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AN IMPROVED UNDERSTANDING OF THE ALASKA COASTAL CURRENT: THE APPLICATION OF A BIVALVE GROWTH-TEMPERATURE MODEL TO RECONSTRUCT FRESHWATER-INFLUENCED PALEOENVIRONMENTS

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ABSTRACT

Shells of intertidal bivalve mollusks contain sub-seasonally to interannually resolved records of temperature and salinity variations in coastal settings. Such data are essential to understand changing land-sea interactions through time, specifically atmospheric (precipitation rate, glacial meltwater, river discharge) and oceanographic circulation patterns; however, independent temperature and salinity proxies are currently not available. We established a model for reconstructing daily water temperatures with an average standard error of ~1.3 °C based on variations in the width of lunar daily growth increments of *Saxidomus gigantea* from southwestern Alaska, United States. Temperature explains 70% of the variability in shell growth. When used in conjunction with stable oxygen isotope data, this approach can also be used to identify changes in past seawater salinity. This study provides a better understanding of the hydrological changes related to the Alaska Coastal Current (ACC). In combination with $\delta^{18}O_{shell}$ values, increment-derived temperatures were used to estimate salinity changes with an average error of 1.4 ± 1.1 PSU. Our model was calibrated and tested with modern shells and then applied to archaeological specimens. As derived from the model, the time interval of 988–1447 cal yr BP was characterized by ~1–2 °C colder and much drier (2–5 PSU) summers. During that time, the ACC was likely flowing much more slowly than at present. In contrast, between 599–1014 cal yr BP, the Aleutian low may have been stronger, which resulted in a 3 °C temperature decrease during summers and 1–2 PSU fresher conditions than today; the ACC was probably flowing more quickly at that time. The shell growth–temperature model can be used to estimate seasonal to interannual salinity and temperature changes in freshwater-influenced environments through time.

INTRODUCTION

Freshwater discharge from coastal mountains into the northern Gulf of Alaska exerts a major control on the Alaska Coastal Current (ACC; Royer, 1982; Johnson et al., 1988; Stabeno et al., 2004; Weingartner et al., 2005). The ACC is a narrow, swift stream that flows alongshore in a counter-clockwise direction from British Columbia to Unimak Pass (Aleutians) where it enters the Bering Sea (Muench et al., 1978; Schumacher et al., 1982; Kipphut, 1990; Spies, 2007). From there, the nutrient-rich, low-salinity waters (25–31 PSU, Mundy, 2005) reach the Arctic Ocean (Weingartner et al., 2005) and foster the productivity and sea-ice formation in polar waters (Hu et al., 2010). Large freshwater discharges increase the speed of the ACC (Royer, 1981) and therefore, the amount of low-salinity waters reaching the Arctic seas. In turn, this can increase sea-ice formation and albedo. Hence, freshwater runoff into the Gulf of Alaska can act as a thermostat, affecting processes in the Bering Sea and northward. Despite its importance in the global climate system, past dynamics of the ACC on seasonal to interannual time-scales have been barely studied due to the lack of high-resolution climate proxy archives. Most available records only report on precipitation patterns on land (dendrochronology, e.g., Garfinkel and Brubaker, 1980; Wiles et al., 1996, 1998; Barber et al., 2004) or only provide low temporal resolution, typically on an annual scale, such as from pollen (Bigelow and Edwards, 2001), lake deposits (Abbott et al., 2000; Anderson et al., 2001), or foraminifera (Keigwin et al., 2006). Recently, coralline red algae have been employed to reconstruct interannual temperature and salinity changes at the Aleutians (Halfar et al., 2007; Hetzinger et al., 2009); however, these records only extend back to the end of the nineteenth century.

Alternatively, shells of intertidal bivalve mollusks can provide sub-seasonal to interannual records of salinity and temperature changes. Living at the interface between land and the open ocean, bivalves are exposed to changes in freshwater runoff, as mediated by the ACC. Bivalves are highly sensitive to ambient environmental changes and encode a number of environmental parameters in their shells in the form of variable growth rates and geochemical properties (Epstein et al., 1953; Williams et al., 1982; Goodwin et al., 2001; Schöne et al., 2005a, 2011; Butler et al., 2010). The butter clam *Saxidomus gigantea* (Deshayes) is the most abundant clam on beaches in Alaska, British Columbia, and Puget Sound, Washington (Rickets and Calvin, 1962). It also is abundant in archaeological shell middens covering almost the entire Holocene. This species inhabits the intertidal and shallow subtidal zone, lives buried in sandy to gravelly sediments about 30 cm beneath the sediment-water interface, and attains a lifespan of more than twenty years (Quayle and Bourne, 1972).

In Alaska, shell growth of *S. gigantea* ceases for up to six or seven months per year from approximately October–November to April–May (Hallmann et al., 2009). Daily microgrowth patterns have demonstrated that shell growth is strongly linked to water temperature with the fastest rates occurring during the summer and slowest growth during spring and fall (Hallmann et al., 2009). The lower and upper growth temperature thresholds are ~4–5 °C and 20 °C, respectively (Bernard, 1983; Gillikin et al., 2005a; Hallmann et al., 2009). Despite its potential importance for paleoclimate studies, the butter clam has rarely been studied by means of sclerochronological techniques (Gillikin et al. 2005a, 2005b; Kingston et al., 2008; Hallmann et al., 2009). In its shell, *S. gigantea* produces distinct lunar daily (circadian), fortnightly, and annual growth increments, which can be used to assign precise calendar dates to each portion of the shell (Hallmann et al., 2009). Furthermore, geochemical properties of the shells can provide serviceable environ-

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