

Analysis of naticid gastropod predation across the trans-Arctic invasion in the Tjörnes beds, Iceland, and the Red Crag Formation, East Anglia, England

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Invasive species are wreaking havoc on modern ecosystems; however, species invasions are not new threats to ecosystems. The fossil record allows conservationists to acquire deep-time perspectives on long-term effects of natural invasions before anthropogenic impacts. Drill holes from invasive naticid gastropod predators on bivalve prey can be quantified to provide evidence of the impact of these invasive predators on ecosystems. An asymmetrical faunal interchange, known as the trans-Arctic invasion (TAI), occurred between the Pacific and Atlantic oceans during the Pliocene (~3.5 Ma) because of the opening of the Bering Strait. This interchange could have changed naticid gastropod drilling predation on bivalves due to the migration of Pacific fauna into the Atlantic Ocean.

The Tjörnes locality of northeast Iceland well characterizes the TAI because this site has preserved genera in three distinct levels that divide the invasion into the pre-invasion (*Tapes* and *Macra* zones) and the post-invasion (*Serripes* zone). Temporal comparisons can be made between these pre- and post-invasion zones to analyze drilling predation across the TAI. Spatial comparisons of drilling predation in the post-invasion deposits can be made by correlating the *Serripes* zone (3.6-2.6 Ma) to the Red Crag Formation (2.54 Ma) of East Anglia, England, because these localities are of similar age and contain similar taxa. Specimens from the Tjörnes Beds, Iceland, were analyzed in collections housed at the Icelandic Institute of Natural History. Red Crag Formation specimens were analyzed at the Academy of Natural Sciences at Drexel University, Philadelphia, PA. Height and length of bivalve specimens were measured. The occurrence of complete and incomplete (unsuccessful) drill holes and drill hole diameter were recorded for all whole bivalves. Drilling frequency (DF = % mortality) and prey effectiveness (PE = % of attempted drill holes that were incomplete) were calculated.

Icelandic samples included 28 bivalve species (857 specimens) in the pre-invasion zones, whereas 37 bivalve species (1295 specimens) were recorded in the *Serripes* zone. The Red Crag Formation samples included 78 bivalve species (531 specimens). For temporal comparisons of Icelandic samples, DF decreased from 0.070 to 0.058 from pre- to post-invasion, whereas PE increased (0.115 to 0.167). However, DF (0.065 to 0.077) and PE (0 to 0.214) increased from the *Tapes* to *Macra* zones. Increased DF between the *Tapes* and *Macra* zones can be attributed to the invasion of naticids into the Atlantic. The escalation hypothesis is supported by the decrease in DF in the *Serripes* zone and by the increase in PE from pre- to post-invasion. Spatial comparisons were made for naticid drilling in post-invasion samples. DF was higher in the Red Crag Formation (0.082) than the *Serripes* zone (0.058), whereas PE was lower in the *Serripes* zone (0.167) than in the Red Crag Formation (0.333). Analysis of the size of bivalve prey (*Macoma*, *Lentidium*, and *Thracia*) compared to drill hole size suggests invasive naticids transitioned to select smaller-sized bivalve prey in the later stages of the *Serripes*; however, analysis of *Astarte* suggests that invasive naticids selected larger-sized prey in the Red Crag Formation than in the *Serripes*.