A 200 Year Archeozoological Record of Pacific Cod Life History as Revealed Through Ion Microprobe Oxygen Isotope Ratios in Otoliths

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Introduction

Pacific cod is an abundant marine fish species inhabiting the Alaska continental shelf whose importance for food spanned centuries from modern industrial fisheries back to traditional subsistence use by Alutiiq communities. Intact fossilized Pacific cod otoliths found at archeological sites in the Gulf of Alaska (GOA) provided a unique opportunity to explore the interactions between climate and fish populations on temporal scales not typically available to modern ecologists. Using otoliths recovered from archeological sites dated from 200+, 100+ years before present (YBP) along with modern collections in Aialik Bay, Alaska (Fig. 1) we analyzed oxygen isotope ratios ($\delta^{18}O$) to reconstruct the near shore temperature regime and Pacific cod habitat use in the GOA since the Little Ice Age.

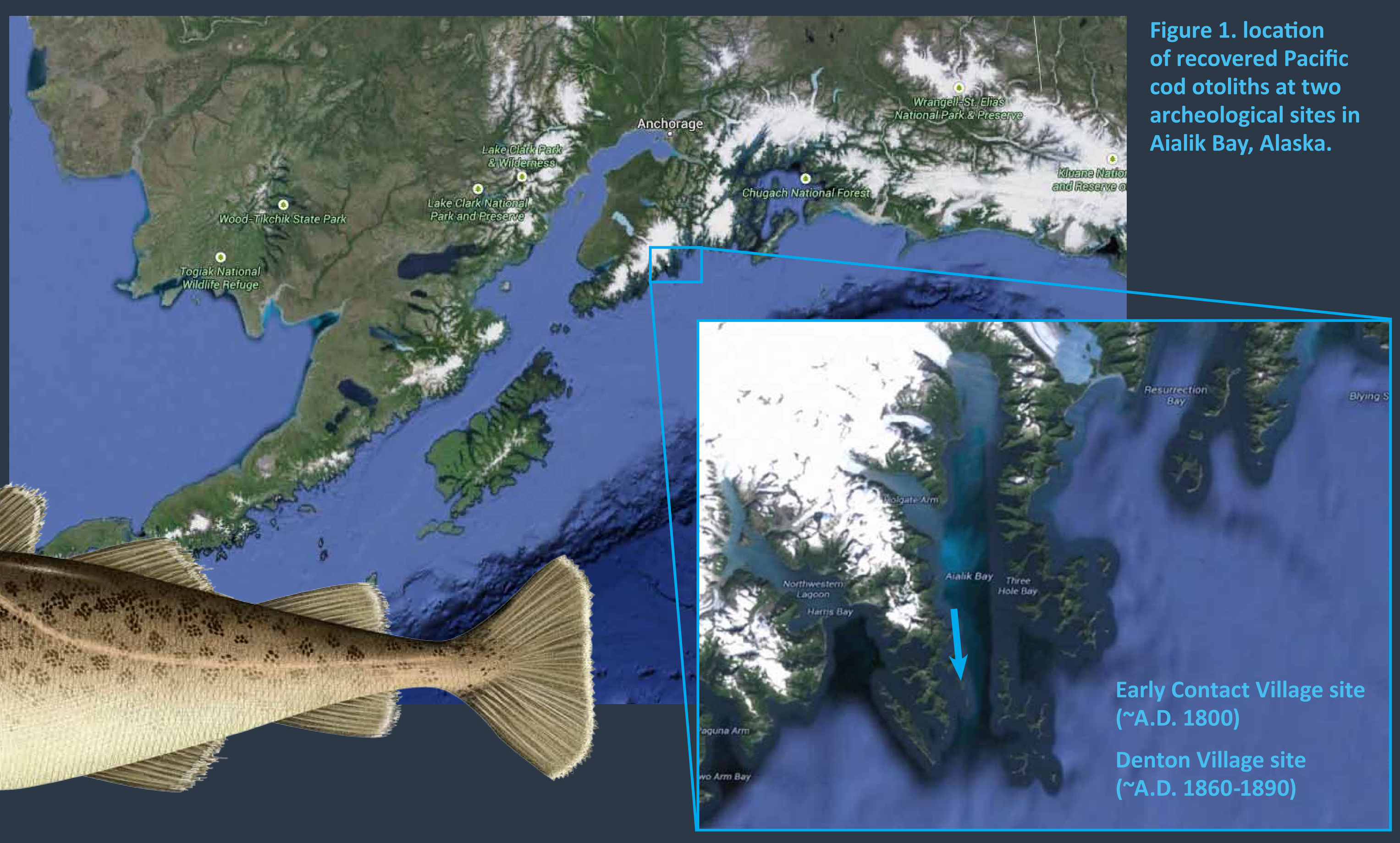

Figure 1. location of recovered Pacific cod otoliths at two archeological sites in Aialik Bay, Alaska.

Methods

- In all nine Pacific cod otoliths, 3 from 200+ YBP and 3 from 100+ YBP sites along with 3 from modern caught (2004) fish in Aialik Bay were thin sectioned, polished and gold coated in preparation for microsampling using the WiscSIMS ion microprobe (Fig. 2).
- Transects comprising between sixty to eighty 10-micron spot samples from the otolith core (juvenile stage) to edge (adult stage) were sampled with the ion microprobe (Fig. 2) and values $\delta^{18}O$ measured from a secondary ion mass spectrometer were plotted as ‰ relative to Vienna PDB standard.
- Measured $\delta^{18}O$ was converted to temperature using a fractionation equation developed from ion microprobe analysis of 7 modern Pacific cod otoliths from which *in situ* bi-hourly temperature and depth records were recorded in electronic archived tags (Fig. 3). Specifically, spot samples of measured $\delta^{18}O$ that were sampled near the outer edge of the otolith representing the aragonite material accreted during the period at liberty were regressed with average monthly *in situ* instrumental temperatures.

Figure 2. Thin sectioned Pacific cod otolith recovered from 200+ year old archeological site in Aialik Bay, Alaska. WiscSIMS ion microprobe spot samples from otolith core to edge.

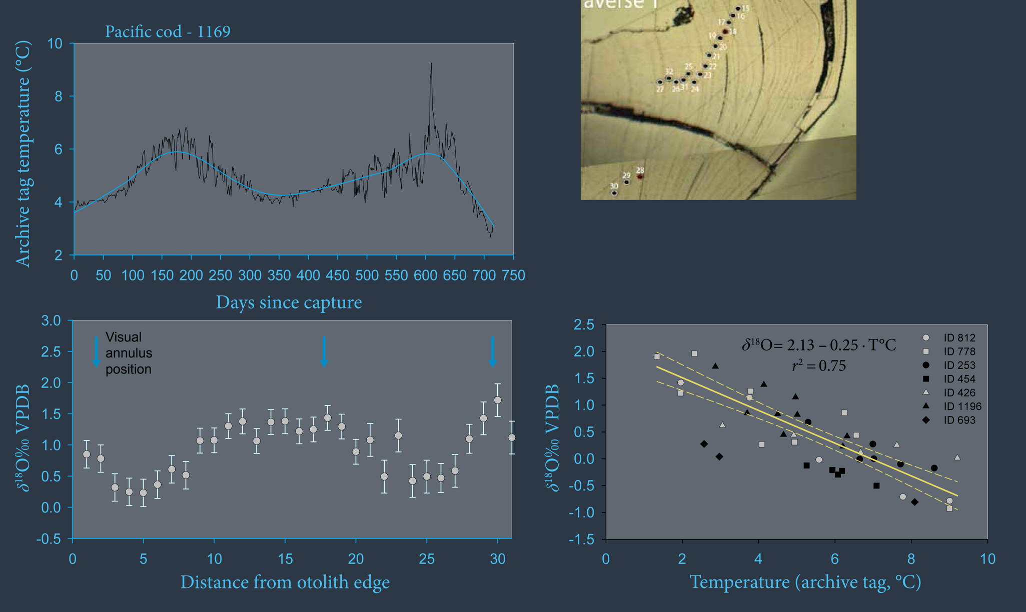

Figure 3. Sequence of ion microprobe spot samples measuring stable oxygen isotopes $\delta^{18}O$ (‰ VPDB, ±2 S.D.) made at WiscSIMS from a traverse sectioned Pacific cod tagged with an electronic data logger (temperature and depth) and at liberty for 716 days. Spot samples 1-31 were sampled near the outer edge of the otolith and represented the aragonite material accreted during the period at liberty. As expected, relationship between Pacific cod otolith aragonite ($\delta^{18}O$) and bottom temperature showed an inverse, statistically significant linear relationship (r=0.75, p<0.001).

Results

- We obtained sample densities along a linear transect that were at least 2 to 3 times greater than micromilling/ conventional mass spectrometry techniques with high spot-to-spot analytical precision ($\delta^{18}O$ ±0.3‰).
- Measured values of $\delta^{18}O$ were typically lower near core samples (-4.08 to -2.21 ‰ PDB) than spot samples near the otolith edge (0.52 to 1.44 ‰ PDB) (Fig. 4).
- Rapid rise in of $\delta^{18}O$ after the first year of life followed by higher but cyclical $\delta^{18}O$ concentrations reflect ontogenetic migratory behavior from warmer near shore habitat during the first year of life to cooler deeper waters at later ages (Fig. 4).
- Estimated fractionation equation from archive tagged Pacific cod confirms a statistically significant inverse relationship between otolith aragonite ($\delta^{18}O$ ‰ PDB) and *in situ* temperature (Fig. 3; r=0.75, p<0.001).
- A decline in the average $\delta^{18}O$ of core spot samples from archeological (200+, 100+ YBP) to modern otoliths suggest increasing sea surface temperatures from the late Little Ice Age to present. Temperatures calculated from the $\delta^{18}O$ in aragonite suggest a 2-3°C rise in coastal marine sea surface temperatures in the Gulf of Alaska over the last 200 years (Fig. 5).

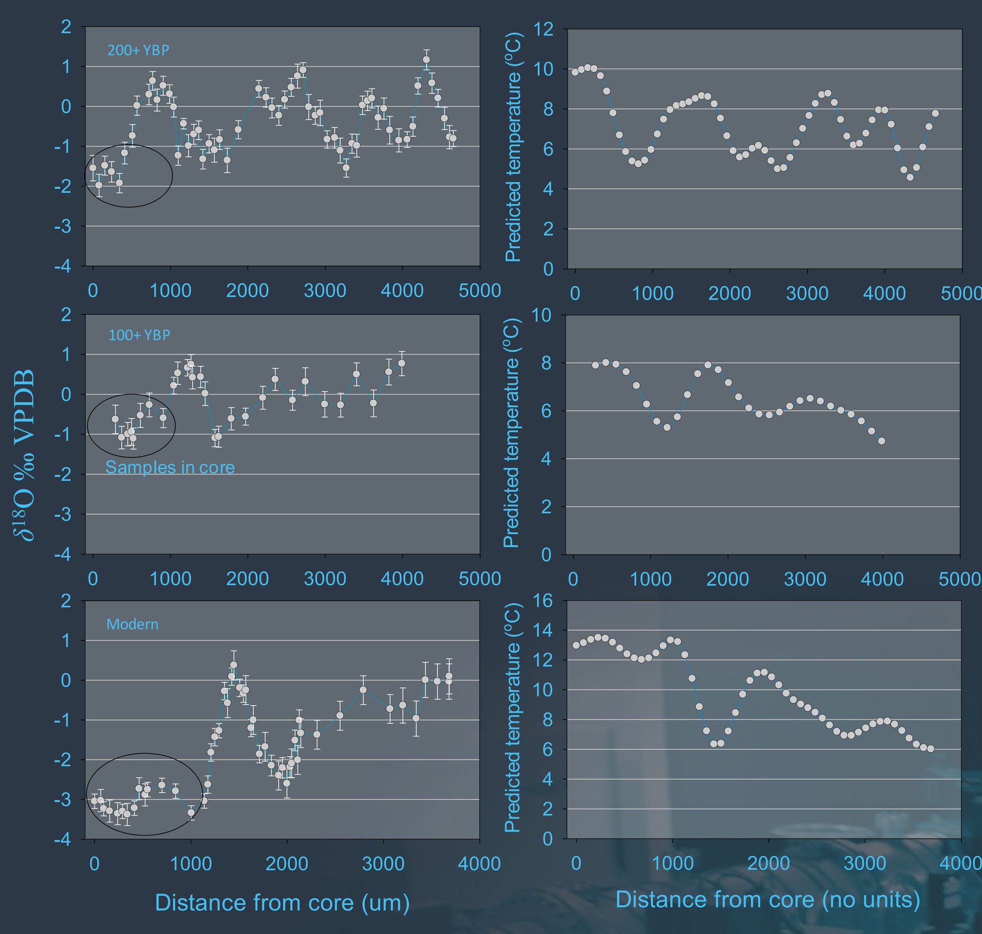

Figure 4. Sequence of ion microprobe spot samples from otolith core to edge measuring stable oxygen isotopes $\delta^{18}O$ (‰ VPDB, ±2 S.D.) made at WiscSIMS with predicted temperatures estimated from fractionation equation. Circles show spot samples within the otolith core used to reconstruct near shore temperature change since Little Ice Age.

Conclusions

- High resolution sampling for $\delta^{18}O$ provides a unique perspective on Pacific cod biogeography and migratory behavior, showing habitat preference for warmer near shore water during early life stages followed by migration to cooler deeper water. This life history strategy has not appeared to have changed over the past 200 years.
- Near shore temperatures in the Gulf of Alaska, inferred through archeological and modern $\delta^{18}O$ samples from Pacific cod otoliths, appeared to have increased since the late Little Ice Age. The difference of about 2-3 °C cooler around the decade A.D. 1800 from otolith $\delta^{18}O$ is consistent with tree-ring derived estimates of cooler air temperature during the same period.

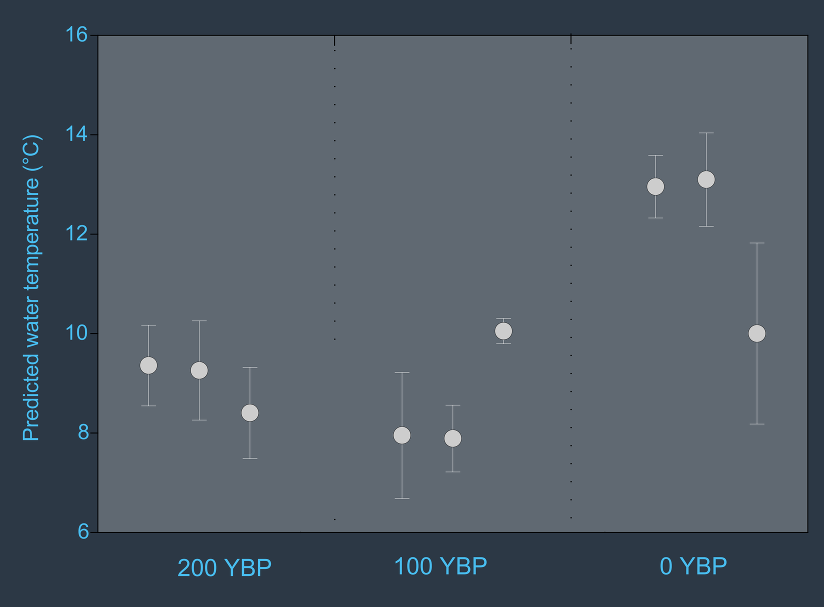

Figure 5. Predicted near shore water temperature since the Little Ice Age (200+ YBP) to modern times from 9 Pacific cod otoliths (six of which were recovered from archeological sites and dated to 200+ and 100+ YBP) sampled for stable oxygen isotopes $\delta^{18}O$. Temperature was reconstructed from fractionation equation.

Selected References

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