Introduction

Animal domestication: from distant past to current development and issues

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Domestic animals have played an important role in shaping human Evolution and History. After millennia of constructing niches based on hunting, gathering, and foraging, a range of communities in diverse parts of the world embarked on trajectories of food production which in some instances led to the emergence of complex societies, urbanism, and empires, sowing the seeds for our current globalization. Thanks to intensive zooarcheology and genomics research, it is now common knowledge that, apart from dog domestication within hunter–gatherers societies around 23,000 years Before Present (BP) *terminus post quem* (Perri et al., 2021), the domestication of globally important livestock animals occurred within sedentary communities engaged in early agriculture in three independent cradles. The oldest of these is located in Southwest Asia where cereals (wheat, barley), legumes (pulse, peas, lentils), and fruits (figs) were domesticated between 12,000 and 10,000 BP, followed by sheep, goat, pigs, and cattle between 10,500 and 10,000 BP (Colledge et al., 2013). The second cradle is located in China where domesticated millets and rice were cultivated in the Yellow and Yangtze River valleys by 10,000 BP. This was followed relatively rapidly by pig domestication in the Yellow River valley (Jing and Flad, 2002; Cucchi et al., 2016). The last major center of ungulate domestication is located in the Andes, where agriculture based on imported maize and locally domesticated potato, beans, and squashes emerged between 9000 and 8000 BP along with South American camelids, llamas and alpacas, later followed by Barba's duck and the guinea pig around 4000 BP (Pearsall, 2008; Hardigan et al., 2017). North America, also contributed to global animal domestication with the turkey by 2000 BP (Speller et al., 2010). In the Old World, a later series of animal domestications focused on the use of animal labor, with the domestic forms of donkey, horse, and camel emerging between 5000 and 2000 BP (Clutton-Brock, 2014). These animals revolutionized human economies and transportation, boosting the power of states, empires and the scale of warfare. Domestic animals have continued to emerge in recent times, including the rabbit in medieval Western Europe, rodents (including rats and hamsters) in the 19th and 20th centuries, as well as the fast-growing field of fish domestication in the 21st century.

Searching for the origin of food production through plant and animal domestication has been a central preoccupation of prehistorians since the mid-20th century (Boyd, 2017), with narratives focusing on themes of technological progress, intentionality and human mastery over their environment (Childe, 1946). These perspectives are firmly anchored in a western anthropocentrism characterized by a strong nature/culture dualism and are still strongly embedded in the archeological literature (Hodder, 1990). However, since the 1980s, anthropologists have emphasized perspectives beyond western ontologies (Descola, 2005) providing ethnographic examples in which distinctions between wild and domestic, culture and nature are minor or even nonexistent (Ingold, 1996). The field of zooarcheology has therefore moved away from earlier narratives emphasizing animal domestication as human domination over nonhuman animals toward a focus on the ecological, cultural, and coevolutionary relationships that have always existed between humans and nonhumans and their intensification and elaboration in the contexts of early farming societies (Vigne, 2015).

Zooarcheology has struggled to find an approach that can take into account the vast range of human–nonhuman interaction and the biological and social components encompassed by the concept of domestication (Russell, 2002). From the biological side, some scholars have focused on domestication as an evolutionary process, drawing inspiration from the work of Darwin (1868). This perspective focuses on the role of intentional human selection in driving the evolution of domestic animals (Clutton-Brock, 1994) or on the consequences (both intentional and unintentional) of human niche construction (Zeder, 2016). The biological side can also focus on the mutualistic/symbiotic relationships between humans and nonhuman animals (Zeuner, 1963; O'Connor, 1997), emphasizing the active role of nonhuman animals in these relationships (Orton, 2010). From a social perspective, scholars emphasize the continuum of relationships between human and nonhuman animals by

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rejecting a simple wild/domestic dichotomy and focusing instead on the role of human intentionality in bringing animals into the cultural sphere where they become incorporated into the human social world (Jarman et al., 1976; Hecker, 1982). Recently, Zeder (2012) has used the concept of domestication pathways as a synthesis of biological and social components of domestication. In this comprehensive approach, evolutionary process, mutualism, and human intentionality are mobilized to propose three pathways for animal domestication: the commensal pathway, the predation pathway, and the directed pathway. This model has provided a useful framework to explore the domestication process in archeology. More recently, the powerful conceptual framework of Niche Construction Theory has been mobilized to further bridge the social and biological views on animal domestication and provide new insights into the coevolution of human and nonhuman societies (Zeder, 2016). To merge social with biological views and tackle the full complexity of animal domestication, a systemic socioecological approach of the interaction dynamics between of human and nonhuman societies has also been proposed (Vigne, 2015).

In addition to the theoretical framing of domestication, the when and why of early animal domestication continues to be debated. Dating the beginning of animal and plant domestication relies on the recognition of observable modifications of the morphologies of seeds and animal bones from archeological sites, testifying to the occurrence of plants and animals already transformed by an ongoing domestication process. But long before this "proper" domestication, we find that by 12,000 BP, in Southwest Asia, evidence that human populations were modifying the landscape to facilitate the growth of local wild plants by tilling and tending cultivated fields, several thousand years before clear evidence of morphological changes were found in the archeological record (Hillman et al., 2000). This form of management predating morphological changes is sometimes referred to as "pre-domestic cultivation" and emphasizes that genetic changes in target populations must predate their first appearance in the archeological record (Willcox, 2012). Such management of the landscape has been a key component of the economies of the people of the Amazonian floodplain, creating an anthropogenic forest and waterscape to secure plant and animal resources (Clement et al., 2015). For animals, hunters have long been interfering with their environment to facilitate and sustain their access to valuable animal resources (both alimentary and symbolic) by selectively hunting and fishing, managing streams to promote spawning, transplanting animals to populate islands devoid of game, and raising juveniles. In light of these practices, it is clear that close relationships including management and cohabitation between humans and animals began long before the appearance of "domestic" forms and should be explored in the broader scope of the domestication of the environment (Scott, 2017). The efficient cognitive apprehension by hunters societies of their environment (Lévi-Strauss, 1962) suggest that animal domestication was not a cognitive revolution but rather a response by some assemblages of human–animal pairings to socioecological conditions conducive to intensification. The example of dog domestication, which has been dated through ancient genomics to the late Pleistocene, proves that this intensification could happen in a wide range of socioeconomic conditions not limited to sedentary farming.

Since the Neolithic (referred to by some as the start of the Anthropocene), animal domestication represents a major shift in the influence of humanity over their life on earth and ultimately over humanity's future. One of the key components of the "sixth extinction" of animal species which we are facing is the tremendous biomass reached by domestic animals (Barnosky, 2008). The impact of domestic animals on current ecosystems and their massive consumption of resources is more obvious when we consider that two thirds of the terrestrial vertebrate biomass on earth is made of domestic animals; humans representing the other third while wild animals only represent 3% to 5% of this terrestrial biomass, demonstrating how humans and livestock have dramatically transformed the biosphere since the advent of animal and plant domestication (Smil, 2003). Virtually all extant megafaunal species are currently under threat and if, as seems likely, they go extinct, the largest terrestrial mammal in the coming centuries will be cattle (Smith et al., 2018). Along with the global presence of herding animals, since the 19th century the number of new small animals kept as pets and incorporated into global supply chains represents a huge threat for the biodiversity and human health. These new pets include newly domesticated mammals (e.g., golden hamster, chinchilla) and birds (budgerigar, parakeet) as well as species of wild mammals, fishes, reptiles, arthropods, and birds which are directly collected from their natural habitat to feed an exponentially growing global pet market. These species can be vectors of zoonosis but can also be potentially invasive, threatening autochthonous wildlife in addition to the ecological damage brought by the trapping and catching of popular (especially tropical) species. The future of animal domestication is now facing a huge challenge ahead. The human population is projected to reach 10 billion in 2050 according to OECD. The ever-growing desire for animal protein also fostered by globalization and the spread of affluent consumer economies will not be met by the current unsustainable agroeconomic model (Smil, 2001). Fish and insect domestication could be a part of the solution, although the challenges are numerous.

Included in this issue of *Animal Frontiers* are eight review and two perspective articles showcasing the long-lasting history of animal domestication, the challenging task to document its origin in the archeological record and its latest development to face the challenge of food production. The first review takes us to Brazil, where Gabriela Prestes Carneiro from UFOPA in Brazil and colleagues from UFPA and from the Natural Museum of Paris in France, propose a concept of "Waterscape domestication" to capture the management and husbandry of aquatic animals by forest people and the time depth of these practices in the Amazonian floodplain (Prestes-Carneiro et al., 2021). The next four reviews provide the latest understanding on the origin of five emblematic domestic animals. Dr Benjamin Arbuckle and Theo Kassebaum from the University of North Carolina propose a rethinking of the origins of cattle management in Southwest Asia, hypothesizing that intensification in human–cattle relationships may have occurred within many early farming communities

of the Fertile Crescent, long before domestic forms of cattle are evident in the archeological record (Arbuckle and Kassebaum, 2021). Dr Daniel Fuks from the University of Cambridge and Dr Nimrod Marom from the University of Haifa explore the long-term relationship between humans, sheep, and wheat which has its origins in Southwest Asia but which, they argue, is reflective of a long process of globalization (Fuks and Marom, 2021). Dr Hitomi Hongo and Hiroki Kikuchi from Tokyo University and Hiroo Nasu of Okayama University describe divergent pathways of early pig management in the Yellow River and Yangtze valleys in China, linking processes of pig management to local environmental conditions as well as agricultural systems based on millet in the north and rice in the south (Hongo and Kikuchi, 2021). Dr Hugo Yacobaccio from the University of Buenos Aires provides a review of the archeological evidence for the still elusive South American camelid domestication process (Yacobaccio, 2021). Finally, Dr Masaki Eda from the Hokkaido University in Japan tracks the genomic and archeological evidence of chicken domestication in Southeast Asia (Eda, 2021). The next two reviews provide an insight into the many trajectories and complexity of potential pathways toward animal domestication. Dr Andrew Somerville from Iowa State University and Dr Nawa Sugiyama from the University of California, Riverside provide an example of a discontinuous domestication relationship. Focusing on cottontail rabbits in the Americas, the authors describe clear evidence for intensive rabbit management at the ancient city of Teotihuacan but propose behavioral barriers inherent to the species as well as cultural factors to explain the ultimate failure to produce a long-term domestic leporid population (Sommerville and Sugiyama, 2021). Dr Ardern Hulme-Beaman from Liverpool University and colleagues from York University and the Natural History Museum of Paris provide new insights into the poorly understood history of the brown rat, proposing different steps in the domestication trajectory of this rodent, from a commensal species in Neolithic China to a laboratory model animal and a popular new pet (Hulme-Beaman et al., 2021). This special issue finishes with two perspectives on the ongoing process of animal domestication to face the challenges of feeding the 21st century human population with animal protein in a sustainable way. Dr Fabrice Teletchea from the University of Lorraine in France provides the latest understanding of the fast-growing process of fish domestication and proposes the application of a directed domestication pathway on local fish species to avoid future failure and foster sustainability (Teletchea, 2021). Finally, Dr Thomas Lecoq and Dr Lola Toomey from the University of Lorraine in France propose a program workflow built on the accumulated knowledge of animal domestication to develop the future of insect domestication (Lecoq and Toomey, 2021). Together, the papers in this volume provide a picture of the past, present, and future of animal domestication and emphasize the immense impact of this phenomenon on both human history and global ecology.

About the Authors

Thomas Cucchi received its PhD from the Natural History Museum of Paris in 2005. He is a zooarcheologist whose research focuses on the origins, spread, and evolution of anthropogenic species over the last 15,000 years. Using an integrated approach associating zooarcheological studies with the latest development in morphometric and molecular studies, he has published on animal domestication, commensalism, and dispersal in South Western Asia, China, Island South East Asia, and Europe. He is currently working on new methodological approaches of early process of animal domestication in archeology, using functional plasticity in bone morphology and epigenetic markers. **Corresponding author:** cucchi@MNHN.FR

Benjamin Arbuckle received his PhD from the Department of Anthropology at Harvard University in 2006. He is an archeologist whose research focuses on the prehistory of Southwest Asia and the intersection and human and nonhuman animals in human history. He has published on the early domestication of livestock in the Neolithic of SW Asia as well as the rise of pastoral lifeways in later periods. He is currently working on projects exploring the history of horse hunting and husbandry in ancient Turkey as well as on the history of wool.

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