



Ecological specialization in Neanderthals: a stenobiont perspective

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Abstract. Neanderthals (*Homo neanderthalensis*) represent a remarkable example of a stenobiont hominid species, exhibiting adaptations to a narrow ecological niche. This study explores their geographic, dietary, and cultural specializations, emphasizing their reliance on temperate and subarctic climates, meat-based diets, and specialized hunting strategies. While not extremely stenobiont, Neanderthals were more restricted in ecological flexibility compared to *Homo sapiens*. These limitations, coupled with climatic changes and competition, contributed to their extinction around 40,000 years ago. The findings contrast Neanderthals' specialized adaptations with the ecological versatility of *H. sapiens*, offering insights into survival dynamics and evolutionary trajectories.

Key Words: dietary specialization, ecological niche, human evolution, Neanderthals, stenobiont adaptations.

Introduction. Among the hominids, Neanderthals (*Homo neanderthalensis*) stand out as a species with adaptations that suggest a stenobiont lifestyle - one characterized by a narrow ecological niche. The term "stenobiont" describes organisms that are highly specialized and can thrive only within specific environmental conditions. While other hominid species, such as *Homo sapiens*, demonstrated remarkable ecological flexibility, the Neanderthals were comparatively constrained by their evolutionary adaptations, geographic range, and resource utilization (Estévez 2004; Pearson 2007). The Neanderthal was not extremely stenobiont, but evidence shows that it was more stenobiont than *H. sapiens*. This study examines the ecological, dietary, and cultural adaptations of Neanderthals as a stenobiont species, focusing on their specialization in narrow niches and the factors contributing to their extinction. It also contrasts their adaptations with those of *H. sapiens* to highlight differences in survival and ecological flexibility.

Geographic range and environmental specialization. Neanderthals lived primarily in Europe and parts of western Asia during the Middle to Late Pleistocene, roughly 400,000 to 40,000 years ago (Roebroeks & Soressi 2016). This region was subject to significant climatic fluctuations, including glacial and interglacial periods. Neanderthals were well-adapted to cold environments, as evidenced by their robust skeletal structure, shorter limbs, and larger nasal cavities - features that helped conserve heat and warm inhaled air (Rosas et al 2022). However, these adaptations were specifically tailored to temperate and subarctic climates, limiting their ability to thrive in more diverse ecosystems, such as tropical or desert regions.

In contrast, *H. sapiens* exhibited greater geographic and ecological flexibility, migrating into a wide array of environments across Africa, Asia, and beyond (Bădărașu 2007). This adaptability likely contributed to the eventual dominance of modern humans over the Neanderthals (Bădărașu 2007).

Dietary specialization. Neanderthals were primarily carnivorous (Richards & Trinkaus 2009), relying heavily on large game animals such as mammoths, woolly rhinoceroses, and reindeer (Estévez 2004), but they were also skilled fishers and scavengers, diversifying their diet with aquatic resources and carrion (Estévez 2004; Pearson 2007). However, their abilities in food diversification were limited compared to other hominids (Pearson 2007). Stable isotope analyses of Neanderthal bones reveal a diet that was heavily meat-based, supplemented with some plant material when available (Larsen et al 2022). Their hunting strategies were highly specialized, involving close-range ambush tactics that required physical strength and coordination (Villa & Soriano 2010; Lombard & Moncel 2023).

This dietary specialization made Neanderthals vulnerable to ecological changes that disrupted the availability of large game. During periods of climatic instability, the decline of megafauna populations likely strained their food resources (Estévez 2004). In comparison, *H. sapiens* employed more diverse subsistence strategies, including fishing, foraging, and the use of smaller, more adaptable prey. This dietary flexibility provided a critical advantage in surviving environmental changes.

Cultural and technological constraints. While Neanderthals developed sophisticated tools and cultural practices (Villa & Soriano 2010; Lombard & Moncel 2023), their technological innovations were less versatile than those of *H. sapiens*. The Mousterian tool industry, associated with Neanderthals, was highly effective for hunting and processing large game but showed limited adaptability to other tasks or environmental conditions (Douka & Spinapolice 2012). In contrast, the Upper Paleolithic toolkits of *H. sapiens* included a broader array of implements, enabling them to exploit a wider range of resources (Pradel et al 1966).

Furthermore, Neanderthals exhibited less evidence of symbolic behavior and long-distance social networks compared to *H. sapiens* (Pearce 2018). These limitations may have hindered their ability to adapt to changing environments by sharing knowledge and resources across groups (Pearce 2018).

Extinction and legacy. The combination of narrow ecological specialization, climatic changes, and competition with *H. sapiens* likely contributed to the extinction of Neanderthals around 40,000 years ago. Their reliance on specific environmental conditions and resource types made them highly vulnerable to disruption, highlighting the risks associated with a stenobiont lifestyle.

Despite their extinction, Neanderthals left a lasting legacy through their genetic contributions to modern human populations (Liston et al 2021). Interbreeding between Neanderthals and *H. sapiens* has resulted in the incorporation of Neanderthal genes into the genomes of many contemporary humans (Liston et al 2021; Reilly et al 2022), influencing traits such as immune responses and adaptation to cold climates.

Conclusions. Neanderthals represent a fascinating example of a stenobiont hominid species. The Neanderthal was not extremely stenobiont, but evidence shows that it was more stenobiont than *H. sapiens*. Their specialized adaptations allowed them to thrive in specific environments but ultimately limited their ability to cope with ecological and competitive pressures. By studying their evolution, adaptations, and extinction, we gain valuable insights into the dynamics of survival and the factors that shape the success or failure of species.

Conflict of interests. Authors declare that there is no conflict of interest.

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