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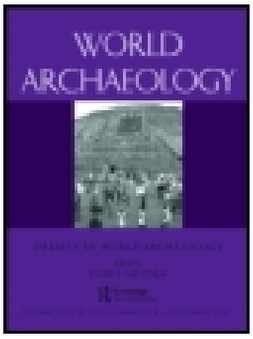

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Reconsidering domestication from a process archaeology perspective

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ABSTRACT
Process philosophy offers a metaphysical foundation for domestication studies. This grounding is especially important given the European colonialist origin of 'domestication' as a term and 19th century cultural project. We explore the potential of process archaeology for deep-time investigation of domestication relationships, drawing attention to the variable pace of domestication as an ongoing process within and across taxa; the nature of domestication 'syndromes' and 'pathways' as general hypotheses about process; the importance of cooperation as well as competition among humans and other organisms; the significance of non-human agency; and the ubiquity of hybrid communities that resist the simple wild/domestic dichotomy.

KEYWORDS
Domestication; process; agriculture; herding; niche; hybridity

Introduction

Studies of 'domestication' in archaeology and beyond continue to harbour notions of human mastery that reflect the European colonialist origins of the term. Accounts of farming origins routinely posit a 'step change' in human cultural development *because* domestication is something humans 'did' to plant and animal species. The causality of domestication begins exclusively with human interests or human niches. As a verb, 'to domesticate' is transitive, with a subject (humans, the domesticator) and an object (domesticates) (cf. Stépanoff and Vigne 2018).

It is in some ways remarkable that this understanding of domestication persists. Darwin himself drew attention to the importance of 'unconscious selection' in domestic relationships (Darwin 1868) and his later work on earthworms (Darwin 1881) foreshadowed the growing 20th century

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recognition that organisms continually (re-)construct their own environmental niches. From the beginnings of evolutionary biology, therefore, it was implicit that human relationships with other species, including those bracketed off as 'domestication', fitted into a broader web of evolutionary interactions. Archaeologists have followed biologists (Lewontin 1978, 1983) by demonstrating wide empirical support for co-evolutionary relationships among humans and other organisms, and for mutualistic symbioses and niche construction activities that include farming and herding (Rindos et al. 1980; Rindos 1984; Smith 2007; Rowley-Conwy and Layton 2011). Zeder (2016) has built a detailed empirical case to argue that early domestication relationships among humans, plants and animals offer a model case study in niche construction. Archaeological studies of domestication are thus relevant to wider acceptance of the 'extended evolutionary synthesis' (EES), in which niche construction theory (NCT) plays a central role (Zeder 2017).

From a philosophical standpoint, it is less surprising that human-centred notions of domestication – a sort of 'one-sided' niche construction – continue to persist. In both biology and archaeology, the acceptance of NCT occurred on the basis of *empirical* evidence, without requiring philosophical or metaphysical reflection. This is where process philosophy can make a useful contribution to the study of domestication, and to unlearning its tacit assumptions.

Early 20th century process philosophers such as Alfred North Whitehead took inspiration from biology, building cathedrals of ideas on the basis that all phenomena commonly regarded as 'things' are actually processes, and hence organism-like, culminating in a 'philosophy of organism' (Whitehead 1925, 1929). In this perspective, the onus of explanation is on *stability* rather than change, and those explanations must accommodate causalities that may be complex, diverse and extended in time. Philosophers of biology (Nicholson and Gawne 2015; Dupré and Nicholson 2018) have shown how Whitehead's process philosophy influenced the 'organicists': pioneers of philosophical biology between the world wars who developed ideas of process in organisms that anticipated the niche construction perspective of the later 20th century. In fact, Whitehead's teaching at Harvard in 1924–5 reveals his reciprocal interest in the emerging 'organicist' perspective on what has come to be called niche construction (P. A. Bogaard 2020).

One figure of archaeological interest in the 'organicist' movement was Ludwig von Bertalanffy (Von Bertalanffy 1941). By the 1950s, Bertalanffy's focus had shifted from 'organism' to 'system' in his efforts to transform biology into a 'nomothetic' science based on general laws (Pouvreau and Drack 2007; Dupré and Nicholson 2018), and he is better known for General System(s) Theory (Von Bertalanffy 1949, 1950). GST was a generalising, formal mathematical framework of pattern-searching for laws applicable to the natural and social sciences. It was one of many influences on American 'New Archaeologists' of the 1960s, who developed what became known as a 'processual' approach (Kushner 1970; Trigger 2006, 418–22). Flannery (1967, 1972) used GST to frame cultural change as an ecologically driven process, abstracted from its historical context, in order to generate 'rules' or principles of systems dynamics. Binford's definition of 'process' as 'the dynamic relationships (causes and effects) operative among the components of a system or between systemic components and the environment' (Binford 1968, 269) similarly reflects GST. The 'processualism' of New Archaeology also referred to the comparative anthropological goal of identifying 'a finite number of general cultural processes' (Caldwell 1959, 306), to which Binford (1968) added his distinctive emphasis on 'middle range' processes linking past dynamics with the static material archaeological record.

In sum, 'processual' New Archaeology never embraced process as a contingent, historical unfurling of particular circumstances, the explanatory priority of stability over change, or the prospect of complex, diverse causality. GST-influenced 1960s processualism gave rise to models of domestication that depended on simplified, human-centred causality and rationality. Classic examples include

the Broad Spectrum Revolution model and related perspectives from Optimal Foraging Theory (Flannery 1969; Stiner 2001). These models are useful in a heuristic sense (Outram and Bogaard 2019, 29–49), but as literal predictions or adequate 'explanations' for the origins of farming, they have since been found wanting, giving way in particular to NCT perspectives (Zeder 2012b, 2016, 2017).

Here, we explore process philosophy as a foundation for current NCT-influenced perspectives on domestication relationships that are empirically based. We develop the argument that 'domestication' is more usefully understood as one set of processual relationships within a wider sea of processes, and that its isolation from these wider processes takes us farther away from, rather than closer to, understanding their causal background. We develop this argument by first considering how philosophers of biology think about organisms as processes, how this extends to non-living matter, and why this is relevant for studies of domestication. We then consider the emergence of 'domestication' as a term within European colonial history. Finally, we highlight current empirical evidence for domestication phenomena in different parts of the world, and on different temporal and spatial scales, in order to demonstrate how a process archaeology perspective accommodates the insights of NCT/EES, while expanding the possibilities for causal explanation.

Processes versus things

To observe that domestication, like all of evolution, is a process, or a cascade of processes, is banal. On a metaphysical level, however, prioritising processes over the 'things' we might abstract from them – that is, placing the onus of explanation on stability rather than change – remains a radical and challenging perspective. The philosopher of biology John Dupré has developed this perspective in a series of works and collaborations (Dupré 2012, 2017, 2020; Dupré and Nicholson 2018).

Building on work by Nicholson and Gawne (2015), Dupré and Nicholson (2018) identify the precursors of modern philosophy of biology in 'organicism', a movement that itself took inspiration from Whitehead's (1925) book, *Science and the Modern World* (Whitehead 1925). As he unpacks the rise of science over centuries, Whitehead's concern in *SMW* was to show how Newtonian assumptions left physics unprepared for the 'shock' of relativity theory. He proposed a 'philosophy of organism' or 'nature,' and set the scene for biology to seek its metaphysical foundation not from physics, but from its own observations about organisms. Organicists took up this challenge and developed their own processual line of thought founded on the insistence that organisms were processes, and that regarding them as things was an obstacle to understanding. Thus, wrote Woodger (1929, 219), with serendipitous reference to the first domesticate:

> "Your pet dog to-day and your pet dog yesterday are two *different* temporal parts of the same dog, just as his head and his tail are two different *spatial* parts of the same dog. It is in virtue of the particular kind of continuity of the dog yesterday and the dog to-day that we call it the 'same', and this seems to be the proper sense of the term. But it can no more be taken for granted that to-day's temporal part is the same as yesterday's than it can be taken for granted that one spatial part, e.g. the head, is the same as another, e.g. the tail. We know, in fact, that they are not the same. Organisms are temporally as well as spatially differentiated."

That these observations remain radical in their implications is borne out by the continued dominance of thing- and substance-based thinking in biology (Dupré and Nicholson 2018). If Woodger's dog is regarded as a 'thing', or a combination of substances, rather than a dynamic 'process', its persistence through time is taken for granted, or 'explained' as subject to a lack of external forces

causing change. If instead the dog is a dynamically stabilised process, this persistence demands explanation and leads to understanding of how and why the dog functions.

In addition, by thinking of the dog as a thing and not a process, we will tend to misunderstand or even deny its agency (Dupré 2017; Walsh 2018). This insight is at the heart of Lewontin's critique of classical Darwinism and the modern synthesis, in which organisms are the object of evolution rather than its subject (Lewontin 1985). In archaeological narratives under the lingering influence of classical Darwinism, an implicit thing- or substance-based metaphysics colludes with the view that humans are an exclusive source of effective agency. Particularly in any study of niche construction involving humans, including 'domestication' relationships, denying other organisms agency automatically undermines the very insights that niche construction offers as a theory. As agents, organisms have goals, and means of attaining them, and they respond to 'affordances' (Gibson 1979), 'the joint product of the organism's own capacities and the features of its setting' (Walsh 2018, 181).

If humans as organisms are processes, too, then process ontology brings in wider questions of political philosophy that also impinge on discussion of domestication. Individual self-interest has been a prominent 'explanation' for how domestication was initiated (Hayden 1990). A process perspective, however, draws attention to the cooperative nature of individual organisms as parts of 'colonies', lineages and so on. Human niche construction provides especially dramatic examples of this 'super-organism' level of agency (Dupré 2020) and is arguably more relevant to the initiation of early farming as a cooperative endeavour than perspectives that assume 'hard-boundaried self-interested individualism' (Dupré 2020) familiar from the contemporary political mainstream.

Though both dogs and humans are processes, or hierarchies of processes (metabolism, reproduction, etc.), they are clearly differentiated by their time scales (life cycles), spatial scales and species-specific trajectories (cf. Dupré 2020). This differentiation allows for potential independence as well as forms of co-dependence. A more dramatic example is microorganisms, functioning on vastly different temporal and spatial scales to their dog or human hosts. Together they can be thought of as symbiotic wholes or holobionts (Margulis 1991): universes of processes within processes, with fluid boundaries. Recognising the processual nature of organisms ushers in a far richer ecology and potential for understanding. An emerging challenge (and opportunity) for a process archaeology of domestication is therefore to consider not only the causal agencies of dog and human, but also their microbiomes.

A final consideration for this discussion of things versus processes is whether the process perspective should be limited to organisms. As argued by Malafouris et al. (this volume), what archaeologists call 'material culture' – the materials and objects entangled with humans – is deeply engaged in their mutual becoming. Dupré (2020) suggests that the way to conceptualise both living and non-living matter in a process ontology is to think of their stabilisation as playing out on radically different timescales. A process archaeology of domestication thus accommodates the niche constructing agencies of all interacting organisms, as well as the agencies of their material culture.

The 'invention' of domestication

Stépanoff and Vigne (2018) have drawn attention to 18–19th European century conceptions of 'domestication as domination'. As pointed out by Digard (1990), the power as well as the fallacy of this view are neatly illustrated by images of Lord Rothschild driving a zebra-drawn carriage in the late 19th century (Figure 1).

Figure 1. Lord Walter Rothschild's carriage drawn by zebras and a disguised horse, in front of the Royal Albert Hall (© The Trustees of the Natural History Museum, London. Licensed under the Open Government Licence).

From the Middle Ages to the 18th century, the notion of domestic animals did not necessarily imply human domination, but rather proximity to human habitation (Latin *domus*). In scientific taxonomy, the word *domesticus* still echoes this old conception: *Passer domesticus* (House sparrow), *Acheta domesticus* (House cricket) or *Mus musculus domesticus* (House mouse) are called domestic though they are 'wild commensals' in present zoological terminology.

From the 18th century, naturalists developed new concepts inspired by confidence in human power over nature. For Buffon, mirroring wild animals created by God, domestic animals are quasi 'creations' of human labour. They have been withdrawn from the rules of nature and made 'unnatural': 'Man changes the natural state of animals by forcing them to obey and serve him for his use' (De Buffon 1753). These concepts were stimulated by new breeding practices developed in the 17–18th centuries aiming to 'improve' numerous breeds of domestic animals including horses, pigs, dogs, and chickens through selection and hybridisation with Asian populations, just as horticulturists were simultaneously creating and marketing hundreds of new flower and tree cultivars.

During the 19th century, the word 'domestication' came into use, designating a specific scientific and economic field in the frame of the Societies of Acclimatisation (founded in Paris in 1854, and in London in 1859). The aim of these societies was to submit all animals that could be economically useful to human control by collecting them from different parts of the world, and acclimatizing them in European countries. The famous criterion of domestication, reproduction under human control, introduced by the founder of the French Society of Acclimatisation, Isidore Geoffroy Saint-Hilaire, is directly borrowed from the rules of international competitions organized for the domestication of exotic species. Submitting wild animals became a prestigious game for European elites, as illustrated by Lord Rothschild's famous zebra carriage (Figure 1). Thus, the cradle of 'domestication' is in a sense western European parks of acclimatisation of the 19th century, and European colonial conquest, submission and improvement. To study the associations between human and non-human societies in other areas and other periods, we need to enlarge our understanding of this notion.

Given its origins, the term 'domestication' tends to imply closely controlled management. There are rich ethnographic examples of alternative approaches in which people explicitly recognise the

reciprocal contributions and agency of other species, and that their own agricultural practices serve the needs of these species (e.g. Gudeman and Rivera 1990; Ingold 1996). Stépanoff (2017) has contrasted Siberian/reindeer and European/industrial perspectives on human-animal domestication relationships, raising also the prospect that the lasting biological effects of domestication on non-human species – a 'domestication syndrome' (see below) of traits – can range from 'low' to 'high', depending especially on the degree of reproductive control.

Here, we use the term 'domestication' in a broad sense, in reference to the relationships between humans, plants and animals that are not necessarily initiated or closely monitored by humans, but which persist for myriad reasons, normally presumed to be 'mutual benefits' to the species involved. In sympathy with NCT and EES (Müller 2017), we choose not to limit the definition using an arbitrary threshold of reproductive isolation or genetic change. It is only by allowing for the definition to expand beyond its standard confines that we can contextualise the peculiarity of recent European approaches.

Current perspectives on domestication in (bio)archaeology

Current work on domestication relationships in archaeology offers multiple avenues for exploring the potential of a process approach. We offer 'vignettes' of five such topics.

Domestication as a dynamic, ongoing process

A misconception embedded in archaeological discussion of domestication is to talk of 'domestication events' and to seek the 'origins' in time and space of a domesticate. Standard summaries state, for example, that barley was domesticated ~8000 BC in the Upper Euphrates, or rice was domesticated ~6500 BC in the Yangtze valley (e.g. Bellwood 2005). Archaeologists typically use these dates as markers in cultural-historical accounts of Neolithic 'revolutions', while geneticists model the age and population size of such 'events' with coalescence theory (e.g. Bollongino et al. 2012). But as a process, domestication is both extended and structured over time, whether the pace is fast, slow or variable. The structure and rate of this process is crucial for assessing the causal framework. The more extended in time a process unfolds, the greater the likelihood that the causal elements were diffuse and complex. To state that domestication traits became 'fixed' is itself shorthand for indicating a shift in the pace of change, though of course the evolution of the taxa did not cease. To comprehend domestication as an ongoing process, stability requires as much explanation as change.

The growth of data related to domestication processes has demanded a revision of how the process is conceptualised. A generation ago, the prospect of a rapid domestication process (20–100 years) emerged from experiments that modelled strong selection on a single key recessive gene of interest in cereals like wheat, emphasising a shift in human harvesting technology (sickle use) at the forefront of cause (Hillman and Davies 1990). In animal domestication, the Russian Fox-Farm experiment suggested that numerous morphological and behavioural changes occurred within a few decades of selection for tame behaviour (Trut 1999; Lord et al. 2020a).

The bioarchaeological evidence of plants and animals, however, has resisted expectations of rapid change. Instead, diverse cereals including wheat, barley, rice and pearl millet (Tanno and Willcox 2006; Fuller et al. 2014, 2021) exhibit both protracted periods of morphological change over millennia *and* variable rates of change (Allaby et al. 2017). West Asian livestock and Chinese pigs alike, whether considered in terms of size and shape of individual elements, log standard methods, or age profiles (e.g. Hongo and Meadow 1998; Cucchi et al. 2011, 2016; Peters, Arbuckle, and Pöllath

2015; Dong and Yuan 2020), similarly reflect protracted change, making simple assignment of specimens to wild or domesticated status difficult.

To assess the pace and variability of domestication processes, we require a metric applicable across a wide variety of species. The 'Haldane' unit offers an estimate of how much a population shifts in the distribution of measurements of a trait per generation. A Haldane of 1 indicates a change in one standard deviation unit in a single generation. Previous estimates of plant traits have calculated averages over entire domestication 'episodes' (i.e. early periods of change), and detected similarity in the pace of seed size changes across plant families, which tends to be slower than the evolution of non-shattering (Fuller et al. 2014). To appreciate the process, we need to embrace *variability* in rate within and across taxa (Allaby et al. 2017; Allaby, Stevens, and Fuller 2020).

In Figures 2–3, rates of change are illustrated with examples from China and western Asia. All taxa display episodes of accelerated phenotypic change, raising questions of causal linkage with local cultural processes. In Yangtze rice (Figure 2), a rapid increase in selection for non-shattering took place in the 5th millennium BC, while ~4000 BC there was a rapid increase in grain size during a period of intensive management of rice and water in small field systems (Weisskopf et al. 2015). Pigs in the Yellow River region (Figure 2) show accelerated size reduction in the 6th millennium BC, corresponding with marked increases in sedentism, demographic growth and millet agriculture (Stevens and Fuller 2017; Leipe et al. 2019). In western Asia, increasing grain size in einkorn in the 9th

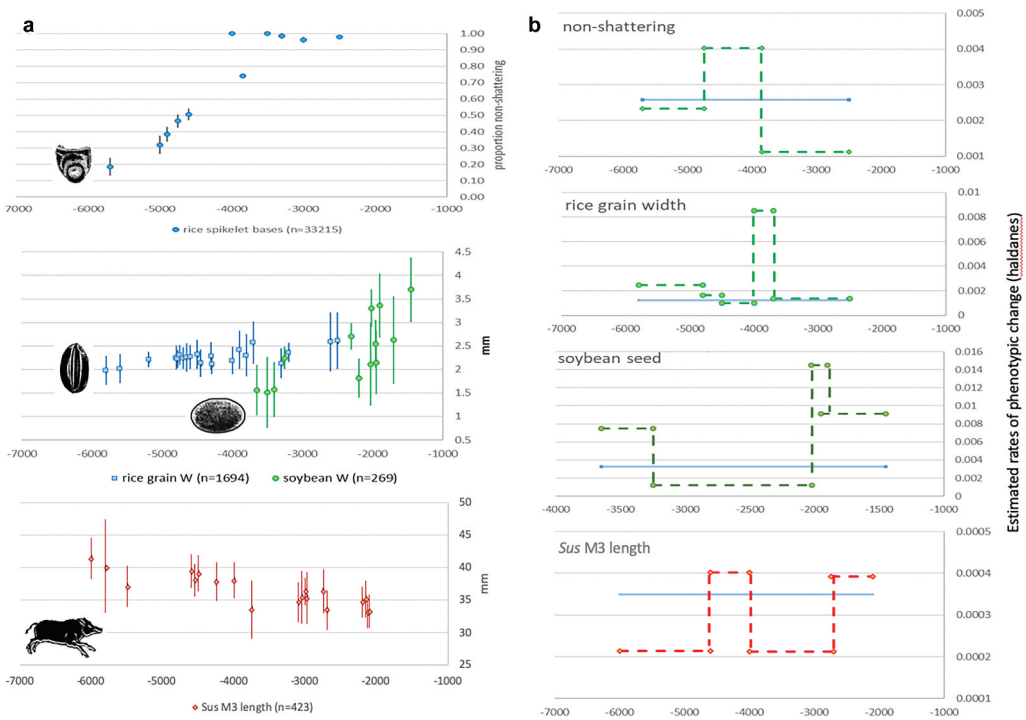

Figure 2. (a). Selected examples of morphological change from China, assemblage mean and standard deviation plotted against median age: rice non-shattering (Allaby et al. 2017), rice grain size and soybean size (Fuller et al. 2014), and pig molar size (Luo 2007; Wang et al. 2015). (b). The same dataset converted to Haldane rate estimates over subsets of the data in comparison to average Haldane rate based on a regression through the whole dataset (assumes 2-year generation for pigs, 1-year for crops).

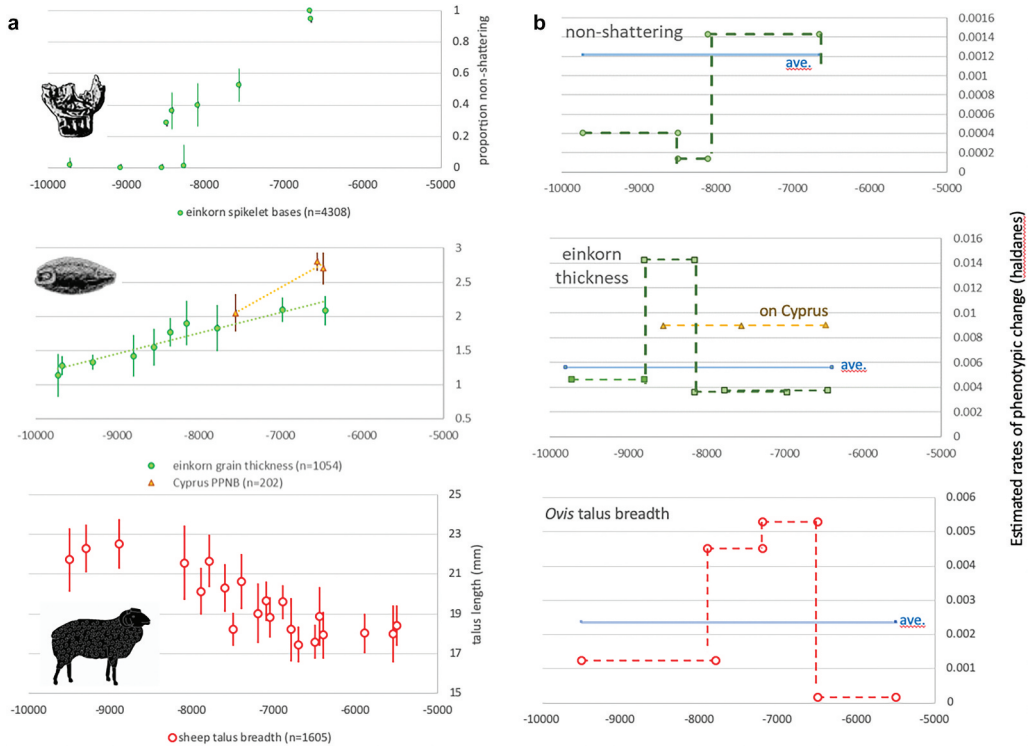

Figure 3. (a). Selected examples of morphological change in western Asia: einkorn wheat non-shattering (Allaby et al. 2017), einkorn grain size (Fuller et al. 2014; Kabukcu et al. 2021) and sheep size based on talus breadth (data compiled by authors Arbuckle and Peters based on their own work and supplemented with published (Küchelmann 2019) and unpublished data). (b). The same dataset converted to Haldane rate estimates over subsets of the data in comparison to average Haldane rate based on a regression through the whole dataset (assumes 3-year generation for sheep, 1-year for crops).

millennium BC preceded an upturn in proportions of cereal non-shattering (Figure 3). The non-shattering increase in the 8th millennium BC coincides with a continuing trend of increased specialisation and frequency in sickle blades, suggesting some kind of co-evolutionary process, though it is clear that sickle use *per se* did not drive the evolution of non-shattering (Maeda et al. 2016). Lithic microwear suggests that the proportion of mature (as opposed to green) cereal plants harvested also increased over this period (Ibáñez et al. 2016), reflecting cereal populations that shifted towards non-shattering and more even ripening.

In western Asia, the emergence of non-shattering cereals coincides with increased rates of change in sheep (Figure 3), suggesting links between domestication processes in different taxa. At Aceramic Neolithic Aşıklı Höyük (central Anatolia), dung concentrations reveal that sheep and goats were penned between houses by *c*. 8300 BC (Stiner et al. 2014). However, restrictions on mobility and dense corralling of caprines caused lasting joint damage (Zimmermann et al. 2018), likely increasing the abortion and neonate death rates (Pöllath et al. 2021). Waste products from caprine penning were subsequently integrated in small-scale intensive cultivation, indicated by stable isotope values derived from Neolithic grains (Styring et al. 2017) and weed assemblages at Catalhöyuk from c. 6700 BC (Green, Charles, and Bogaard 2018), where the evolution of non-shattering continued in the 'new glume wheat' (*Triticum timopheevii* group) (Charles et al. 2021).

Thus, the dynamics of domestication processes entail interlinked agencies of animals, plants, people and material culture. The evidence of rate fluctuations makes clear that domestication was a complex, dynamic process, one that we have only begun to comprehend.

From domestication 'syndromes' and 'pathways' to processes

Domestic organisms are often described as possessing a suite of shared phenotypic characteristics that distinguish them from their wild progenitors. In plants, these include an increase in the size of the edible portion (fruit, tuber, grain), the loss of seed dispersal (shattering) in seed crops, increased apical dominance, and shifts in the timing of production (*i.e.* greater synchronicity in seed crops and less in some tuber crops) (Denham et al. 2020). Domestic animals share traits including, but not limited to, variable, non-camouflage colouring, giant and miniature sizes, and tamer dispositions (Lord et al. 2020a).

Though Darwin (1868) observed and discussed the co-occurrence of these traits in a wide variety of domestic taxa, the term 'domestication syndrome' was first coined by botanists in the later 20th century (Harlan, De Wet, and Price 1973; Hammer 1984). The domestication syndrome was developed by tabulating parallel traits distinguishing cultivated cereals from their wild relatives. Harlan, De Wet, and Price (1973) explored parallels across wheat, barley, oats, rice, sorghum, maize and pearl millet, while Zohary and Hopf (1973) drew attention to parallel changes in pulses. Hammer (1984) later recognized that many of these same traits could be found much more widely, and distinguished different combinations in seed-grown 'field' and 'garden' crops.

Exploration of common traits of vegetative crops, including tubers and bananas, suggests the presence of environmentally influenced tendencies not only of hard-wired traits, and also that the expressions of some are opposite to those of seed crops (Denham et al. 2020). These contrasts highlight the lack of a universally applicable 'domestication syndrome'. The syndrome concept has aided comparative studies, but variation across crops and crop types highlights its limitations.

Despite widespread use since the 1980s, the domestication syndrome in animals has not been rigorously evaluated. A recent study (Lord et al. 2020a) questioned the direct link between selection for tameness (as in the Russian Farm-Fox Experiment (Belyaev, Plyusnina, and Trut 1985)) and the appearance of traits associated with the domestication syndrome. The same study also questioned the evidence for numerous syndrome traits, including the assertion (Kruska 1988) that domestic animals possess smaller brains than their wild counterparts (Lord, Larson, and Karlsson 2020b).

Domestication studies have benefited from the recognition of multiple 'pathways' through which different animal species entered the human niche. Zeder's three domestication pathways, the commensal route, the prey route, and the directed route, categorised species by the manner in which they first began their association with people (Zeder 2012a). The 'pathways' concept has since been applied to plants, yielding at least six different routes through which the association between plants and people arose (Fuller and Denham In press): the cereal pathway (including most seed crops), the segetal pathway by which new cereals and many fodder crops were recruited from weeds, and additional pathways for tubers, tree fruits, fibre crops or fibre varieties of crops like hemp and flax. Another pathway involves forms of ecosystem engineering that transform landscapes for production of species like oil palm or sago palm, which were accompanied, at least initially, by few obvious trait adaptations.

Like domestication syndromes, 'pathways' can be understood as hypotheses about processes, but where causal mechanisms are necessarily generalised. The emerging challenge is to move from checklists of traits or generalised scenarios of domestication and towards evidence-based accounts of situated processes. Jones et al. (2021) have recently taken a step in this direction through

experimental work to improve understanding of the ecological processes underlying selection for domestication traits in western Asian cereals. A key finding is that increases in seed size are likely a by-product of selection for larger, more competitive plants through improved growing conditions (e.g. fertility) resulting from human management, and that larger seeds did not necessarily increase yield. This lends further support to the view that human intention and rationality played a complex and indirect role in the selection of domestication traits (see also Allaby, Stevens, and Fuller 2020).

Cooperation versus competition

The interconnectedness of all life is a fundamental principle of process philosophy in biology: all organisms, including viruses, bacteria and complex multicellular organisms, can only survive as part of entanglements with other organisms (Dupré and Nicholson 2018). Dupré and O'Malley (2009) describe these relationships as 'collaborations', ranging from cooperative to competitive. Many explanatory frameworks for the origins of domesticated animals and plants, however, emphasise competition over cooperation, especially between humans. We argue that most if not all domestication relationships contain a strong cooperative element. Not all cooperative relationships begin with mutual or equal benefits for all partners, and many involve the mere tolerance of organisms in an environment, conventionally termed commensalism (O'Connor 1997; Vigne 2011; Zeder 2012a).

Competition between human individuals or groups plays a central role in economy- and ownership-centred narratives of the emergence of farming. In his influential model, Hayden (1990) argued that individual 'aggrandizers' used rare plants and animals in feasts to gain prestige and status, thereby initiating the management of rare food resources. Although the focus on individual 'aggrandizers' and rare foods has diminished in importance in recent years due to the lack of supporting archaeological evidence (Hayden 2009; Zeder 2009), competition continues to play a pivotal role in models that place early agricultural intensification and domestication primarily in the context of competitive feasts and/or emerging private property (e.g. Lueck and Torrens 2020).

These models are too narrow to account for all processes that culminate in domestication relationships. By concentrating on 'selfish individuals' competition-centred models fail to acknowledge widespread evidence for cooperation in early farming societies. For example, early Neolithic communities in western Asia maintained relatively egalitarian social and economic structures, with communal activities and funerary rituals that promoted community cohesion and household integration (Kuijt 2004, 2008; Twiss 2008; Bogaard et al. 2009; Makarewicz, Finlayson, and Biehl 2018). This does not mean that social differentiation and individuals with access to special knowledge would not have existed, but a focus on these competitive elements masks the inherently cooperative nature of early Neolithic farming communities.

Cooperation in domestication relationships also developed between humans and non-humans. This took place, for example, when humans became seed dispersers in place of large herbivores in numerous small-seeded crop progenitors (Spengler and Mueller 2019; Mueller et al. 2020), and when commensal animals were mutually tolerated in anthropogenic environments (Zeder 2012a). Both the wolf (Lahtinen et al. 2021) and the wild boar (Price and Hongo 2020) were likely initially attracted to human settlements by human food waste before entering a cooperative relationship, obtaining protection against predators and a secure food source from the human community. Small felids colonized early farming settlements in both western and eastern Asia, a process that predated cat domestication (Vigne et al. 2004; Hu et al. 2014). While cats potentially obtained shelter and access to prey, humans would have benefited from their role as protectors of granaries against pests who were themselves attracted to the human niche. This narrative has been undermined by a recent

study that questioned the efficiency of felids at controlling rodent populations (Mahlaba et al. 2017). A lack of detrimental effects may be sufficient to foster tolerance of commensals.

The integration of plants and animals in mixed agricultural systems further demonstrates how cooperation in domestication relationships can emerge between species that are otherwise competitors. In early farming systems in western Asia, integrating livestock with crop cultivation provided manure and fodder/stubble grazing, driving the intensification of early plant and animal husbandry practices (Bogaard 2005). Outside of such multispecies collectives, however, wild cereals and other palatable, large-seeded species are sensitive to heavy grazing (Noy-Meir 1990). These dynamics were turned around with the development of mixed farming systems, where the growth of cereals and other grain crops significantly benefits from their cooperation with grazers. In the context of African savannas, the palatability of sorghum to early livestock may account for why this species appears to undergo domestication in the eastern Sudan (Winchell et al. 2018).

Human and non-human agency

Decentering domestication away from humans has several important consequences. First, agency is shifted from questions of human intentionality and distributed to the members of multi-species hybrid communities. Research on goats (*Capra hircus*) suggests that their ecological network was crucial in directing the domestication relationship. Within the mountainous range of the bezoar (*Capra aegagrus*), a combination of altitudinally structured landscape, strong diurnal and seasonal variations in resources and the behavior and physiology of the bezoar (Korshunov 1994; Lomolino 2001) created a unique collaborative relationship between bezoars and people in the central Zagros mountains of western Asia by the 9th millennium BC. At this time, archaeological signatures of goat husbandry, such as sex- and age-specific culling, penning and dung use, are first evident in the mid-altitudinal winter habitats of wild goats. This period has also revealed the first evidence for zoonoses (Fournié, Pfeiffer, and Bendrey 2017), suggesting goats and people were in closer proximity as a result of goat seasonal mobility between mid and upper elevations and were accompanied by human co-dwellers. Recent aDNA analysis of early managed goats in the central Zagros suggests some genetic divergence from local wild populations, but without a genetic bottleneck or phenotypic differentiation (e.g. coat pigmentation) from wild goats (Daly et al. 2021). Goat management appears in adjacent lowland regions in the 8th millennium BCE (Saña Segui 2000), further reflecting the agency of goats whose physiology and disease ecology promoted transhumant co-residence with humans. The ecological and behavioural patterns of goats prevented them from being translocated to lowland regions for more than a millennium, at which point they became morphologically distinct in the absence of gene flow with wild populations (Daly et al. 2021).

Second, by focusing on networks of interaction, a process approach emphasizes that each community member actively constructs niches. Domesticatory co-evolutionary relationships are reincorporated into their broader ecological contexts. This approach encompasses historically unique collaborations such as those between humans and foxes (*Vulpes vulpes*) in prehistoric western Asia (Yeshurun, Bar-Oz, and Weinstein-Evron 2009), and relationships with organisms not involved in 'modern' global economies such as 'reindeer herding', and management of nondomestic crops and aquatic resources in neo-tropical forests (Fausto and Neves 2018). One promise of an expanded view of domestication is recognition of resource management techniques and economically useful plant/animals hiding in plain sight beyond the temperate cereal and livestock zones. Recent examples include the açai (*Euterpe oleracea*) and pequi (*Caryocar brasiliense*) (Fausto and Neves 2018).

Third, if domestication is perceived as an emergent property of the process of multi-species collaboration, and one that is never completed but always in the process of becoming, single-cause explanations (*e.g*. demographic growth, game depression, comet impacts, feasting) recede in favour of more complex, multi-causal accounts that accommodate non-human agencies. Moreover, simple explanations of domestication tend to underestimate the productivity and resilience of forager-hunter economies and to project later agricultural economies back in time. Food insecurity is frequently assumed to instigate domestication relationships even though increased demand for food is not related to domestication in any straightforward manner (Arbuckle 2015). Critique of the 1960s processual Broad Spectrum Revolution model has pointed to indications of diverse resource use in situations of resource abundance rather than scarcity (Zeder 2012b), of which early agricultural Çatalhoyuk, central Anatolia, now provides a clear example through the 7th millennium BC (Wallace et al. 2019; Bogaard et al. 2021).

Turning to yield, recent experiments with North American crop progenitors have shown that wild plants are capable of producing similar yields to their domesticated relatives when sufficient labour is invested in cultivation (Mueller, White, and Szilagyi 2019). Since the selective pressures associated with cultivation are the most likely explanation for how domestic annual plants emerged, these results suggest that some increases in yield pre-date domestication. The implication is that domestication was an incidental byproduct of increased investment in cultivating certain crops, not the mechanism by which people achieved these increases, as also hypothesised also for west Asian cereals (Jones et al. 2021).

For animals, behavioural plasticity has long been appreciated as an important factor in domestication (Zeder 2006). Recent experimental work with wild boar has also demonstrated that the entire skeleton of animals, and not just their behaviours, show immediate responses to life in anthropogenic ecosystems (Harbers et al. 2020), facilitating the emergence of new morphologies (Neaux et al. 2021). Similarly, wild crop progenitors may be especially plastic, capable of responding to cultivation or anthropogenic ecosystems (Ménard et al. 2013; Piperno et al. 2015, 2019; Matesanz and Milla 2018; Mueller, White, and Szilagyi 2019).

We encourage a shift of focus from perceived human needs to the processes and contexts of interaction. The question of 'how' this interaction operates becomes the answer to 'why' domestication occurs (Stépanoff and Vigne 2018). Mueller et al. have argued that the domestication of certain annual seed crops in eastern North America arose from deep evolutionary relationships between these plants and bison herds (Mueller et al. 2020). They envision the early Holocene landscape created by grazing bison as a template for the later agroecosystems created by people: hotspots (Marshall et al. 2018) harbouring dense stands of seed-bearing plants in nitrogen-enriched soils exploited and then recreated by people. This process may have played out in various forms in other regions as people became effective seed dispersers (see Guimarães, Galetti, and Jordano 2008 for South America), thereby altering the selective pressures acting on plant communities that spurred phenotypic change (Spengler and Mueller 2019). Domestication of small-seeded annual plants can be seen as an emergent property of interactions between humans, grazing animals, and grasslands, playing out over extended periods of time.

From 'domestic versus wild' to 'hybrid communities'

The conceptual dichotomy between 'wild' and 'domestic' emphasises arbitrary thresholds rather than processes, ignoring intermediate forms or taxa/communities that do not meet the wild/domestic criteria. This focus obscures the significance of hybrid communities.

A textbook example of hybrid communities that are conventionally separated into categories of 'cultivated/domestic' and 'weed/wild' are arable fields, which often support several crops associated with a weed community. In evolutionary terms, however, this distinction becomes obsolete when we consider cultivated fields as multispecies communities in highly disturbed habitats where all species experience selection pressures (Harlan and deWet 1965; Hammer 1984). In fact, 'wild' progenitors of crops are associated with an accompanying 'weed' flora, an observation that has only recently begun to enter into discussions of early cultivation scenarios in western Asia (Weide et al. 2018, 2021). Many weeds developed effective adaptations to different arable environments and 'crop mimics' exhibit many traits also found in crop species (Bogaard, Ater, and Hodgson 2018). The cereal mimicking *Aegilops* (goat-face grass) became a dominant and economically important component of crop harvests in extensive early urban agrosystems of western Asia; other weeds with 'opportunistic' habits offered valued sources of food or fodder in more intensively managed arable fields since the Neolithic (Bogaard, Ater, and Hodgson 2018).

The fundamental role non-crops play in arable communities includes pollinators (insects, bats), providers of nutrients or defence against pathogens (rhizobia bacteria in legume roots, endo- and exophytic microbes on roots and leaves in livestock manure and other degrading biological materials), grazers to encourage tillering/prevent lodging (Halstead 2006) and draught animals. No organism is truly independent, but rather part of a 'holobiont' (Margulis 1991) that typically consists of a larger scaffold organism interacting with a diverse array of (principally) microbial symbionts. While the role of such microbial partners was once assumed to be largely limited to nutrient uptake and conversion on plant roots and in animal digestive tracts, we are beginning to appreciate the range of roles they confer on their host, including defence mechanisms against pathogens (Rosshart et al. 2017), adaptive capacity (Alberdi et al. 2016), and in animals, even conditioning behaviour (Liang, Wu, and Jin 2018). Recent metagenomic research has found that wild and cultivated cereals affect the microbiome composition of the soil in different ways, with higher microbiome diversity in wild forms (Bulgarelli et al. 2015; Shenton et al. 2016) and implications for nutrient uptake or disease vectors (Pérez-Jaramillo, Mendes, and Raaijmakers 2016). Palaeogenomic analyses are creating new opportunities to identify ancient microbiomes in, for example, dental calculus, raising the prospect of reconstructing past holobionts (Warinner et al. 2014).

The domestic and wild dichotomy does not account for the continuum that often exists within a species. In pigs and rabbits, for example, selection over the past 10,000 years has resulted in a myriad of intermediary forms across the globe. Hybridisation is likely still taking place between populations of pigs along the domestication continuum, as in southern Europe (Frantz et al. 2019), where multiple lineages of pigs often cohabit, and interbreed, from highly selected 'modern' domestic pigs to free-living pigs and wild boar (Albarella, Manconi, and Trentacoste 2011).

Although most episodes of gene flow in pigs were likely not intentional, there is evidence of both unintentional and intentional breeding among highly differentiated 'domestic' and 'wild' forms in donkeys and camels. Donkey's solitary behaviour and largely unsupervised foraging led to encounter-based breeding among managed, feral donkeys and African wild asses over 6,000 years (Marshall and Weissbrod 2009; Marshall et al. 2014). To maintain strong, hardy transport animals, Roman period and historic herders also intentionally encouraged interbreeding with large, arid adapted wild asses (Marshall and Weissbrod 2011). Donkey's roles in trade led to further interbreeding among domestic donkeys in diverse human networks and over long distances.

As unattended foraging is also typical in camels, addressing an animal's domestication status within the native distribution of the wild form is difficult. Following long-distance trade with

Bactrian camels into regions populated naturally by (wild) dromedaries more than 3,000 years ago, cross-breeding two- with one-humped camels became widespread practice in order to obtain performance and therefore highly valued hybrids for the caravan trade (Heide and Peters 2021).

Hybridisation along the domestication continuum is also common in plants. Flax absorbed genetic variability from local populations while spreading from western Asia into Europe during the Neolithic expansion (Gutaker et al. 2019). Multiple waves of intermediary forms of maize left Mesoamerica (Kistler et al. 2018), and later expansions carried altitudinal adaptations from a second wild progenitor species (*Zea mexicana*) which were taken up by populations in both South and North America, allowing for the occupation of the mountainous Andes (Calfee et al. 2021).

The extent of hybridisation along the domestication continuum varies dramatically. Palaeogenomic data suggest that hybridisation between wolves and dogs was extremely limited over the last ~11,000 years, implying some form of selection against gene flow (Bergström et al. 2020). This is particularly striking given that, though dogs, pigs, cattle and flax were all translocated into Europe during the Neolithic expansion, dogs did not admix significantly with local European wild populations of the same or related species (Larson and Fuller 2014).

Conclusions: process lessons for domestication, and vice versa

The process perspective as developed in the philosophy of biology, since emerging in archaeology (Gosden and Malafouris 2015), offers crucial metaphysical 'scaffolding' for the challenges of niche construction and the extended evolutionary synthesis, for which domestication has emerged as a model case study (Zeder 2016, 2017). To embrace these opportunities, we advocate combining the rich and multi-stranded nature of current (bio)archaeological data with the insights of process ontology, to investigate the causal background of domestication relationships. This shift of perspective is not simply an intellectual exercise, but fundamental to redirecting approaches to contemporary dilemmas surrounding food security and sustainability. Archaeologists are uniquely positioned to debunk the myth, invested in the very word 'domestication', that these relationships depend on human control and rationality. By striving for a more sophisticated deep-time understanding that depends on the variable dynamics, diversity, cooperative aspects, diffuse agency and hybrid nature of domestication relationships, the way is open to improve future strategies.

We also hope to have shown that the development of domestication studies in archaeology holds interest for process philosophy. By taking a topic such as 'domestication' that is inherently, unarguably processual in nature, we are confronted by the challenges of situating complex processes in time and space, and of addressing 'process' in a way that 1960s 'processual' archaeology neither attempted nor recognised.

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