	Euphausiids	Large	Neutral

Table 1. Summary of environmental conditions, prey field quality, and juvenile fish biological metrics across sampling years (2003–2019).

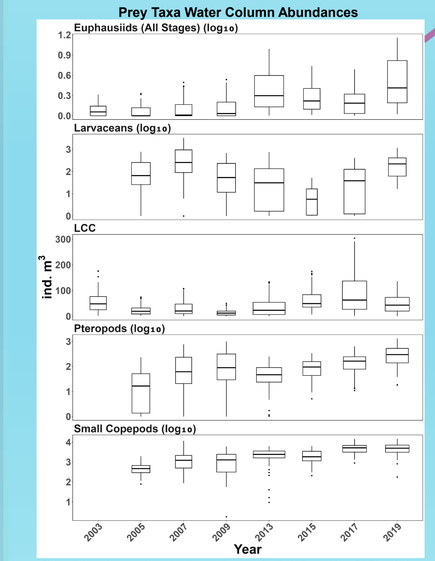


Figure 4. Annual water column abundances of top age-0 pollock diet taxa from PSIRI analysis. 2003 sampling was done with Tucker trawl (333-µm mesh) only.

Temperature: Satellite and in situ measurements revealed distinct warm (>10.5°C) and cool (<10.5°C) periods, marked by a sharp, sustained increase in bottom ocean temperature anomalies after 2013.
Zooplankton: Euphausiids consistently ranked as top prey despite low water column abundance, whereas large calanoid copepod (LCC) diet representation closely mirrored their water column availability
Pollock Size & Condition: Model results indicated fish length increased significantly with day of year (+0.75 mm/day) and prior SST (+3.5 mm/°C), resulting in larger fish in warm years (except 2015) but lower overall body condition compared to cool years, $R^2 = 0.55$
Diet Composition: Diets shifted ontogenetically from large calanoid copepods to euphausiids as pollock grew, though copepod consumption remained unusually high across all size classes during 2015 and 2017
PSIRI Results: Large calanoid copepods and euphausiids co-dominated overall diet importance (% PSIRI = 22–56%), with each leading in an equal number of survey years and no other prey taxa exceeding 17%
Prey Energy Content: Model results indicated fish weight was the single strongest driver of diet energy density (a 28-fold energy increase per 10-fold increase in body mass), with minor negative effects from night sampling and higher SST, yet model $R^2 = 0.25$

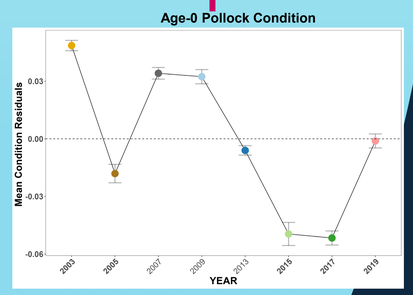


Figure 5. Mean body condition residuals of a regression of log weight(g) as a function of length (mm) for age-0 pollock subsampled for diet analysis (excluding fish subsampled for at-sea length) by year. Warmer water temperature years in bold (x-axis). Error bars represent standard error of the mean.

CONCLUSIONS

Dominant Prey & Ontogenetic Shifts: Age-0 pollock diets are overwhelmingly dominated by large calanoid copepods (LCC) and euphausiids, exhibiting a consistent ontogenetic shift to euphausiids that was disrupted only during the 2014–2016 MHW period (2015/2017) when pollock relied heavily on LCC.
Euphausiid Buffering & MHW Thresholds: Euphausiid availability serves as a critical buffer against warm ocean temperatures, but persistent extreme events cross a threshold where prey abundance alone cannot prevent poor pollock condition (e.g., 2015).
Prey Quality & Management Indicators: Unexplained variability in diet energy model could reflect the effect of unmeasured interannual prey lipid quality, establishing LCC and euphausiid dynamics as key indicators for predicting pollock overwintering and recruitment success

Multi-Year Heatwaves & Adjacent Years(2015 & 2017)



- **Nutritional Deficit**: Sustained warm anomalies suppressed multi-year euphausiid recruitment, forcing age-0 pollock to rely heavily on large calanoid copepods (LCC) and resulting in the lowest body condition residuals across the study.
- **Gape Limitations & Foraging (2015)**: Exceptionally small pollock size (mean ~50 mm) during the 2015 marine heatwave created gape-width limits against large euphausiids, favoring capture of abundant LCC (highest recorded % PSIRI) to meet high metabolic demands.
- **Inadequacy of LCC**: High water column abundance and consumption of LCC in both 2015 and 2017 failed to provide the nutritional value or energetic buffer required to maintain positive fish condition during warm conditions.

Single or Acute Warming Years (2005 & 2019)



- **Energetic Buffering**: High euphausiid availability in 2005 and 2019 successfully mitigated the physiological stress of elevated water temperatures, maintaining neutral body condition and supporting robust growth.
- **2019 Marine Heatwave Resilience**: High euphausiid abundance (44.5% PSIRI) enabled 2019 pollock to achieve larger-than-expected sizes (+10.9 mm above predicted in model 1) despite severe surface and bottom temperature anomalies.
- **Acute vs. Chronic Warming**: Euphausiid stocks can rapidly recover from single-year or acute warming events (2005, 2019) to buffer juvenile fish growth, but prolonged, multi-year heatwaves (e.g., 2014–2016) deplete euphausiid populations beyond this buffering capacity.

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