

Perspective

Is the domestication phenomenon more perceived than real?

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Abstract

Human associations with animals involve a diversity of sectors that promote animals as being domesticated, and that position may also convey that individuals used in those situations require lesser concern in captivity than if they were utilised wild organisms. The domestication phenomenon is complex and multi-stage, involving genetics, successive generations, extensive time periods, and other factors—and is not merely a process of selective breeding for desired characteristics. This report considers whether the domestication phenomenon is more perceived than real. We examine the use of the term and its inferences, examples of species that are considered to be domesticated, and analyse those species for their adherence to or divergence from domestication principles. As assessed by their ability or inability to establish invasive or self-sustaining released or introduced populations, of the 46 studied species recorded as domesticated, all were associated with confirmed invasive or self-sustaining populations, with the qualified exception of domestic dogs. We conclude that available material does not indicate that the domestication phenomenon genuinely applies to any animal, and therefore requires urgent revision. Wrongly assuming or misrepresenting animals as being adapted to highly controlled and restrictive captive conditions based on their presumed domestication may overlook major biological needs, and result in significant or severe deprivation, stress, morbidity, and premature mortality, as well as mislead consumers regarding the nature of animals and their by-products.

Keywords Domestication · Wild animal · Exotic pet · Animal welfare · Agriculture · Culinary trade · Mobile zoo

1 Introduction

Human associations with animals involve a diversity of sectors or industries, including: agriculture and culinary (e.g., animal protein sources); exotic pets (e.g., wild-pets or non-traditional pets [companion animals]) [1–3]; fashion (e.g., fur, skin) [4, 5]; traditional medicines and curios (e.g., body-parts including heads, feet, and teeth) [6, 7]; entertainment (e.g., elephant tourism, circuses, dolphinariums, aquariums, and traditional zoos) [8–11]; and mobile zoos (e.g., mobile live animal experiences, travelling shows, animal education workshops) [12, 13]; among others.

Within various sectors, the term ‘domestication’ is often used or promoted in messaging to infer that domesticated animals may be considered inherently suitable for, or even content with, their captive situations. For example, in chicken farming it is suggested that perching needs are decreased with domestication [14], and traders of some pet animals promote exotic forms as being domesticated to increase their appeal as easy to keep [15–17]. Also, certain government sources suggest that the behavioural needs of farmed domesticated animals differ from wild counterparts [18]. Other perspectives on agriculture have stated that behaviours and needs are more predictable and

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manageable for domesticated animals, including that housing, nutrition, and healthcare are more straightforward, and that these animals are adapted to resources and human-controlled environments, as well as require less space compared with wild forms [19]. In addition, common and scientific definitions of domestication (Box 1) frequently imply that such animals are adapted to captivity and use by humans, as will be explored in more detail later. Combined, those positions may convey that animals used in such situations require reduced concern because they have been 'developed' for purpose.

The term domestication derives from the Latin word '*domus*', or 'belonging to the house'. Although not entirely clear, broadly, the origins and use of the term domestication appears in relation to animals under the incidental or direct influence or control of humans, notably, in the earliest associations, dogs as affiliative co-hunters, and later cattle, goats, pigs, and others for cultivation purposes as livestock [20–22]. Historically, keeping of livestock would include animals that co-occupied spaces within rustic home quarters of humans (e.g., byre dwellings), which was frequently performed to protect animals from harsh climates and weather; indicating cultural and socio-economical associations [23–25]. Subsequently, more structured farming emerged that was reminiscent of current agricultural production [21, 22]. In those contexts, domestication did not imply scientific understanding regarding any biological changes caused by humans [23, 25, 26].

Today, the colloquial use of the term may essentially be interpreted to represent animals with a long or particular history of being kept and bred for human benefits [27]. However, again, in itself, that interpretation has no relevant biological rationalisation. A lack of unified understanding of domestication may be one factor contributing to why the term has been regarded as misunderstood [22, 28] and confusing [25, 28]. Scientific use of the term domestication is variable. Common themes between these variables include references to animals with histories of being multigenerational captive-bred, selectively bred, or genetically manipulated [28, 29]. Relatedly, additional or concomitant inferences emphasise the changing of animals from their natural wild state to partly or wholly conform to a captive lifestyle under varying, typically highly managed, degrees of human husbandry [23, 26]. Thus, domestication infers altered animals that are amenable to or even possess preferences towards captivity. The term 'domestication phenomenon' (also called 'domestication syndrome') broadly describes the issue and characteristics of domestication in a scientific context. Relevantly, uses and implications for the term domestication have recently been subjected to focused criticisms. For example, a study of Russian farmed foxes examined behavioural selection for tameness, and concluded that claims in respect of domestication have been overstated [30]. Also, another recent study into the ways that the terms 'domesticated animals' and 'wildlife' are used by governments noted the significance of domesticated organisms as invasives, and similarly concluded that the terminology is imprecise and requires reform [28]. References to domestication can include plants and fungi, however, those classes are beyond the scope of this discussion.

Although frequent and differing references to domestication regularly occur in the scientific literature, several studies have focused largely on the foundation of domestication, its practical development, and roles in husbandry and commodification (e.g., [20, 21, 25, 33, 35, 36, 39, 41, 42, 45–49]). In contrast, others have conducted combined biological, cultural, political, legal, and ethical analyses of domestication, and point to the phenomenon in relation to animal-centric issues that potentially lead to concerns regarding welfare or abuse (e.g., [23, 29, 38, 50–52]).

Broadly, the scientific literature suggests that the biological basis of domestication is primarily founded on artificial selection of desired traits [46]. However, the phenomenon is complex, multi-stage, and diversely involves or requires certain key characteristics, including: adaptive (notably pre-adaptive) plasticity among animals; relevant evolutionary history; amenable environmental situations; conducive genetics; appropriate psychological organisation and behavioural traits; resultant behavioural and morphological change; significant reproductive capacity, and other factors [20–23, 25, 33, 35, 36, 39, 41, 42, 45–49]. Accordingly, the potential for domestication among animals is not merely a process of selective breeding for desired differences. In particular, behavioural adaptivity and subsequent change are major factors in the domestication phenomenon [25]. Importantly, although behavioural response thresholds may change during the process, the behaviours themselves are neither added nor removed [25]; indicating only the potential modification and not elimination of traits.

This report aimed to: 1. examine the use of the term domestication and its inferences; 2. cite key examples of species that are considered to be domesticated; and 3. analyse key example species in respect of their adherence to or divergence from domestication, as measured by their ability or inability to establish invasive or self-sustaining (e.g., feralised or naturalised) populations where incidentally released or introduced. Also presented, is a hypothesis in which issues of domestication adherence, divergence, or readaptation to the wild are discussed in relation to some significant implications for claims that seek justify the use of animals by humans.

Box 1 Common and scientific summary descriptions for domestication

Definition	Context	Source
1. The adaptation of a plant or animal from a wild or natural state (as by selective breeding) to life in close association with humans	Common/colloquial	[31]
2. Domestication is a process in which wild plants or animals are selectively bred and controlled by humans for their own benefit. It involves changes in behavior, genetics, and physical traits of the domesticated species compared to their wild counterparts. Domestication has played a crucial role in the development of agriculture and the establishment of human societies. It is a co-evolutionary process that involves a mutualistic relationship between humans and the domesticated species. The process of domestication can lead to the origin of new species or differentiated populations that are essential for human survival	Semi-scientific	[32]
3. "A distinctive coevolutionary, mutualistic relationship between domesticator and domesticate and distinguished from related but ultimately different processes of resource management and agriculture."	General	[33] p. 3191
4. "A sustained multigenerational, mutualistic relationship in which one organism assumes a significant degree of influence over the reproduction and care of another organism in order to secure a more predictable supply of a resource of interest, and through which the partner organism gains advantage over individuals that remain outside this relationship, thereby benefitting and often increasing the fitness of both the domesticator and the target domesticate."	General	[33] p. 3191
5. "An evolutionary process forced by human influence."	Elephants	[34] p. 2
6. "A process by which a population of animals becomes adapted to a captive environment by the combination of genetic changes and environmentally induced developmental events."	Poultry, chicken, meat	[35] p. 10
7. "Multi-generational control of animal breeding that results in detectable changes in genetics, morphology, and behaviour."	Cattle, bovine, meat	[36] p. 117
8. "Genetic change in plant and animal stock, such that the domesticated form is genetically different from anything in the wild."	Agriculture	[37] p. 54
9. "A process whereby captive animals adapt to man and the environment he provides."	Feralisation	[38] p. 186
10. "The process by which a population of animals becomes adapted to humans and captive environments by one or more combinations of genetic modifications throughout generations and developmental events induced by the environment, recurring in each generation."	Fisheries, aquaculture	[39] p. 388
11. "A long and endless process during which captive animals become gradually adapted to both humans and captive conditions."	Wildlife conservation	[40] p. 3
12. "That process by which a population of animals becomes adapted to man and to the captive environment by some combination of genetic changes occurring over generations and environmentally induced developmental events reoccurring during each generation."	Farm animals, pet animals	[20, 41] p. 2
13. "That condition wherein the breeding, care and feeding of animals are more or less controlled by humans and/or the adaptation to captivity via population genetic mechanisms in which natural selection is largely replaced by artificial selection."	Parrots	[42] p. 2
14. "Domestication is defined as an evolutionary process arising from an ecological interaction: one species actively manages the survival and reproduction of another, which ensures resources and services to the former. Domestication is a long process that ultimately leads to a range of physiological, morphological and behavioural changes in the domesticated species."	Dogs, general	[43] p. 2
15. "A mutualistic and co-evolutionary process where both humans and domestic animals (and plants) reshape environments and landscapes, and in turn are affected themselves by these changes, both in terms of their life histories and evolution. Further, domestication is defined as an emergent or ongoing process rather than a threshold passed long ago with the first appearance of genotypic or phenotypic difference."	Dogs	[44] p. 114

2 Methods

For this study, we identified species commonly regarded to be domesticated, and examined these examples in the context of reported invasive species or self-sustaining populations. Categorisation of animals by species can imply that all individuals of that type are entirely included. However, for this report, references to species are intended to convey that individuals or groups of individuals belong to a species (e.g., populations of a species). For example, it is possible that not all individuals or groups of animals within the same species will manifest success or failure as invasives or self-sustaining populations. Invasive species are organisms introduced (whether accidentally, intentionally, or incidentally) through human-mediated means into habitats where they are non-indigenous, and where frequently their presence has ecologically disruptive effects [53, 54]. Self-sustaining populations (here implying artificially introduced) can include any species that successfully occupies an area, or becomes feralised [25, 55], whether or not invasive [56, 57].

Relatedly, we assessed whether, and if so which, species that are scientifically recognised as domesticated have successfully adapted to and occupy natural habitats and become free-living invasive or self-sustaining populations. Accordingly, we examined reports identifying where domesticated species had become successful if released or introduced. If exemplary species that are recognised to be domesticated are incapable of becoming successful where released, then this outcome could indicate that the domestication phenomenon is strong, because modified animals would be remaining dependent on artificial environments and human assistance. However, if such species are capable of becoming successful when released or introduced, then this outcome could indicate that the domestication phenomenon is weak or more perceived than real, because those animals would in effect remain capable of naturalising.

To produce an objective database of domesticated species (cited in Table 1), sources were identified that listed scientifically accepted examples [25, 28, 58–60]. Next, a standardised database (Global Invasive Species Database (GISB) [61]) of recorded invasive species was used to assess whether the claimed domesticated animal is associated with invasive or self-sustaining populations. This target information was subsequently cross-checked for reports via Scholar for each listed species by using the species scientific name + 'invasive', and then the process was repeated using the species scientific name + 'self-sustaining population' to further verify the relevant status of the selection. Where species were not recorded on the GISB system, supplementary standalone searches were conducted via Scholar using (first) the species scientific + 'invasive' and/or, (second) the species scientific name + 'self-sustaining population', and/or (third) the species scientific + 'introduced', and where available, added confirmatory citations accordingly. The tabulated information in this study records species as invasive or self-sustaining populations without specifying the association because, first, almost all were identified as invasive, and, second, the categorisation is relatively unimportant whether or not a species has become successful when released because all were recorded as stable populations.

3 Results

Table 1 provides examples of species frequently claimed, and scientifically recognised, to be domesticated, and their reported status as invasive or self-sustaining; i.e., successful when released or introduced. Of the 46 recorded domesticated bird and mammal species (including subspecies), listed in Table 1, all were associated with confirmed invasive or self-sustaining populations; i.e., the introduced and successful organisms (whether individuals or groups) belong to those species, with the exception of dogs, which are discussed later.

4 Discussion

A range of scientific descriptions (Box 1) were identified regarding the term domestication, as well as various rationalisations or justifications for its use. As indicated previously, claims in industry, government, and other sources suggest that domesticated animals may have reduced biological and behavioural needs. Claims regarding domestication can be extremely broad and include species as diverse as octopuses and giant crocodiles on the sole basis of them being captive-bred [103]. Relatedly, of the 15 definitions cited in Box 1, six (numbers 6,9,10,11,12,13) make clear references to domestication as implying that the relevant species are adapted to captive conditions. These claims may play a role in whether and to what extent other authors, policymakers, and practitioners may further regard, report, or interpret

Table 1 Example species frequently considered to be domesticated, and their reported status as successful or otherwise when released (i.e., whether or not invasive species or self-sustaining population)

Common name	Scientific name of species stated as domesticated [Source]	Confirmed as invasive species or self-sustaining population [Source]
Chicken	<i>Gallus gallus domesticus</i> [28, 59, 60]	Yes [62, 63]
Guinea fowl	<i>Numida meleagris</i> [28, 59]	Yes [64]
Turkey	<i>Meleagris gallopavo domesticus</i> [28, 59]	Yes [65]
Duck	<i>Anas platyrhynchos domesticus</i> [60]	Yes [66]
Pigeon	<i>Columba livia domestica</i> [28, 59]	Yes [67]
Ostrich	<i>Struthio camelus</i> [68]	Yes [69]
Dog	<i>Canis lupus familiaris</i> [28, 58–60]	No (some exceptions) [70]
Cat	<i>Felis catus</i> [28, 58–60]	Yes [71–73]
Rabbit	<i>Oryctolagus cuniculus domesticus</i> [28, 59]	Yes [74, 75]
Guinea Pig	<i>Cavia porcellus</i> [58]	Yes [76]
Ferret	<i>Mustela (putorius) fero</i> [58, 59]	Yes [77]
White lab rat	<i>Rattus norvegicus domestica</i> [28, 59]	Yes [78]
White lab mouse	<i>Mus musculus domestica</i> [28, 59]	Yes [79, 80]
Mink	<i>Neogale vison</i>	Yes [55, 81, 82]
Coypu	<i>Myocastor coypus</i>	Yes [55, 81]
Muskrat	<i>Ondatra zibethicus</i>	Yes [55, 81]
Cow	<i>Bos taurus, B. indicus, B. primigenius, B. namadicus</i> [25, 28, 58–60]	Yes [83]
Bali cattle	<i>Bos javanicus</i> [25, 60]	Yes [84]
Yak	<i>Bos grunniens</i> [25, 58]	Yes [85]
Mithan	<i>Bos frontalis</i> [25]	Yes [86]
Water buffalo	<i>Bubalus bubalis</i> [25, 28, 58–60]	Yes [87]
Llama and alpaca	<i>Lama glama, L. pacos, L. guanicoe, V. vicugna</i> [25, 28, 58–60]	Yes [88–90]
Sheep	<i>Ovis orientalis aries, O. musimon</i>	Yes [91]
Reindeer	<i>Rangifer tarandus</i> [25]	Yes [92]
Pig	<i>Sus domesticus, S. scrofa, S. celebensis, S. barbatus</i> [25, 28, 58–60]	Yes [93–96]
Goat	<i>Capra aegagrus hircus, C. aegagrus, C. falconeri</i> [25, 28, 58–60]	Yes [97]
Camel	<i>Camelus bactrianus, C. ferus, C. dromedarius</i> [25, 28, 58, 59, 98]	Yes [99, 100]

Table 1 (continued)

Common name	Scientific name of species stated as domesticated [Source]	Confirmed as invasive species or self-sustaining population [Source]
Donkey or ass	<i>Equus asinus</i> , <i>E. africanus</i> [25, 58, 60]	Yes [101]
Horse	<i>Equus caballus</i> , <i>E. ferus</i> , <i>E. przewalski</i> [25, 28, 58–60]	Yes [102]

domestication to mean that animals are—as a result of the process—better suited to captivity. Captivity, by both its definition and nature, is associated with restrictive conditions regarding habitat, spatial, and social diversity and complexity, among other factors, compared with natural environments. Thus, implicitly, labelling animals as domesticated also suggests that they have less complex and diverse needs than their wild counterparts.

By comparing a list of accepted domesticated species with their success or otherwise as subsequently free-living populations, provides an outcome-led assessment, regardless of genetic and other biological histories. The occurrence of invasive or self-sustaining populations of species commonly recognised as domesticated demonstrates their ability to ‘re-wild’ or inability to truly ‘de-wild’.

In this hypothesis it is proposed that domestication as a phenomenon is typically weak, has minimal biological relevance in that it does not alter the inherent natural lifestyles and needs of animals, and is in almost all claimed examples more perceived than real. It can be argued that within current regular perspectives on domestication there exists a continuum between false references to what are manifestly captive wild species (i.e., indigenous normally free-living wildlife) and reasonable references to, for example, domestic dogs. However, it may also be argued that if domestication is predominantly an impermanent condition or minimally represented as an evolutionary outcome, then it would appear disproportionate to assign strong import to the term and its use; not least because in balancing the ‘wild *versus* domesticated’, the natural condition is clearly the winner. Similarly, the term non-domesticated arguably constitutes a distraction by reference to a predominantly ingenuine state. Therefore, the term ‘semi-wild’ may constitute a more scientific and genuine descriptor for species or types that have been formerly regarded as domesticated, including animals that are highly modified for human exploitation, such as agricultural groups.

Whilst Table 1 is based on key lists of species recognised as domesticated, and was objectively selected, it is possible that other examples could manifest different outcomes; i.e., provide other cases of domestication to explore. Consideration was also given to examining reintroduction and relocation programmes, because those are examples that inherently test the possible extent to which captive-breeding and long-term captivity may affect survival among released individuals. Such success or failure rates arguably indicate whether animals have been changed by captivity for captivity. However, scientifically-informed and conservation-motivated captive-breeding programmes deliberately aim to preserve original genetic integrity wherever feasible; thus, such examples cannot be considered altered through domestication, and do not lend themselves to providing model cases. Nevertheless, an important allied point arises in that even organisms across all classes that are raised with the intention of their release for conservation repopulation purposes, frequently fail to thrive in the wild [104, 105]. Thus, various in-situ ecological and other environmental factors may be relevant to the survival and success of any introduced animals rather than the fitness of the animals themselves. Accordingly, should presumed domesticated animals fail to thrive in the wild, such failure does not necessarily imply that the scenario resulted from any adaptation to captivity.

In the reviewed literature, certain invertebrates (e.g., [106, 107]), fishes (e.g., [28, 39, 58, 59, 108]), amphibians (e.g., [109–111]), and reptiles (e.g., [109, 110]), were sometimes referred to as domesticated. However, none of those sources provided detailed scientific rationales or evidence for considering those species to meet the criterion. Rather, their classification as domesticated relied largely on the simple issue of artificial selection and reproduction in closed systems, which is widely regarded as overly simplistic. Moreover, other assessments, for example, most notably but not exclusively pertaining to reptiles, have determined that there are no domesticated examples, despite many generations of selective breeding, and that inherently these animals are resistant to the phenomenon due to their innateness or hard-wired biologies, among other factors [29, 51, 52]. Essentially, whilst there are various reports in the literature containing detailed and scientifically rationalised descriptions of domestication for some birds and mammals, there appear to be no descriptions for ectothermic species, such as invertebrates (e.g., insects, arachnids, crustaceans, squid, and octopuses), fishes (e.g., sea horses, carp, salmon, and rays) amphibians (e.g., frogs, toads, newts, and salamanders), and reptiles (e.g., turtles, tortoises, lizards, and snakes). Therefore, whilst all of the aforementioned animals are variously farmed or otherwise captive-bred,

none of these ectotherms can be regarded as domesticated or adapted to commercial reproduction conditions or other related situations. Thus, the inclusion of ectotherms herein for focused consideration would be arbitrary.

As reported in Table 1, all species that were scientifically and formally identified as domesticated were also associated with confirmed invasive or self-sustaining populations. Feralisation has been reported in highly domesticated examples including for chicken and dog populations [112, 113], which essentially signifies demonstrable readaptation from assumed domestication traits. However, it can also follow that not all individuals or populations of a species, for example, rabbits [75] succeed as invasives. Therefore, importantly, human manipulated changes in domesticated animals does not prevent their re-occupation of natural environments, and may have only minimal to no effect regarding their readaptation to nature. Accordingly, even where one might argue that dogs may meet some criteria for domestication, here too the phenomenon appears fragile and incompletely genuine. Thus, in both common and scientific contexts, the implications for the term domestication are arguably frequently overstated, wrongly used, largely redundant, and mostly invalid; with animals remaining essentially wild or semi-wild depending on their access to nature.

Studies at the genetic level suggest that where released or escaped animals revert to nature, the process may not constitute mere reversal of the domestication history; rather that different genetic pathways essentially enable organisms to readapt and revert to natural conditions [112]. Thus, whilst the term domestication reversal is frequently encountered, and sometimes possibly narrowly interpreted or incorrectly mentioned, 'reversal' may more appropriately imply adaptational outcomes that lead to reversion to wild state, based on new selection pressures that exist in the wild.

Also, genetic distinction absolutely does not imply that ethological needs and instinctive drives are reduced. If this were the case, then there would be no function for reproductive neutering and mutilations to, for example, the teeth, beak, or horns of animals, which are designed to suppress reproductive drives of these so-called domesticated species.

Several allied issues of relevance may potentially inform discussion regarding the domestication phenomenon. First, some animals may to varying extents life-share with human society or other species (e.g., via urbanisation and symbiosis), and certain examples can be analysed for their relevance to the domestication phenomenon. Second, because domestic dogs appear to be the most strongly emphasised example of domestication, these animals arguably warrant focused examination. Third, extreme manipulation of animals for special breeds can also be considered within the debate concerning the domestication phenomenon.

4.1 Urbanisation and symbiosis

Many wild and free-living species may occasionally or regularly occupy urbanised environments, notably in towns and cities, and thus use human environments. However, such behaviour in itself does not indicate true dependence on humans. Numerous wild, free-living, species exploit human environments, for example: frogs (e.g., *Hyla* sp.) occupy urbanised areas including artificially lit product vending machines in order to prey on invertebrates similarly attracted by such lighting [114]; lizards (e.g., *Iguana* sp., and *Anolis* sp.) are among many reptiles exploitatively inhabiting towns and cities for basking sites and prey acquisition [115]; birds (e.g., *Passer* sp.) use man-made structures for perches and nests [116]; and foxes (e.g., *Vulpes* sp.) utilise refuse bins and other feeding opportunities [117].

Relatedly, numerous species, such as spiders (*Sparassidae* sp.) [118], lizards (*Hemidactylus* sp.) [119], and mice (*Mus* sp.) [120], may frequently enter or semi-reside in houses or farms to acquire live prey or other food and return to natural habitat afterwards, or even become semi-resident. Essentially, such habitat or resource exploitation implies opportunism towards resources within an altered natural home range, and may better be regarded as commensal associations [22]. Thus, behaviours exploitative of human environments and activities, including in urbanised areas, are different from, and do not imply or confirm, the domestication phenomenon.

Some species also manifest symbiotic or semi-symbiotic ('mutualistic') biologies in nature, where individuals frequently share shelters or activities; for example, shrimp (*Alpheus* sp.) and goby (*Ctenogobius* sp.) [121], clownfish (*Amphiprion* sp.) and anemones (*Heteractis* sp.) [122]. Thus, again, whether an individual animal, or by habit its species, voluntarily occupies the home environment of another does not indicate domestication.

4.2 Dogs

Domestic dogs (*Canis lupus familiaris*) manifest overt close associations with humans and society to include voluntary and genuine life sharing interactions [113, 123, 124], and arguably constitute the primary example of domestication. The domestic dog may have the longest human association—potentially 15,000 years—of any species (e.g., [123, 124]). Of the species listed in Table 1, the domestic dog is the only example for which some free-living (free-roaming), or feralised

populations are reported to frequently be semi-dependent on some human assistance for their reproductive success and sustainability and, therefore, are non-self-sustaining [113]. Perhaps unsurprisingly, dogs possess exemplary pre-adaptive and commensal traits that are important to the domestication phenomenon, including strongly affiliative psychological and behavioural histories, highly socialised structures, and malleability to imprinting [20, 113, 123].

Some possible key factors in the apparent degradation of reproductive sustainability amongst free-living or feralised dogs are increased neoteny and reduced ability to hunt [113]. However, even amongst dogs, there exist arguably relevant examples where populations have become self-sustaining. For example, dingoes (*Canis lupus dingo*) appear to have emerged from former domesticated dogs to manifest self-sustaining populations [55]. Although such successes may have arisen over long periods of time, such adaptations mean that other free-living dog populations could revert to natural life after domestication. Relatedly there may be other, latent, reasons, such as unrecognised regional ecological constraints, why certain populations of dogs are not self-sustaining. Also, artificial manipulation may have de-selected (at least temporarily) key survival traits and selected unfavourable traits that would normally be naturally deselected or suppressed. In addition, emergence of self-sustainability among dog populations may be a matter of when and not if.

Regardless, even if domestic dogs are enduringly incapable of self-sustaining their populations through reproduction, then it remains relevant that these animals frequently maintain highly successful lives as free-roaming adults, and also possibly as small groups, and develop complex social and environmental strategies within a human meta-ecology [113]. Indeed, despite potentially being mostly unsuccessful reproductively, free-roaming domestic dogs are known to become competitive, albeit reduced-capability, hunters of wildlife in novel ecologies; thus, constituting limited invasive species in that regard [113]. Therefore, a lack of reproductive sustainment reflects only a partial biological adherence to domestication. Whilst dogs may be the most naturally pre-adapted and affiliative species for humans and society, possess the longest history of association and manipulation, and also be the most scientifically documented example of domestication, these animals also manifest malleability towards reversion from the phenomenon.

4.3 Extreme manipulation

Certain animals may be regarded as examples of domestication due to the extreme changes to them brought about by human manipulation; for example, various breeds of dog (e.g., bulldog) and cat (e.g., Persian) possess severe brachycephalic malformations as a result of selective breeding [125–127]. These animals experience common and highly problematic consequences including respiratory distress and dermatological disease [125–127]. Also, extreme production methods involve certain types of broiler chicken possessing artificially large body-mass states [128], cattle with traits including double-muscling and grossly enlarged udders [129], goldfish manifesting distorted morphologies [130], hairless cats [131], and giant rabbits [132], that may prevent normal independent activities. Such conditions may result in the strong dependence of these animals on human intervention and support, including general husbandry and limited corrective surgery, for individual survival [128–132]. Thus, these animals may not be able to survive without human help. However, this dependence does not indicate an improvement in an animal favouring adaptation to human lifestyles, rather it may arguably signify examples of deliberate genetic damage, and be superficially considered akin to injury from cosmetic removal of a limb or limbs.

Two hypothetical questions may be relevant to judging whether an animal is genuinely domesticated. One question is to ask whether, if humans were not present in an environment, would free-living 'domesticated' animal survive? Another question is that if an explorer arrived in a new territory of entirely unfamiliar animal occupants with self-sustaining populations from formerly domesticated types, would those animals be obviously identifiable as domesticated (i.e., not perceived as indigenous wildlife?). If the answers are yes to the first question and no to the second question then the status of those formerly recognised domesticated species would be entirely academic.

It is reasonable to recognise that selective breeding may, or does, result in various alterations at the genetic, physiological, morphological, and behavioural levels, and that such changes arguably infer that such animals are essentially different in certain respects from their original wild forms. However, because those same animals, in becoming invasive species, manifest little, no enduring, or no adherence to such changes then the success or survival outcome of any domestication process is, in effect, significantly indistinguishable from no domestication having occurred.

4.4 Implications

Numerous industries are currently misdescribing species as domesticated, including as part of their promotional messaging or operational justifications. For example, many exotic animal keepers, such as snake propagators, selectively

breed animals over multiple generations for desired differences of colour and pattern variations, also called 'morphs', and otherwise market reptiles as domesticated for pet purposes [15–17, 51, 52]. However, none of these exercises in selective breeding constitute domestication, nor approach incorporating genuine scientific concepts and practices towards the phenomenon (e.g., [17, 51, 52]). Indeed, such approaches to selective breeding have resulted in introduced genetic disease and increasing animal health concerns [2, 133].

Describing species as domesticated potentially enables commodifiers to claim that, in particular, animal welfare is assured because it is implied that those individuals were 'made' for certain uses and thus are presumed content with such lifestyles; regardless of frequently deprived environmental conditions and intrusive husbandry practices. Most importantly, assuming animals to be comfortable within and/or adapted to highly controlled and restrictive captive conditions based on their presumed domestication may overlook major biological needs, and result in significant or severe deprivation, stress, morbidity, and pre-mature mortality.

Misinterpreting or misdescribing species as domesticated also has at least two further plain problematic ethical or legal implications. One implication is that whether intentional or incidental, misinforming the public regarding the history of commercial products that they provide potentially or actually interferes with or deprives people of making informed decisions (ethical or otherwise) concerning the nature of animals or their by-products that they may acquire. The other implication is that in principle, and in some cases in law, misleading or encouraging potential customers into believing that purchasing animals or their by-products on the basis that those animals were suited to the system of production from which they emerged (i.e., falsely claiming those species as domesticated animals that are amenable to captivity) arguably constitutes plain dishonest marketing. A range of measures, including legal frameworks exist that recognise the impropriety of such conduct, and provide punitive remedies for control (e.g., [134–136]).

Given the numerous interpretations and misinterpretations of the term domestication, it would appear not unreasonable that many operators across all industry sectors could wrongly yet unintentionally ascribe the term to their activities. However, going forward, any such position or claimed defence using the term domestication as a supporting attribute for captive animal use should be avoided and reformed.

4.5 Potentially useful definitions?

The apparent lack of scientific justification or relevance for the term domestication raises important questions regarding any pertinence or function for its use. This report and analysis indicated that all animals studied, regardless of degree of subjugation to human-mediated modification or captive or free-living status, inherently retain their fundamentally 'wild' biologies. Although clearly harbouring histories of human-mediated alteration from their original forms, manifestly such animals also do not share the same histories as their entirely wild conspecifics. Accordingly, the terms 'semi-wild' (any scenario), 'urbanised' (e.g., feralised), or 'agricultural' (e.g., farmed livestock) animals may more accurately relate their true nature by reflecting their in-situ status, without ascribing loss of inherent wildness. Importantly, none of these terms should be considered to assume suitability of any animal to captivity and to human use, nor should they act as replacements for the term domestication. Rather, these terms could act as models for redefining the concept of domestication, which undervalues the role of wildness in all animals, as well as promoting its redundancy.

5 Conclusions

A lack of clear descriptions for the applied use of the term domestication and its context may, at least in part, indicate poor standardisation, understanding, or consensus, for its relevance. For these reasons it is understandable that the interpretation and use of the domestication term or phenomenon has persisted. Whether or not colloquial references to domestication continue as ad hoc descriptors for animals that are farmed or affiliative around humans, the scientific, ethical, and legal bases of its utilisation are due for re-examination and general reform.

Towards this required understanding it can be proposed that three simultaneous and thus co-present markers should exist in order to declare true domestication in any species: 1. permanent or enduring positive animal welfare centric biological change in animals caused by human intervention; 2. resultant introduced primary preference among animals for captive conditions over natural life, beyond symbiotic or opportunistic cohabitation or use of human environments; and 3. essential dependence of animals on human environments and captivity for survival. Based on the outcomes of their release and associated abilities to become invasive or self-sustaining in the wild, available material does not indicate that the phenomenon meets these criteria, and thus few or no species may genuinely be domesticated.

At the very least, in many, if not most or all situations, references to domestication appear to be assumptions that over-interpret artificially manipulated animals to be fundamentally more different in relation to their wild counterparts than they truly are. Such assumptions place captive animals at risk of poor welfare due to deprivation of fundamental and complex biological needs, and potentially misinforms or misleads consumers of animal-based foods, fashion, pet, curio, or other products who may wish to be informed or assured regarding ethical purchasing.

6 Recommendations

1. The term domestication should not be used to describe any species of invertebrate, fish, amphibian, reptile, bird, or mammal—save as for the cautiously qualified exception of dogs (*Canis lupus familiaris*).
2. The term domestication should not be used as a supporting or promotional attribute for any captive animal commodification or keeping purposes.
3. Governments, non-government organisations, industry policy-makers, commodifiers, educators, and others, should endeavour to express future caution against using the term domestication.
4. According to situation, the terms ‘semi-wild’ or ‘urbanised’ or ‘agricultural’ may more accurately define both the in-situ status and inherent wildness of animals historically referred to as domesticated.

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Data availability No datasets were generated or analysed during the current study.

DeclarationsDeclarations

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