Understanding mammoth ecology and niche variability using stable isotopes of collagen and amino acids

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Woolly mammoths (*Mammuthus primigenius*) were keystone herbivores in Beringian environments. Understanding Beringian ecology, and associated vulnerabilities of megafauna to extinction threats, rests in part in comprehending the interactions between them and coeval species. Earlier studies determined that the woolly mammoth had a distinct physiological, dietary or habitat niche, as its collagen was typically enriched in ^{15}N relative to coexisting megaherbivores and had similar nitrogen isotopic compositions to carnivores. We previously determined the source of this nitrogen isotopic signal to be dietary- or habitat-related by examining amino acid-specific isotopic compositions of woolly mammoths and coeval species from Old Crow, Yukon Territory, Canada. Adult woolly mammoth collagen contains source amino acids with higher $\delta^{15}N$ values than other herbivores or carnivores. Thus, the high mammoth collagen $\delta^{15}N$ values indicate consumption of ^{15}N-enriched vegetation, the origin(s) of which remains uncertain (possibilities include aridity, dung fertilization, plant selection, plant-part selection, aeolian nitrogen deposition). We then compared the extent of overlap between the $\delta^{15}N$ values of woolly mammoths and coeval herbivores in Yakutia (Russia), Alaska (USA), the Yukon (Canada) and Alberta (Canada). The degree of overlap increased moving south, indicating that environmental effects (e.g. the length of the growing season) affected the extent of niche overlap. This distinct niche in severe climates, combined with the mammoths' ability to adapt to different environmental conditions, suggests that these animals showed resilience in the face of climate change alone. Mammoths may have been more vulnerable to extirpation when they encountered a simultaneous combination of climate change and human predation.