RESEARCH ARTICLE

AGROBIOLOGICAL RECORDS

ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)

Open Access Journal

UNVEILING BEHAVIORAL RESPONSES OF WILD ANIMALS: INSIGHTS FROM DOMESTICATION IN THE FACE OF ANTHROPOGENIC CHANGE

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ABSTRACT

In our rapidly changing world, where human activities have profound effects on nearly all forms of life, understanding the dynamics of organismal adaptation to human-induced environmental changes is of paramount importance. This paper delves into the concept of domestication as an early manifestation of the Anthropocene, shedding light on how animal populations respond to domestication selection provides valuable insights into the intricate interplay between plastic responses and evolutionary changes. By examining this relationship, we gain a deeper understanding of the fate of wild vertebrates as they navigate a human-altered world. Through a comprehensive analysis, intentional breeding, managed hunting, and extermination emerge as interconnected elements within a continuum of anthropogenic agents driving ecological selection. Moreover, we identify shared targets of selection that extend beyond domestication, encompassing a broader range of human-induced selection pressures. Remarkably, many traits that facilitate successful domestication also equip wild animals with the adaptive capacity to thrive in human-dominated environments, highlighting their importance in understanding the larger context of adaptation. Additionally, domestic animals serve as a source for feral lineages and genetic exchange with their wild counterparts. This exchange, coupled with shared ecological constraints and gene flow, contributes to convergent or congruent changes across various responses to human influence. By recognizing domestication as another source of anthropogenic selection, we unlock valuable insights for conservation efforts and present a promising avenue for unraveling the mechanisms underlying behavioral adaptation. In summary, this review emphasizes the urgent need to comprehend how organisms adapt or fail to adapt to human-induced environmental changes. By elucidating the intricate relationships between domestication, human-induced selection pressures, and adaptation, we deepen our understanding of the complex dynamics within the Anthropocene and pave the way for effective conservation strategies while shedding light on the mechanisms that drive behavioral adaptation.

***Keywords*:** Climate change, Animal, Feralization, Plasticity

Article History (ABR-23-126) || Received: 13 Apr 2023 || Revised: 15 Jun 2023 || Accepted: 30 Jun 2023 || Published Online: 17 Jul 2023

1. INTRODUCTION

Modern conveniences have been shown by multiple studies (Hussein et al. 2021) to generate light, noise, and chemical pollutants that can have far-reaching effects on ecosystems (Manan et al. 2022). It is essential to comprehend how organisms respond behaviorally, ecologically, and evolutionarily to human-induced rapid environmental change (HIREC) in order to effectively manage species and protect their critical habitats (Zafar et al. 2022). From the perspective of animals, domestication represents a unique and significant form of HIREC, characterized by intentional selection and substantial divergence from wild populations. The fundamental principles of Darwin's theory of evolution were grounded in the observable heritable variations observed by pigeon breeders (Darwin, 1868). In our context, domestic animal species are defined as those whose breeding and food resources are managed by humans, leading to discernible differences in phenotype, genotype, and behavior compared to their wild ancestors. These differences typically include traits that are advantageous or beneficial to humans. Emphasizing the evolutionary nature of domestication, this definition underscores the use of archeology, anthropology, and historiography to reconstruct the population structure and selection pressures involved in the domestication of various species (Zeder, 2018). In recent times, advancements in comparative genomics have revolutionized our understanding of domestication evolution (Frantz et al. 2020). This interdisciplinary knowledge offers a fascinating opportunity to explore and compare a broad range of taxonomic groups that share a common history of anthropogenic selection. The consequences of domestication selection, both in terms of behavior and

Citation: Rasheed M and Du X, 2023. Unveiling behavioral responses of wild animals: insights from domestication in the face of anthropogenic change. Agrobiological Records 13: 34-43. https://doi.org/10.47278/journal.abr/2023.023

genetics, have been extensively investigated. Several scholars have proposed that specific factors must align for a species to be considered suitable for domestication (Larson and Fuller, 2014). Furthermore, it has been suggested that domestication selection leads to the emergence of predictable sets of interconnected traits and genes (Wilkins, 2020). These findings raise the question of whether such insights can inform our understanding of which species are more likely to adapt and persist in the face of HIREC, as well as how we can anticipate their evolutionary trajectory.

2. HUMAN INFLUENCE ON BEHAVIOR

2.1. Domestication as an Example of Adaptive Evolution in the Anthropocene

In the Anthropocene, the current epoch characterized by significant human impact on the Earth's ecosystems, humans have become a powerful force shaping the evolution of other species, including through domestication. Domestication can be viewed as a special case of adaptive evolution, where humans intentionally and unintentionally select specific traits and behaviors in animals. Humans have been selectively breeding and manipulating the genetics of certain species for thousands of years, resulting in the domestication of numerous animals such as dogs, cats, cows, and chickens. This intentional selection has led to the emergence of distinct traits and behaviors in domesticated animals that are advantageous or useful to humans. For example, in dogs, domestication has led to a wide variety of breeds with different sizes, coat colors, and temperaments, tailored for specific tasks or roles (Geffroy et al. 2020).

Domestication involves not only genetic changes but also behavioral modifications. Animals that can adapt their behavior to coexist and interact with humans are more likely to be successfully domesticated. Over generations, domesticated animals have undergone behavioral changes to better suit human needs and preferences. For instance, dogs have acquired social behaviors, such as attentiveness to human cues, that enable them to effectively communicate and cooperate with humans. The process of domestication provides valuable insights into the role of humans as a selective pressure on behavior. It demonstrates that human preferences and actions can significantly shape the behavioral traits of other species. The selection imposed by humans during domestication is often intense and rapid, leading to pronounced changes in behavior within a relatively short span of time (Beckman et al. 2022).

Understanding the mechanisms and consequences of domestication can shed light on how species may respond and adapt to HIREC in the Anthropocene. Domestication provides a model system for studying the impacts of human selection on behavior and the potential for rapid evolutionary change. By examining the domestication process and its effects, researchers can gain insights into how species may cope with and adapt to novel environments, altered ecological interactions, and human disturbances. Furthermore, studying domestication can inform management strategies for wild populations facing HIREC. By identifying the factors that contribute to successful domestication, such as behavioral plasticity and genetic predispositions, conservation efforts can be better tailored to promote the resilience and adaptability of wild species in the face of anthropogenic disturbances (Beckman et al. 2022). The process of domestication provides valuable insights into the adaptive strategies of animals in response to human presence. Zeder (2012) identified three primary pathways to domestication, namely: (1) commensal relationships, (2) animals serving as prey for humans, and (3) direct manipulation of breeding (Fig. 1).

By examining the commensal pathway, we gain a deeper understanding of the gradual transformation of wild animals into domesticated companions, and how their behavior and ecological niche changed over time. These species illustrate the capacity for adaptation and flexibility in response to the presence of human settlements and the availability of novel food resources. The commensal pathway highlights the reciprocal relationship between humans and animals, wherein animals take advantage of the resources provided by human settlements, while humans benefit from the services and companionship of these domesticated species (Zhang et al. 2018). Studying the commensal pathway enhances our comprehension of the intricate interplay between animals and humans in the process of domestication. It showcases the capacity of animals to adapt and thrive in proximity to human activity, ultimately shedding light on how different species can navigate and succeed in the anthropogenic landscapes of the modern world.

The pathway to domestication through hunting prey involves species that were initially targeted for food purposes. Archeological evidence indicates that various hunter-gatherer societies practiced managed hunting, exhibiting a preference for hunting males rather than reproductive females (Zeder, 2012). Towards the end of the Pleistocene epoch, climatic changes and hunting pressures led to a decline in the availability of large game species, prompting a transition to the herding of animals. This included the domestication of cattle, from the wild Bos primigenius to the domestic *B. taurus* (Helmer et al. 2005) and the domestication of goats, from the wild Capra aegagrus to the domestic *C. hircus* (Daly et al. 2021).

On the other hand, directed domestication, the third pathway, typically occurred in regions where early domestication of other species had already taken place (Larson and Fuller, 2014). The direct domestication of fish

ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
Open Access Journal

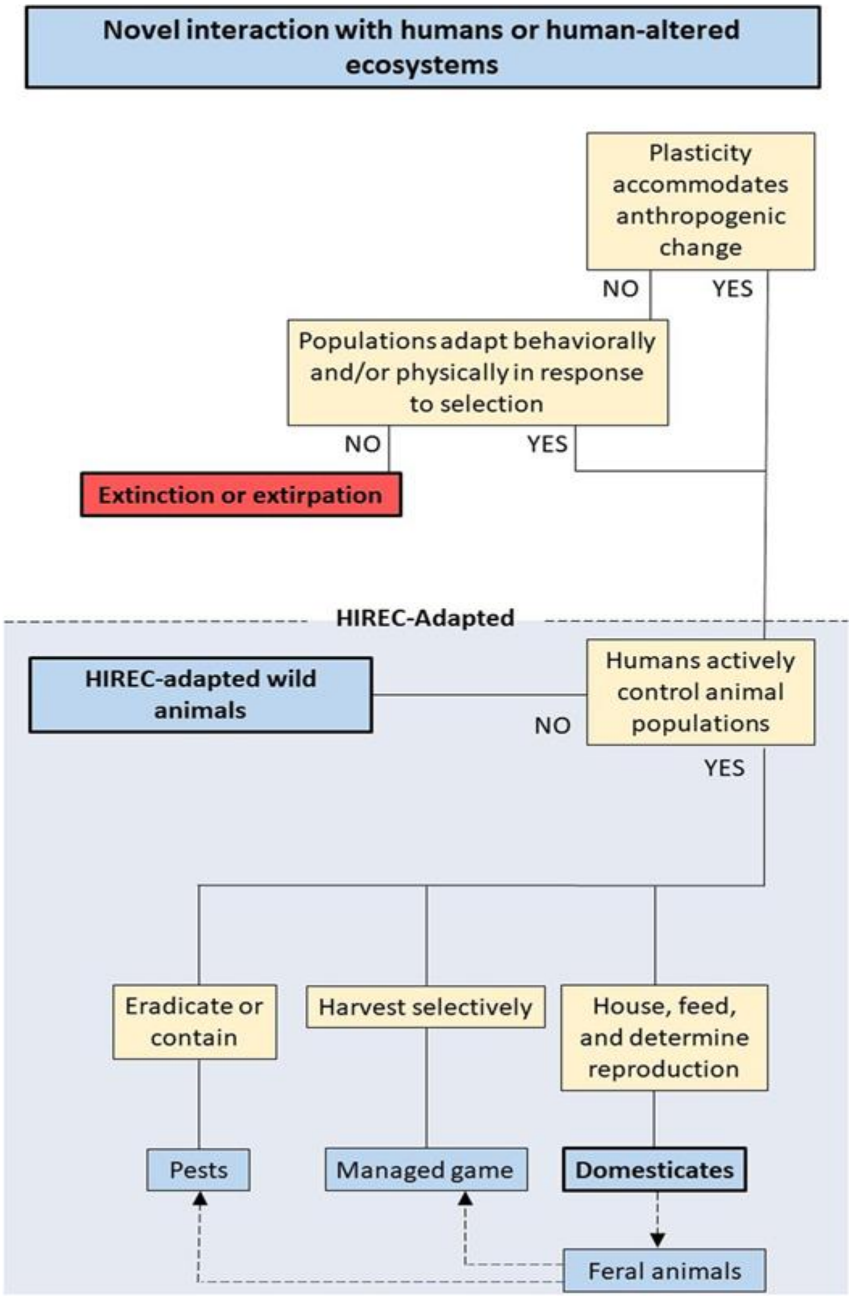

Fig.1: Evolutionary fate of populations is subject to novel interactions with humans (Beckman *et al.*, 2022).

for entertainment or as pets also gained popularity during this period (Balon, 1995). These examples demonstrate the targeted selection and deliberate manipulation of breeding practices in the domestication process. They highlight how animals were intentionally adapted for specific purposes, resulting in traits that would be less favorable in natural or wild environments. The historical accounts of horse domestication and the establishment of specialized enclosures for rearing rabbits and fish provide evidence of early-directed domestication efforts. By examining the prey and directed pathways to domestication, we gain a deeper understanding of the diverse approaches taken by humans to cultivate and transform various species for their own benefit. These pathways demonstrate the versatility and adaptability of human interactions with animals, as well as the significant role humans have played in shaping the evolutionary trajectories of these domesticated species (Daly et al. 2021).

3. DOMESTIC ABILITY AND ADAPTIVE RESPONSES TO HIREC

Domestic ability refers to the degree to which a species can be successfully domesticated by humans. It involves the ability of a species to adapt to and thrive in an environment shaped by human activities. Understanding

ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
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domestic ability is crucial in predicting how species may respond to HIREC and how they can be effectively managed in the face of these changes (Beckman et al. 2022).

Researchers have identified several factors that contribute to the domestic ability of a species. These factors include behavioral traits, such as social tolerance, flexibility, and docility, as well as physiological and genetic characteristics. Species that exhibit these traits are more likely to form close associations with humans and undergo successful domestication. Adaptation to HIREC involves the ability of a species to adjust and persist in environments altered by human activities. Human activities, including urbanization, habitat fragmentation, pollution, and climate change, have transformed ecosystems worldwide. These changes pose challenges to many wild species, and their ability to adapt to these anthropogenic pressures is crucial for their survival (Beckman et al. 2022).

The domestication process can provide insights into the adaptive strategies of species in response to HIREC. Domesticated species have undergone significant changes in their physical, genetic, and behavioral traits compared to their wild ancestors. The selective pressures exerted by humans during domestication have led to the emergence of traits that are advantageous in human-managed environments. By studying the domestication process, researchers can gain insights into the genetic and physiological mechanisms underlying the adaptation of species to novel environments (Sih et al. 2011).

Furthermore, domesticated species can serve as models for understanding how animals cope with human-altered habitats. They offer valuable opportunities to study the genetic basis of behavioral and physiological adaptations, as well as the potential for rapid evolutionary change. By examining the genetic variations and selective pressures associated with domestication, scientists can identify the underlying mechanisms that enable species to adapt to HIREC. Understanding domestic ability and adaptation to HIREC has practical implications for conservation and management strategies. By identifying the traits that contribute to domestic ability, conservation efforts can focus on protecting and enhancing the adaptive potential of wild populations. This may involve promoting genetic diversity, maintaining critical habitat connectivity, and minimizing anthropogenic disturbances. Additionally, insights from domestication studies can inform the development of captive breeding programs and reintroduction efforts for endangered species (Mason et al. 2013). Diamond (2002) presented a significant paper outlining six conditions that must be fulfilled for a species to be considered suitable for domestication. Of these criteria, only one, which involves the existence of social dominance hierarchies exploitable by humans to control groups of animals, may not directly apply to adaptation to humans in a broader sense. The remaining conditions are as follows:

1. Ability to adapt to a diet provided by humans: The ancestors of domesticated species are often motivated to establish initial contact with humans due to food-related factors (Larson and Fuller 2014). In fact, the significance of diet is evident through genetic evidence, such as the presence of selection markers in dogs that allowed them to consume starch-rich foods, thereby aiding the domestication process (Axelsson et al. 2013). In contemporary times, both domesticated and wild species that have adapted to human-influenced environments consume food from novel sources and incorporate new food items into their diet.
2. Rapid growth rate and short intervals between births: Species that have extended periods between births tend to prolong the domestication process. Domestic chickens (*Gallus domesticus*) exemplify a strong selection for decreased birth spacing, with certain breeds laying up to 300 eggs per year (Bell, 2002). Likewise, certain wild bird species establish nests in human-altered environments and demonstrate higher reproductive success compared to populations in less disturbed areas (Chace and Walsh 2006).
3. Non-threatening to humans: Animals with more friendly and tolerant dispositions have historically been easier to tame (Diamond, 2002). For instance, Brubaker and Coss (2015) demonstrated that zebras (*E. quagga*) had greater flight distances than feral horses (*E. c. ferus*) and suggested that zebras likely faced more intense hunting pressure in ancient times, leading to their wariness and aggression towards humans, whereas horses became more suitable for domestication (Brubaker and Coss, 2015). Disposition also plays a role in determining which domesticated animals become indoor pets and which wild animals humans are inclined to approach and feed in public.
4. Species in human-altered environments: Species located at the fringes of the commensal or prey route often exhibit reluctance to reproduce in captivity. Nonetheless, certain species can overcome this barrier and successfully breed, either naturally or through artificial means, in social and physical environments that differ significantly from their wild experiences. Passerines, known for their beautiful songs and usefulness in research, and falcons (Falco spp.), valued for their ability to catch small prey, have not been domesticated due to their limited success in breeding in captivity (Zeder, 2012).
5. Resistance to panic in confined spaces: Lastly, the highly developed fight-or-flight responses observed in gazelles (Gazella spp.) rendered them unsuitable candidates for domestication, despite their value as a food source (Zeder, 2012). While many modern domesticated species can adapt to artificial environments through appropriate training and reinforcement, species that venture into human-disturbed habitats often do so because these areas resemble their preferred natural habitats. Consequently, certain wild species have a higher likelihood of successful adaptation to HIREC, including the process of domestication. Nevertheless, every

population confronted with a shifting environment will undergo demographic shifts and encounter new selection pressures, which can enhance their resilience while also rendering them more susceptible to a changing world. As a result, domestication serves as an exceptional trial to gauge a species' ability to adapt to novel environments brought about by human activities.

4. INSIGHTS FOR ADAPTATION TO HIREC

4.1. The evolutionary impacts of domestication

The process of domestication has profound evolutionary consequences for a species, providing valuable insights into its ability to adapt to HIREC. Domestication involves intentional selection and breeding by humans, resulting in the alteration of the genetic makeup and phenotypic traits of a population over generations. As a result, domesticated species often exhibit distinct characteristics compared to their wild ancestors, allowing them to thrive in human-influenced environments. These evolutionary consequences offer important lessons and potential strategies for understanding and managing adaptation to HIREC (Turcotte et al. 2017).

Genetic Changes: Domestication involves artificial selection, which targets specific traits desired by humans, such as increased productivity, tameness, or disease resistance. This selective pressure leads to genetic changes within domesticated populations. Genetic studies have identified genomic regions associated with these selected traits, providing insights into the genetic mechanisms underlying adaptation. Understanding these genetic changes can inform the identification of genetic variants or genes that may facilitate adaptation to HIREC in other species (Sih et al. 2011).

Phenotypic Plasticity: Domesticated species often exhibit increased phenotypic plasticity compared to their wild counterparts. Phenotypic plasticity refers to the ability of an organism to adjust its phenotype in response to environmental cues. Domestication exposes species to novel and variable environments, which can result in the development of flexible traits that allow them to adapt to changing conditions. The study of phenotypic plasticity in domesticated species can offer insights into the adaptive capacity of species facing HIREC (Mason et al. 2013).

Behavioral Adaptations: Domestication involves changes in behavior, such as reduced aggression, increased sociability, and reliance on humans for resources. These behavioral adaptations are crucial for domesticated species to coexist and thrive in human-altered environments. Understanding the behavioral changes that occur during domestication can provide valuable knowledge on how species can adapt their behavior to HIREC, including mitigating conflict with humans, exploiting new resources, or adjusting social dynamics (Duan et al. 2018).

Tolerance to Anthropogenic Factors: Domesticated species have undergone selection for tolerance to anthropogenic factors, including urbanization, pollution, and habitat fragmentation. They have adapted to live in close proximity to humans and in environments significantly influenced by human activities. Studying the mechanisms underlying this tolerance can offer insights into strategies for managing and conserving species in HIREC scenarios (Turcotte et al. 2017).

Interspecies Interactions: Domestication involves complex interspecies interactions between humans and animals. These interactions shape the coevolutionary dynamics between species and can lead to mutualistic relationships, where both species benefit. Understanding the dynamics of interspecies interactions in domesticated systems can provide insights into fostering symbiotic relationships and collaborative approaches in adapting to HIREC (Beckman et al. 2022). By examining the evolutionary consequences of domestication, researchers can gain valuable knowledge and principles applicable to managing adaptation to HIREC. Insights into genetic changes, phenotypic plasticity, behavioral adaptations, tolerance to anthropogenic factors, and interspecies interactions can inform conservation efforts, habitat management, and strategies for promoting resilience in species facing rapid environmental changes caused by human activities.

5. CORRELATED TRAIT EVOLUTION IN THE CONTEXT OF DOMESTICATION

Correlated evolution of traits under domestication refers to the phenomenon where multiple traits tend to change simultaneously during the process of domestication. These traits often show a consistent pattern across different domesticated species, suggesting a shared underlying mechanism. Understanding the correlated evolution of traits can provide valuable insights into the genetic and developmental processes involved in domestication. One well-known example of correlated trait evolution is the domestication syndrome observed in various domesticated mammals. The domestication syndrome includes a set of traits such as reduced brain size, depigmentation, floppy ears, and reduced fear of humans. These traits have been observed in domesticated species such as dogs, pigs, and goats (Sánchez-Villagra et al. 2016). The presence of these shared traits across different domesticated species indicates a common underlying genetic basis for their development.

The correlation between reduced brain size and domestication has been documented in several studies. Domesticated mammals often exhibit a smaller brain size compared to their wild counterparts (Kruska, 1996). This reduction in brain size is believed to be related to the relaxed selection on cognitive abilities in domesticated animals, as they rely more on human-provided resources rather than their own problem-solving skills.

Another correlated trait under domestication is depigmentation. Many domesticated animals, such as dogs, cats, and pigs, often exhibit patches of white or light-colored fur or skin (Zhang et al. 2014). This loss of pigmentation is thought to result from changes in the genes involved in pigmentation pathways. The selection for depigmentation may be related to human preferences for animals with distinct coat colors or patterns. Reduced fear of humans is a critical trait observed in domesticated species. Domesticated animals are generally more tolerant and less fearful of human presence compared to their wild counterparts. Studies have shown that domesticated animals, such as foxes and rats, display reduced fear responses and increased tolerance towards humans (Sato et al. 2020). This reduction in fear is believed to be an essential aspect of the domestication process, as it facilitates interactions and handling by humans. The correlated evolution of these traits can be attributed to different factors. One possible explanation is that similar selective pressures exerted by humans during domestication lead to the parallel evolution of these traits. For example, humans may prefer animals that are less aggressive, less neophobic, and have rapid population growth, which can result in the selection of reduced fear and increased tolerance towards humans (Diamond, 2002).

Parallel changes in specific genes and genetic pathways have also been implicated in the correlated evolution of domestication traits. Studies have identified shared genetic changes in domesticated species, indicating convergent evolution at the molecular level. For instance, parallel genetic changes associated with exploratory behavior, neurotransmission, and metabolism have been observed in chickens and various domestic mammals (Hou et al. 2020).

It is important to note that not all domesticated species exhibit the exact same set of traits, and there can be variations depending on the species and the specific selection pressures during domestication. Additionally, the presence of correlated traits does not imply a causal relationship between them. The genetic and developmental mechanisms underlying the correlated evolution of domestication traits are still a subject of ongoing research. Studying the correlated evolution of traits under domestication provides valuable insights into the genetic and developmental processes involved in the transition from wild to domesticated forms. It helps us understand the selection pressures imposed by humans and the genetic changes that occur during domestication. By unraveling the genetic basis of domestication traits, researchers can gain a deeper understanding of the complex interplay between humans and domesticated animals and the broader implications for evolutionary biology and animal breeding (Beckman et al. 2022).

6. LEARNING, PLASTICITY, AND ADAPTIVE RESPONSES

Learning, plasticity, and adaptive responses are essential factors in the process of domestication and the ability of species to adapt to human-induced environmental changes. These mechanisms enable organisms to adjust their behavior, morphology, and physiological traits in response to new or altered conditions. Understanding how learning, plasticity, and adaptive responses operate is crucial for comprehending the dynamics of domestication and the impacts of human activities on wild populations. One of the primary ways organisms respond to domestication or anthropogenic disturbances is through plastic phenotypic changes. Plasticity refers to the ability of an organism to modify its traits or behaviors in response to environmental cues. Captivity, for example, can lead to rapid morphological changes within a few generations in various species. Studies have documented this phenomenon in different taxa, including canids, Japanese macaques, and house mice (Siciliano-Martina et al. 2021). These plastic responses can include changes in body size, shape, coloration, or other morphological characteristics that enhance survival or reproductive success in the new environment.

The evolution of associated behaviors during domestication is influenced by the interaction between an organism's genotype and the environment. This concept, known as genotype-by-environment interaction, highlights the role of learning in the domestication process. Different species possess varying levels of natural history and cognitive abilities, which can influence their propensity to interact with humans. Some species are more predisposed to learn from and adapt to human presence than others (Zeder, 2018). Individual and social learning play crucial roles in facilitating coexistence with humans, whether the interaction is intentional or unintentional. Reduced fear of humans, often referred to as "tameness" in a narrow sense, can develop as a consequence of learned familiarity with humans. However, this reduced fear can have both positive and negative consequences for humans and animals (Herrero et al. 2005). The process of domestication also encounters challenges related to an organism's innate learning predispositions. For instance, wild horses can be tamed, but zebras pose greater difficulties due to their natural disposition (Brubaker and Coss, 2015).

The tempo and mode of learning play significant roles in determining domestic ability. In the case of domesticated birds, with the exception of pigeons, most exhibit precocial behavior and extended parental care (Larson and Fuller, 2014). Extended parental care often leads to imprinting, where the young animal forms strong bonds with its caregivers. Imprinting plays a crucial role in developing broad-sense tameness, characterized by reduced fear and increased social affiliation with humans. Imprinting can occur in various species, such as Lorenz's famous study on greylag geese (*Anser anser*) (Lorenz, 1935). By manipulating the ontogeny of social development, humans can exploit these learning mechanisms to promote the emergence of domestication characteristics without the need for extensive genetic evolution.

In the context of HIREC, behavioral flexibility becomes crucial for species survival. Learning and plasticity enable individuals to adjust their behaviors and responses to novel environments, facilitating their ability to navigate through disturbance gradients and survive in changing conditions. However, there can be negative consequences associated with the loss of cultural knowledge and traditions. Cultural loss, such as the reduction of song variants in captive regent honeyeaters compared to their wild counterparts, illustrates the vulnerability of cultural knowledge (Crates et al. 2021). The loss of cultural knowledge can also lead to predator naivety, where individuals lack awareness of predatory threats due to the absence of historical exposure. This has been observed when carnivores like wolves and brown bears were extirpated, resulting in a loss of predator cues and increased vulnerability to predation (Berger et al. 2001). Furthermore, cultural losses can have broader ecological impacts, as seen in the disruption of migratory routes due to anthropogenic interference (Caro and Sherman, 2012).

7. FERALIZATION

Feralization refers to the process by which domesticated animals revert to a wild state when they are released or escape into natural environments. It is a fascinating phenomenon that highlights the plasticity and adaptability of domesticated species and their ability to survive and thrive in the absence of human control or intervention. When domesticated animals become feral, they undergo significant changes in their behavior, morphology, and genetics as they adapt to the challenges and demands of the wild. This process occurs when domesticated animals are reintroduced into natural ecosystems or when they manage to establish self-sustaining populations in the wild (Beckman et al. 2022). One notable aspect of feralization is the reversion to ancestral behaviors and traits that were suppressed or modified during the process of domestication. Domesticated animals are typically bred and selected for specific traits that suit human needs and preferences, such as tameness, increased productivity, or specific physical characteristics. However, when these animals are released into the wild, they begin to exhibit behaviors and traits that are more aligned with their wild ancestors. Behavioral changes are particularly prominent during feralization. Domesticated animals, which have been raised in controlled environments and often rely on humans for food and protection, must relearn survival skills such as hunting, foraging, and avoiding predators. They may form social structures, establish territories, and develop strategies to secure resources independently (Beckman et al. 2022).

Morphological changes also occur during feralization. Domesticated animals may undergo phenotypic transformations that make them more suitable for survival in the wild. These changes can include alterations in body size, shape, coat coloration, or the development of specialized adaptations for hunting, defense, or locomotion. Over time, feral populations may exhibit distinct physical characteristics that differentiate them from their domesticated counterparts.

Genetic changes are another important aspect of feralization. As feral populations establish themselves in the wild, they undergo genetic divergence from their domesticated ancestors. This can occur through natural selection, genetic drift, and gene flow with wild populations of related species. Genetic changes can contribute to increased fitness and adaptation to the specific ecological conditions of the wild environment (Larson and Fuller, 2014).

Feral populations can have significant ecological impacts. They may compete with native species for resources, prey on native wildlife, or introduce diseases and parasites. Some feral populations have become invasive species, disrupting native ecosystems and causing ecological imbalances. It is worth noting that feralization is not a guaranteed outcome for all domesticated animals. Some species are better equipped to survive and thrive in the wild than others. Factors such as the duration of domestication, the presence of suitable habitats, the availability of natural food sources, and the absence of human-induced pressures influence the success of feralization (Gaunitz et al. 2018). Overall, feralization is a complex and dynamic process that underscores the resilience and adaptability of domesticated animals. It highlights the capacity of these animals to revert to their ancestral wild state and survive independently in natural environments. Understanding feralization can provide insights into the evolutionary potential of domesticated species and inform conservation efforts for both wild and domestic populations (Ruscoe et al. 2022).

8. Gene flow, domestication, and conservation

8.1. Domestic and human-adapted species

Gene flow, domestication, and conservation are interconnected concepts that have important implications for the management and preservation of both domestic and human-adapted species. Gene flow refers to the transfer of genetic material from one population to another through mating and reproduction. In the context of domestication and conservation, gene flow can occur between domesticated animals and their wild relatives, as well as between human-adapted populations and their wild counterparts. Domestication involves the process of selectively breeding and taming wild species to make them better suited for human purposes, such as food production, companionship,

ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
Open Access Journal

or labor. Over generations of selective breeding, domesticated animals have undergone genetic changes that distinguish them from their wild ancestors. However, domesticated and wild populations can still exchange genes through various mechanisms, including hybridization and introgression (Beckman et al. 2022).

The consequences of gene flow between domesticated and wild populations can be both beneficial and detrimental. On the positive side, gene flow can introduce new genetic variation into wild populations, potentially enhancing their adaptive potential and increasing their chances of survival in changing environments. In some cases, introgression of domesticated genes can contribute to genetic rescue, revitalizing small or endangered wild populations with improved fitness and adaptive traits. On the other hand, gene flow can also have negative impacts. Domesticated animals that escape into the wild can mate with wild individuals, leading to hybridization. Hybridization can disrupt natural population dynamics, dilute the gene pool of wild populations, and potentially reduce their fitness and adaptability. Hybridization can also lead to the loss of locally adapted traits and increase the vulnerability of wild populations to environmental stressors and diseases (Bolstad et al. 2017).

In the context of conservation, managing gene flow between domesticated and wild populations becomes crucial. Conservation efforts often aim to preserve the genetic integrity and unique characteristics of wild species. Thus, it is important to prevent or minimize the negative effects of gene flow from domesticated populations, especially in cases where it threatens the survival of endangered species or distinct subspecies. However, gene flow is not limited to domesticated animals alone. Human-adapted populations, which are wild species that have become adapted to human-altered environments, can also play a role in gene flow dynamics. Human-adapted populations are more likely to coexist with domesticated animals, creating opportunities for genetic exchange between them. This gene flow can impact the genetic composition and evolutionary trajectory of both domesticated and wild populations (Tufto, 2017). To effectively manage gene flow and its implications for conservation, interdisciplinary approaches are needed. Genetic analyses can provide valuable insights into the extent and patterns of gene flow between domesticated and wild populations. Ecological knowledge is essential for understanding the ecological consequences of gene flow and its impact on population dynamics. Conservation strategies should take into account both genetic considerations and ecological factors to make informed decisions about the conservation and management of domesticated and human-adapted species (Stephens et al. 2015).

9. GENE FLOW ACROSS HUMAN-CREATED ECOLOGICAL GRADIENTS

Gene flow across human-created ecological gradients refers to the movement of genetic material between populations of organisms adapted to environments influenced by human activities and their wild counterparts. Human activities, such as urbanization, industrial development, and habitat alteration, have created novel ecological niches that differ significantly from natural habitats. These human-influenced environments often present unique selection pressures and ecological challenges, leading to adaptations in wildlife species that can influence their genetic makeup and population dynamics (Stephens et al. 2015).

One of the well-studied examples of gene flow across human-created ecological gradients occurs in urban environments. Urban areas are characterized by artificial structures, altered landscapes, increased human presence, and various forms of pollution. Despite these changes, numerous animal species have successfully colonized and adapted to urban habitats. These species, known as urban exploiters or commensals, have taken advantage of the resources and opportunities provided by human settlements (Tufto, 2017).

Studies have shown that animals in urban environments exhibit behavioral, morphological, and physiological differences compared to their non-urban counterparts. For instance, urban coyotes may exhibit bolder and more exploratory behavior, adapting to the presence of human activity and modified landscapes. Large carnivores, such as foxes and raccoons, may alter their activity patterns to avoid human encounters, becoming more nocturnal or crepuscular. Additionally, some bird species have adjusted their reproductive strategies, mating behaviors, and vocalizations to cope with urban noise and artificial light (Beckman et al. 2022).

The process of gene flow across human-created ecological gradients can occur through various mechanisms. One mechanism is through the movement of individuals between urban and non-urban populations. Animals may disperse from natural habitats into urban areas, where they breed with urban-adapted individuals, facilitating the exchange of genes. Conversely, individuals from urban populations may disperse to non-urban habitats, potentially influencing the genetic diversity and adaptations of wild populations. Another mechanism of gene flow is through hybridization between domesticated animals and their wild relatives. Domesticated animals can escape captivity or be released into the wild, where they may interbreed with wild populations. This gene flow can have both positive and negative consequences for the wild species involved. It may introduce beneficial traits into wild populations, such as disease resistance or tolerance to human disturbances. However, it can also lead to genetic dilution, reduced fitness, and altered ecological dynamics (Beckman et al. 2022).

The impacts of gene flow across human-created ecological gradients are not limited to urban environments. Similar processes can occur in other human-altered habitats, such as agricultural landscapes, industrial areas, and areas affected by infrastructure development. These habitats may provide new resources, altered environmental

Citation: Rasheed M and Du X, 2023. Unveiling behavioral responses of wild animals: insights from domestication in the face of anthropogenic change. Agrobiological Records 13: 34-43. https://doi.org/10.47278/journal.abr/2023.023

conditions, or unique selective pressures that favor specific genetic traits or adaptations. Consequently, wild populations that inhabit these habitats may undergo genetic changes, diverging from their non-altered counterparts. Understanding the patterns and consequences of gene flow across human-created ecological gradients is crucial for effective conservation and management strategies. It helps us assess the genetic connectivity between urban and non-urban populations, evaluate the potential for adaptation and evolutionary change, and identify species and populations most vulnerable to human-induced impacts. This knowledge can inform conservation efforts, urban planning, and the development of strategies to mitigate negative effects and promote coexistence between human activities and biodiversity preservation (Candolin and Wong, 2019).

10. Conclusion

In conclusion, the intricate relationship between humans and animals, characterized by both conflict and cooperation, highlights the phenomenon of animals evolving to exploit humans as a resource and vice versa. This dynamic shares fundamental properties with coevolving systems in general, whether through domestication or adaptation to Human-Induced Rapid Environmental Change (HIREC). Human activities, particularly domestication, have the power to shape the behavior and genetic makeup of individuals in unprecedented ways. While significant research has been conducted on specific aspects of these changes, there remain numerous unanswered questions regarding the broader impacts of domestication on global biodiversity and speciation processes. The process of domestication, as a form of anthropogenic disturbance, has been invaluable to science, sounding the alarm about the inability of many wild species to cope with the rapidly changing world. However, can science go beyond raising awareness and actively contribute to addressing these challenges? Our current understanding of genomics, coupled with early detection of physiological stress resulting from environmental changes, offers promising avenues for conservation and biodiversity preservation. Admixture, genetic rescue, and selective breeding programs, similar to those employed in zoos to aid the recovery of endangered populations, can benefit from our modern understanding of genomics. By applying these tools, science can play a crucial role in safeguarding vulnerable species and ecosystems. The study of domestication also holds the potential to shed light on conservation issues, as domestic and threatened species often face similar challenges such as genetic bottlenecking, introgression, and human-mediated selection. The fact that only a small number of species have successfully undergone domestication raises concerns about their ability to adapt to the Anthropocene era. Comparisons within and between HIREC-adapted species and domesticated species, utilizing genomic tools, present an excellent opportunity to investigate behavioral, convergent, and parallel evolution. In summary, understanding the complex interplay between humans and animals, especially through domestication and adaptation to HIREC, not only informs us about the evolution of these relationships but also has practical implications for conservation and biodiversity preservation. By leveraging our scientific knowledge and employing innovative strategies, we can strive towards a harmonious coexistence between humans and the natural world, ensuring the survival and well-being of both domesticated and wild species in the face of ongoing environmental challenges.

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Citation: Rasheed M and Du X, 2023. Unveiling behavioral responses of wild animals: insights from domestication in the face of anthropogenic change. Agrobiological Records 13: 34-43. https://doi.org/10.47278/journal.abr/2023.023

ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
Open Access Journal

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