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Ecosystem Engineering Among Ancient Pastoralists in Northern Central Asia

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Ecosystem engineering is an innovative concept that recognizes that organisms impact their environment, and that these changes can be detected over time. Thus, additional datasets from the ecological longue durée are necessary, specifically in response to the onset of the Anthropocene and the impacts of humans and their commensal organisms upon ecologies of all scales. For example, the management and herding of domesticated animals are recognized as having dramatic implications for soil stability, vegetation coverage, and even atmospheric composition the world over. Yet, the point at which pastoralism became a recognizable factor in altering earth systems, with large-scale environmental ramifications, is poorly understood. Here, we respond to this by reviewing and presenting data from the archeological and paleoenvironmental record across northern Central Asia in order to assess broader ecosystem impacts of pastoralism, from time periods when this economic pattern was a relatively novel component of local ecologies and involved limited population densities, through to periods in which it became intensive, coincident with agriculture, and linked to increased sedentism. Probing diverse, published analytical datasets and case studies, we examine pastoral adaptations and environmental impacts, highlighting a region where tensions surrounding resilience and sustainability of pastoralism have peaked in modern times. We draw upon these findings to examine the challenges faced by pastoralists today, and the ways in which archeological data might inform on management decisions into the future.

Keywords: environmental change, Anthropocene, pastoralism, landscape modification, ecosystem engineering

INTRODUCTION

Recent research highlights interactions between humans and environments, with the recognition of the planet's transition into a possible new geological epoch, the Anthropocene. Closely linked to the notion of the Anthropocene is the concept of ecosystem engineering, which acknowledges that humans modify their environment and adapt to the evolutionary pressures to which they are exposed, accordingly shaping their own evolutionary trajectories as well as those of other organisms (Jones et al., 1997; Laland and O'Brien, 2010; Sullivan et al., 2017; Vandermeer and Perfecto, 2018). Ecosystem engineering is defined as a process where organisms, including humans, impact the physical and chemical environments of ecosystems, for example, by changing the abundance and distribution of other organisms (Jones et al., 1997). Humans are the ultimate ecosystem engineers (Jones et al., 1994), producing, modifying, and destroying habitats and resources (Smith, 2007; Laland and O'Brien, 2010). Among the most significant of humanity's impacts has been the domestication, proliferation, and global redistribution of a variety of species, including pastoral animals that have become the mainstay of global food production systems and regional agricultural economies (Smith and Zeder, 2013; Boivin et al., 2016).

People and their animals have produced and modified habitats, stretching the boundaries of realized niches, often outcompeting other organisms, and modifying entire environments (Jones et al., 1994; Smith, 2007; Laland and O'Brien, 2010). Unlike other species, we can attribute some intent to human modifications and translocations, especially the movement of species, within these dynamic systems, which broadly fall under environmental archeology (e.g., Butzer, 1982; Simmons, 1996; Evans and O'Connor, 1999; Dincauze, 2000). Most studies on ecosystem engineering in human prehistory have focused on the effects of cultivation, direct human intervention on a particular species, or controlled burning (Anderson, 2005; Smith, 2007). However, pastoralists are somewhat neglected in discussions of ancient ecosystem engineering despite the known impacts that they have on contemporary environments. Conservationists and ecologists rarely look at the time depth of processes involving animal and landscape management (except see Marshall et al., 2018), in spite of the rapid growth of archeological and paleoenvironmental datasets that are relevant not only to understanding the past but also mediating environmental impacts into the future. While the term engineering might imply intentionality on the part of pastoralists or other human groups, this need not be the case as result of landscape change is rarely achieved intentionally (Wright and Jones, 2006). Understanding how ancient human populations and their livestock modified local environments over long time scales can help to inform localized animal management choices, as well as decisions relevant to the conservation of landscapes and ecosystems.

Livestock play a key role in anthropogenic climate change, vegetation community composition, nitrogen cycling, and phytomass appropriation (Wirsenius, 2003; FAO, 2009, 2011; Galloway et al., 2010). Livestock over-grazing caused by continual use of the same pasture over long periods of time is associated with decreased fertility, reduced plant diversity, soil degradation, and an increase in the release of carbon and nitrogen into the atmosphere (Love and Eckert, 2006; Hilker et al., 2013). Livestock-dominated ecosystems also inevitably have impacts on other, wild fauna, from migrating large mammals to small, burrowing rodents (Li et al., 2016; Arrondo et al., 2019). Organisms have important impacts on the physical and chemical environments of ecosystems, and humans play a part in these trophic dynamics (Jones et al., 1997). For example, large ruminant grazers, including domestic herd animals, are described as ecosystem engineers in terms of their profound impacts on vegetation heterogeneity and ecosystem productivity, with impacts extending up to higher trophic levels (McNaughton, 1984; Smit and Putman, 2010). Strong herbivory pressure shapes vegetation communities by: (1) rapidly removing certain plants from the landscape that cannot cope with such pressures; (2) gradually increasing the prominence of plants with anti-herbivory defenses, such as toxins or thorns; (3) increasing the number of rapid-growing annual grasses and herbs; and (4) concentrating endozoochoric dispersed plants on rangelands (Kuznar, 1993; Lezama-Núñez et al., 2018; Spengler, 2019; Spengler and Mueller, 2019). Human ecosystem engineering compounds these issues and has the potential to profoundly alter landscapes (Fontanari, 2018), as humans are responsible for the introduction, and loss, of species that have substantial effects on ecosystems (Coleman and Williams, 2002; Morrison, 2018). By viewing the impacts of humans, and their domesticated animals, through the lens of ecosystem engineering we have the opportunity to identify variation in the effects of different trajectories of pastoral groups. The impacts of engineering are, of course, context dependent (Wright and Jones, 2006), contingent on the deep history of local environments, societies under study, and the types of animals adopted by humans.

Pastoralists are often stereotyped as environmentally destructive, without any recognition of variation in herding practice, ecological knowledge, and other factors that simultaneously impact the environment (see discussion in Fernández-Giménez, 2000). Increasingly, research is contradicting the view that pastoralists alone are the root cause of ecological degradation, suggesting instead that they have slowly shaped environments for millennia (Seid et al., 2016). We define pastoralism as the practice of raising and maintaining livestock, often within an economy based principally on the products of these animals. This is distinct from definitions that consider specific management strategies, herd size, or patterns of mobility. While mobility can be considered an essential part of livestock husbandry, the degree of movement across a landscape is generally tied to local strategies in herd management. Here, we shift away from the use of "nomad" or "nomadism," which often is part of a typology that differentiates between human mobility, e.g., nomadism and sedentism (strict, quasi, semi) (e.g., Ferret, 2014). Pastoral lifeways exist on a continuum from fully sedentary to highly mobile, in which patterns of movement are flexible and responsive to both social and environmental change (Cribb, 1991). Thus, for the purposes of this paper, the documentation of mobility is partitioned from the identification of pastoralism (following Hammer and Arbuckle, 2017), in an effort to be explicit in defining how these components integrate into socioeconomic systems. In our discussions, "pastoralism" refers to livestock husbandry in a local zone in the immediate vicinity of the archeological site (Hammer and Arbuckle, 2017; Ventresca Miller et al., 2018, 2019). If there is evidence to support specific characterizations of pastoralism then we have clarified by adding qualifiers such as "mobile," "sedentary," "agro-," and "multi-resource" or "vertical transhumant" (e.g., Salzman, 1972; Dyson-Hudson and Dyson-Hudson, 1980; Chang et al., 1998; Hanks, 2003; Rosen, 2003; Barnard and Wendrich, 2008; Hammer and Arbuckle, 2017).

A deep history approach is necessary to link ancient and contemporary pastoralism. Ecologists and historians recognize human–environment interactions and the importance of considering the diversity of pastoralist lifeways, providing data that allow archeologists to identify and interpret behaviors in the prehistoric record. Growing archeological datasets, informed by the increasing application of archeobotanical, zooarcheological, isotopic, and other scientific approaches, provide important insights into the impacts of pastoralism in diverse regions, under varied environmental and climatic scenarios. Further, archeological data can be used to identify ecological changes, for example, paleobotanical studies demonstrate shifts to more endozoochoric plants, zooarcheological research can identify the proportion of each animal species present, while isotopic research provides direct evidence of landscape use and movement. Thus, archeology provides a unique perspective on context-specific pastoral responses and impacts, as we demonstrate here through examination of detailed localized datasets on long-term pastoral and grazing behaviors.

Following Zeder (2015), we investigate the potential environmental impacts of pastoralists and their livestock, including their roles in moving species into new habitats, altering species distributions and composition, and reshaping landscapes and resource availability. This manuscript draws upon archeological data to clarify the timing and extent of pastoral impacts on the landscape associated with different forms of ecosystem engineering during the Bronze through the Iron Ages (2200 BCE to 200 CE) across Kazakhstan and its impact on the local landscape. In an effort to link ancient and modern pastoral strategies, we contextualize observations of past pastoral strategies to explore how these might impact contemporary policy in the broader Eurasian steppe. The effects of ecosystem engineering have long been recognized as context dependent, thus we chose three different environmental zones spanning Kazakhstan, highlighting transitional periods in prehistory (**Figure 1**). Through these we explore, (1) optimal ecosystems for pastoral lifeways where the dietary niches of wild herbivores were appropriated by domesticated herds; (2) areas where pastoral animals were heavily managed to create resilient societies; and (3) diverse ecological zones where agriculture and pastoralism were adapted to mosaic environments.

CONTEMPORARY PASTORALISTS ENGAGE IN ECOSYSTEM ENGINEERING

Research into contemporary pastoral societies in Eurasia is generally an interdisciplinary undertaking that combines elements of ethnography, ecology, and biology (Fernández-Giménez, 1999; Humphrey and Sneath, 1999; Kerven et al., 2006, 2016a,b; Milner-Gulland et al., 2006; Alimaev and Behnke, 2008; Crewett, 2012; Dörre and Borchardt, 2012; Murphy, 2014; Behnke et al., 2016; Robinson et al., 2016, 2017). These studies impart critical information as they outline compromises between resilience and vulnerability, reflecting the interaction between such factors as management practice intensity, changing social contexts, carrying capacity, and redistribution of resources. Here we focus on variation in grassland resource use by pastoralists, including the long-distance movement of herds, pasture degradation, and overgrazing, as well as livestock management. We define degradation as a decrease in vegetation productivity leading to loss of the pasture's ability to support livestock production, defined as sustainable output of livestock products per unit area of land (Robinson and Milner-Gulland, 2003). Diversity in pastoral activities largely depends on environmental factors that shape how the landscape is used (**Figure 2**), but recursive impacts, climate change, and population growth also have known effects. For example, in Central Asia, historical trajectories in pastoralism under Soviet and post-Soviet regimes highlight how social and political infrastructure, and the loss of these, can affect livestock herding and its ramifications for different environments. Withdrawal of the state through dismantling of collectivized agriculture led to fragmentation of herds and loss of economies of scale needed for livestock migration; this in turn led to significant changes in livestock distributions, in particular in remote and arid environments (Kerven et al., 2004, 2006; Robinson et al., 2016).

Today in semi-arid zones, rangeland resource use is uneven as remote pastures and some settlements have been abandoned, while pasture around inhabited villages is heavily impacted (Alimaev et al., 2008; Rachkovskaya and Bragina, 2012; Robinson et al., 2017). When herds become too large to be sustained in the vicinity of villages, mobility of livestock is necessary (Alimaev et al., 2008). Mobile pastoralism both allows grasslands to recover and, by moving animal between ecological zones, provides access to those vegetation resources having the highest nutritional content in each season. However, the long-distance movement of livestock (greater than a 10 km radius around settlements) imposes fixed costs which can only be covered by those with large herds, and it is thus herd size which now determines the extent and nature of migrations (Kerven et al., 2016a; Robinson et al., 2016). Costs of moving livestock include transport to distant sites, the development of water infrastructure en route, as well as pasture rental and winter base development (in that season) at the target site. This is one reason that herding tends to occur in regions surrounding urban or peri urban areas, with nearby markets and good transport infrastructure. Therefore, increasing mobility to exploit distant pastures in contemporary 20th century strategies necessitates capital to pay for associated costs (Kerven et al., 2006, 2016a), or the pooling of personal herds by those with few livestock (Robinson et al., 2012). Although many small-scale village populations choose to maintain herds small enough to be supported by pastures in the immediate vicinity of their settlement, they often supplement human intake of dairy and meat products with garden plots or supplies from larger urban centers (Hauck et al., 2016).

In mountainous areas of southern and eastern Kazakhstan, alpine pastoralism and vertical transhumance are important strategies for local populations. Herders engage in seasonal vertical mobility with their livestock, moving from permanent

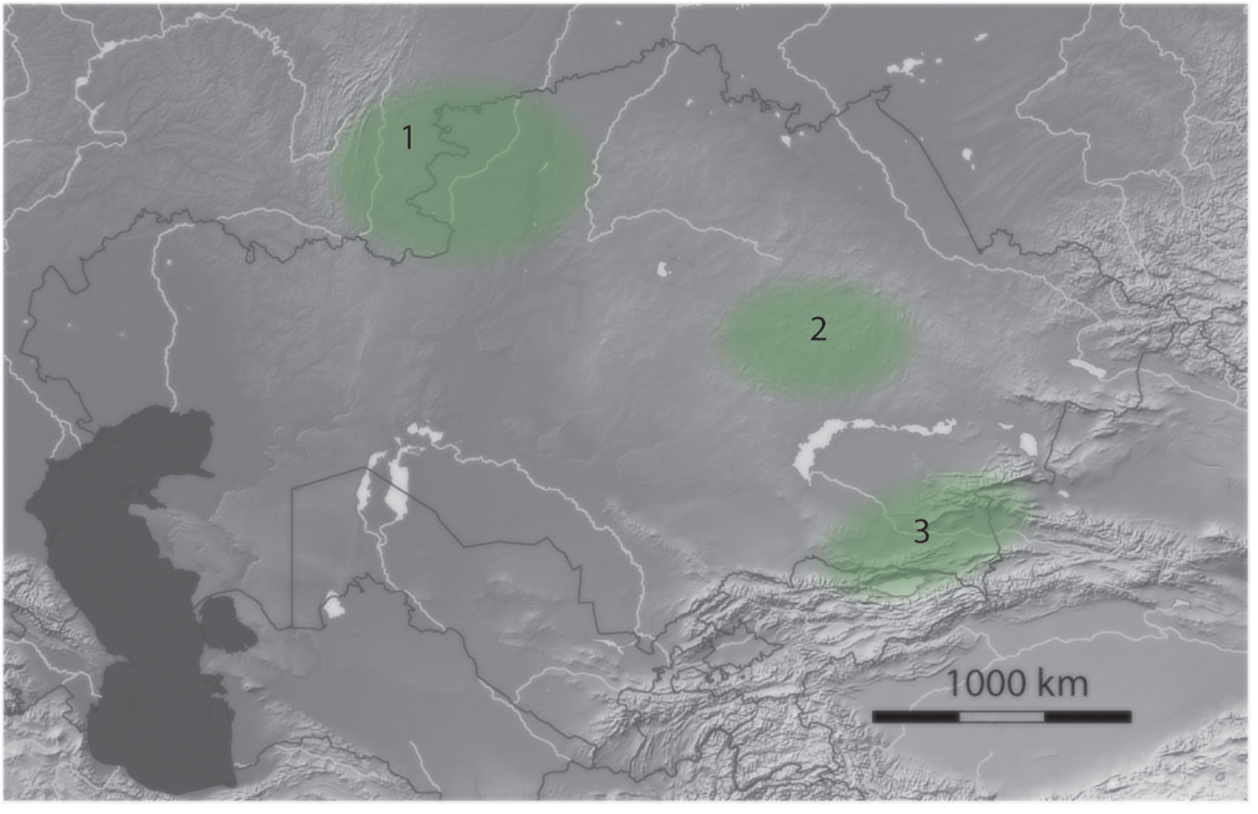

FIGURE 1 | The location of archeological sites and areas discussed (1. Grasslands of the Urals, 2. Semi-Arid Central Kazakhstan, and 3. Mountains of Southeastern Kazakhstan).

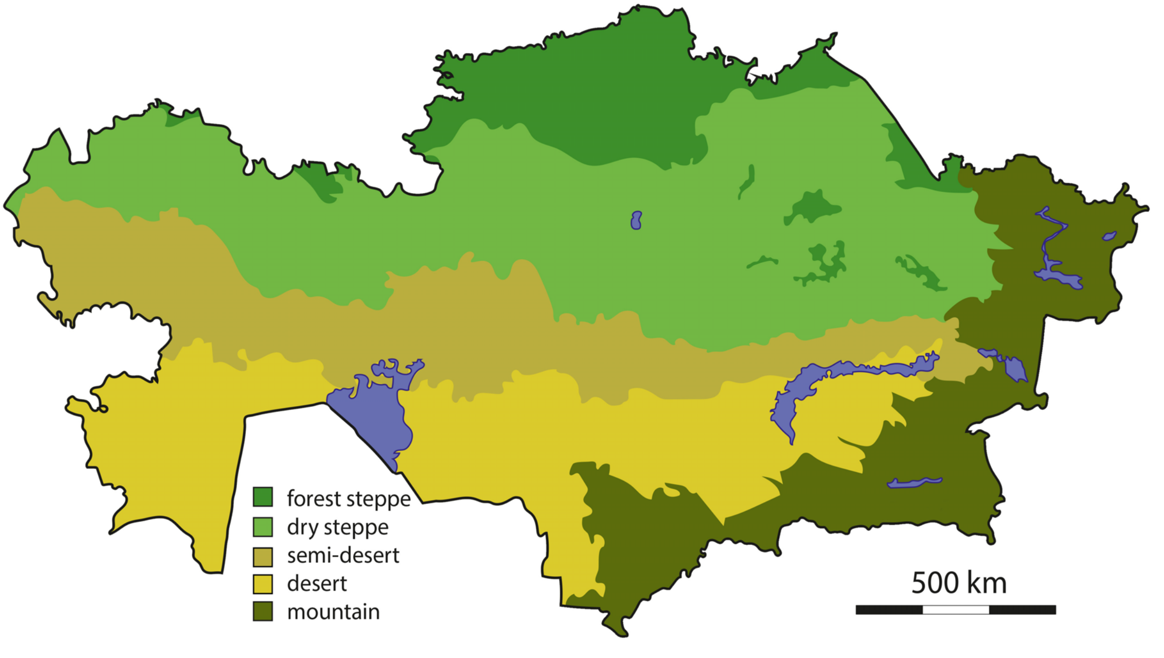

FIGURE 2 | Ecological zones across Kazakhstan.

winter camps in the piedmont, to high-altitude pastures during the summer (Kerven et al., 2011; Ferret, 2013, 2018). High-altitude pastures are preferred due to their high-quality grass and lack of disease-causing insects (Kerven et al., 2011; Ferret, 2013). Most herders in southeastern Kazakhstan spend at least 4 months grazing livestock in mountain pastures, staying until late September or early October (Ferret, 2013). However, transhumance is not a homogeneous lifestyle, as groups engage in different forms and scales of movement (Ferret, 2018, 2013). For example, some villages are permanently occupied while small groups of shepherds, and their families, move with livestock to seasonal pastures (Ferret, 2018). In contrast to the semi-arid plains, rich summer pastures with good water supply are relatively close in these mountain systems, while higher rainfall in the piedmont means that small-scale agriculture can also be practiced. But in both desert and mountain environments, access to winter grazing requires a leasehold and investment in winter bases, so only the largest herds are mobile in this season. In desert areas, these wintering areas are particularly crucial, as supplementary fodder cannot be grown. A lack of winter fodder availability and high feed prices are pressing issues among contemporary pastoralists in Central Asia (Kerven et al., 2011). The residues of cereal farming (stalks and chaff) provide an important source of winter fodder (Kerven et al., 2006), but there are trade-offs between fodder purchase and grazing in winter pastures that incurs different costs (Milner-Gulland et al., 2006). Where fodder can be grown, the preservation of pastures from herbivores and cutting of fodder are time intensive activities, while winter grazing may have fewer direct costs for those who can reach the economies of scale required to practice it. On the other hand, there is ample evidence that irrigated and rain-fed agricultural zones were used for large-scale fodder production in the modern period (Suleimenov et al., 2006; Ur-Rahim et al., 2014). Husbandry choices are also linked to increasing urbanization, availability of winter grazing and infrastructure in pastures, and herd size (Kerven et al., 2006; Crewett, 2012; Vanselow et al., 2012; Liao et al., 2014; Ur-Rahim et al., 2014) which are impacted by land access policies (Jordan et al., 2016).

One of the fundamental issues for herders is the availability of ecological resources such as water and pasture, which influence the amount of human investment required to sustain a population (**Figure 2**). Where risk is high, for example, in semi-arid ecologies, capitalization or investment costs are higher but there is less competition for these resources. Pastoralism in these regions depends on the long-distance movement of animals. Conversely, lower risk areas including high elevations, foothills, or in the northern steppe often have lush pastures and agricultural fields that provide alternative forms of subsistence. In these areas, there are lower investment requirements, but greater competition with other groups for pastures and settlements (Peters, 2004). Pastoral endeavors are easily sustainable in these regions, supporting transhumance and short-distance mobility strategies of herds, but at the same time, there is increased potential for social conflict and competition. Pastoralists engage in different forms of ecosystem engineering according to the availability of resources such as water and pasture, the amount of human investment necessary to sustain livestock and human populations, and the amount of competition with neighboring groups (Behnke, 2018). There is a strong correlation between the amount of available resources, population size, number of livestock which we will show has existed for millennia in northern Central Asia.

A DEEP HISTORY OF PASTORAL LIFEWAYS: ANCIENT ECOSYSTEM ENGINEERING

Pastoralism as a lifeway has been practiced in Central and Inner Asia for thousands of years, with archeological data suggesting that it was a component of regional economies as early as 6500 BCE in southern regions (Uzbekistan, Tajikistan, and Turkmenistan) and going back to at least 3000 BCE in northern areas (Kazakhstan, Mongolia, and Siberia) (Parzinger, 2006; Wilkin et al., 2020). Long-term pastoral activities led to the construction of new niches for human cultural activities in Central Asia, as seen in the prominence of endozoochoric-dispersed plants in archeobotanical assemblages. Archeobotanical studies across the Eurasian steppe clearly illustrate that endozoochoric plants, such as *Chenopodium* spp., *Amaranthus* spp., *Polygonum* spp., *Lithospermum officiale* and *Lithospermum arvense*, and *Echium vulgare* were dominant components of the vegetation communities in areas where herd animals grazed (Spengler et al., 2013b; Spengler, 2014, 2019). Endozoochoric plants use animals to disperse their seeds—for example, when a bird eats a berry, it will spread the seeds in that plant over greater distances than the plant could do alone (Tiffney and Mazer, 1995; Eriksson, 2008). Many of the plants that dominate heavily grazed lands, such as the taxa mentioned above, are endozoochorically dispersed (Spengler, 2014, 2019; Spengler and Mueller, 2019) and have evolved hard seed coats, dormancy, and small seeds in order to pass through the herd animal digestive system. When livestock or wild herbivores consume seeds that have not adapted to endozoochoric dispersal, these competitive plants are removed from the landscape (Spengler and Mueller, 2019). At the same time, endozoochoric seeds are deposited in nitrogen rich packages of fertilizer by livestock. Many of these plants are nitrophilous and they have traits for rapid colonization of disturbed ecologies. Long-term pastoralism accordingly favors reduced plant competition due to heavy herbivory and high nitrogen content of sediments, due to dense dung deposits, lends to an increased dominance of these endozoochoric species through time on a landscape. Fairly continuous niche construction activities by livestock result in new vegetation communities, a process that unfolds over generations.

Herders also reshaped Central Asian vegetation communities in other ways. Heavy herbivory, for example, selects for plants with corresponding defenses; in the Central Asian foothills, these plants include *Rosa* spp., *Ornopogon acanthium*, and *Hyoscyamus niger*. These plants are prominent components in Bronze and Iron Age archeobotanical assemblages in the region (Spengler et al., 2013a,b; Spengler, 2014), suggesting that the landscape around many prehistoric Central Asian sites was already dominated by plants that had specialized adaptations as a result of pastoralist activities. The buildup of animal dung is another key ecosystem modifier. Herders repeatedly return to seasonal grazing lands and cause dung to build up on these ecological pockets, which are often already biologically diverse and resource-rich micro-environmental zones (ecotopes). The concentration of nitrogen, calcium, phosphates, and other essential nutrients that have built up over hundreds to thousands of years are reshaping landscape ecosystems. Marshall et al. (2018) drew on soil chemistry and microstratigraphic analyses to illustrate the construction of so-called "hot spots" on pastoral landscapes in northeast Africa. Many other ecologists and archeologists have noted similar trends on heavily grazed lands (Porensky and Veblen, 2012; Reid, 2012; Riginos et al., 2012; Veblen, 2012; Porensky et al., 2013; Porensky and Veblen, 2015). For example, the construction and maintenance of ecological hot spots by caribou (reindeer) in the tundra and sub-tundra, with notable concentrations of dung near ice patches, date back 5000 years (Andrews et al., 2012). In Central Asia, the process was identified using both ethnographic observations and archeobotanical data, demonstrating that ecological hot spots contain nutrient-rich vegetation, which is a key factor in the current success of herding economies (Spengler, 2014).

Abundant Grasslands in the Urals During the Middle Bronze Age

Within the central Eurasian steppe, the Urals region is an optimal zone for herbivores, with moderate levels of precipitation (∼310 mm per year) and warm summer temperatures (max. 28°C) leading to abundant grassland growth in some areas. Parts of this region are currently utilized for rain-fed agriculture (Eisfelder et al., 2014), and adjacent areas in the southern portion of Kostanai Province form the main summer pastures and birthing areas of contemporary saiga antelope (*Saiga tatarica*). Paleoclimate reconstructions using pollen records indicate that the Middle Bronze Age (2400–1750 cal BCE) was relatively humid (Rudaya et al., 2009) and that vegetation composition in the Urals has remained broadly similar into the modern period (Stobbe et al., 2015). Rich pasturage available in the southern Urals led to an increase in populations of herders and their domesticated livestock beginning in the Bronze Age (c. 2200 BCE) (**Figure 2**).

As grasslands in the southern Trans-Urals are abundant and well-watered, these areas contained established ecological pockets constructed by wild herbivores in previous periods and were easily appropriated by domesticated livestock herds. Middle Bronze Age (2400–1800 cal BCE) people, often referred to as the Sintashta, constructed nucleated settlements, with population estimates ranging from 200 to 700 individuals (Gening et al., 1992; Grigor'yev, 2000; Anthony, 2007; Kohl, 2007; Koryakova and Epimakhov, 2007; Hanks, 2009). As populations increased in the Trans-Urals during the Middle Bronze Age, it is probable that wild herbivores such as saiga and kulan (*Equus hemionus*), modified their selection of sites for aggregation, birthing, and grazing to avoid disturbance and predation by humans. This is supported by modern studies of saiga habitat selection in response to disturbance (Singh et al., 2010) and by studies of the distribution of Pleistocene and modern saiga indicating that they occupied a more diverse range of habitats in the past than in the present day, stretching from France to Vladivostok (Jürgensen et al., 2017). There is also clear evidence for the continued presence of wild Asian ass (*Equus asinus kulan*) and saiga, in small numbers, through the Bronze and Iron Ages (Akhinzhanova et al., 1992; Haruda, 2018). As herders appropriated the regions formerly occupied seasonally by saiga and kulan for the grazing of their own livestock, they effectively re-engineered these landscapes to optimize them for domesticated taxa. Livestock would have kept woody shrubs and young trees down by grazing, both maintaining and working parallel with the remaining wild ruminants and equids.

Sintashta settlements were constructed with distance between them (∼8 to 40 km), suggesting that each site had an adjacent territory (Epimakhov, 2002; Zdanovich and Batanina, 2002). Recent work has confirmed that pastures in the vicinity of Sintashta sites had the capacity to sustain livestock year-round, making each settlement economically sustainable (Stobbe et al., 2015). However, with population growth during this period, anthropogenic effects were felt in the vicinity of settlements, including pasture degradation, shifting vegetation communities, and an increase in soil nitrogen levels (Stobbe et al., 2015). Intensive land use in the vicinity of settlements resulted in an increase in the growth of certain kinds of plants, including Amaranthaceae, *Plantago* spp., and Cichorioideae (Asteraceae), which are indicators of anthropogenic effects on the landscape (Stobbe et al., 2015). Cultural activities like the construction of housing and burial mounds, as well as metallurgy, further contributed to deforestation (Plekhanova and Demkin, 2005). A recursive system of effects from livestock and humans occurred in zones close to settlements, and the sustainability of activities in these landscapes appears to have been variable across space and time.

Evidence for livestock management in the Bronze Age in the Trans-Urals suggests that taxa were herded in different zones, with ruminants such as sheep, goat, and cattle kept in close proximity to settlements as well as in distant pastures, while pastures for horses were located in wetter areas well outside of heavily anthropogenically altered areas (Ventresca Miller et al., 2019). This deliberate distribution of herd species across the landscape occurred at multiple sites in the region bridging the Middle and Late Bronze Age periods (2400–1500 cal BCE) (Ventresca Miller et al., 2019). Further, these results indicate that ruminants were pastured extensively during the earlier period (MBA), with wider dietary niches than in the later period (LBA), indicating a greater dependence on distant pastures (**Figure 3**). It has also been suggested that Bronze Age pastoralists in the southern Urals situated their mortuary monuments in areas of productive pasture (personal communication B. K. Hanks), demonstrating how niche construction was attended and facilitated by human symbolic capital that served to both demarcate and appropriate pastoral landscapes. Herders engineered the grasslands of the southern Urals by occupying the landscape and grazing livestock near settlements for extended periods of time. Through time, these practices led to fundamental

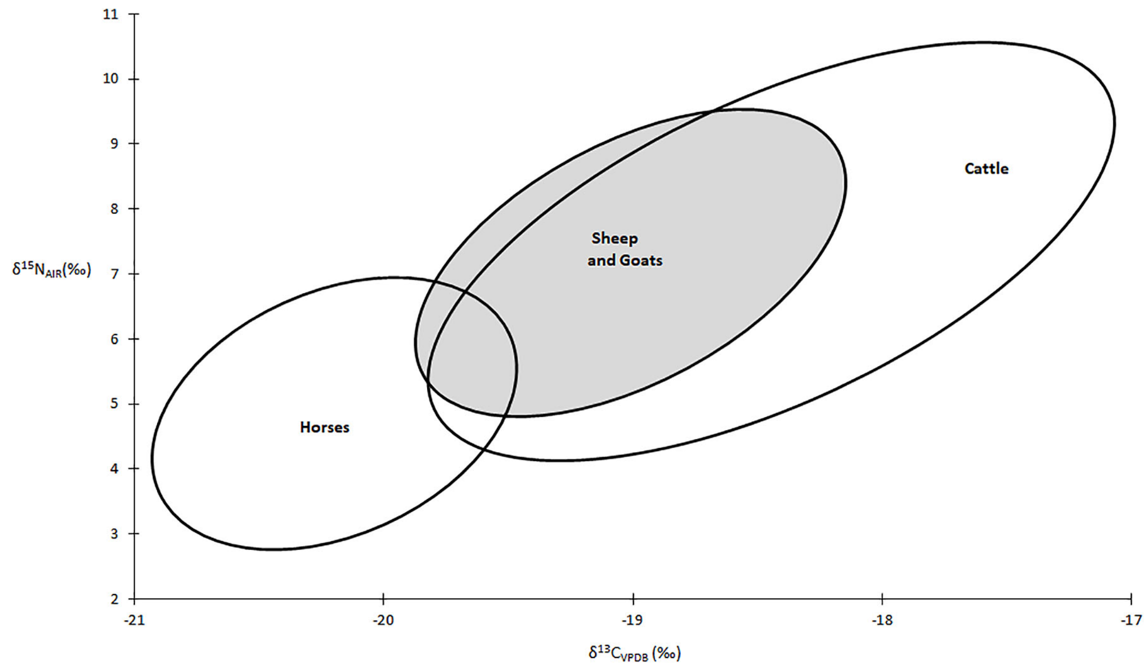

FIGURE 3 | Isotopic niches for horses, cattle, and sheep/goats from Middle and Late Bronze Age sites in the Urals (modified from Ventresca Miller et al., 2019).

changes in the structure of vegetation communities (Stobbe et al., 2015), including deforestation and nitrification of soils.

The trajectory of pastoralism in the Urals begins with the movement of herders, and their livestock, into areas previously occupied by wild ruminants. Domesticated livestock occupy similar spaces as their wild herbivore counterparts, thus there were already niches available that could be appropriated by herders for their domesticates. Our current understanding is that early herders first arrived in the Urals by the Early Bronze Age (∼3000 BCE), and it was not until c. 2200 BCE that we have clear evidence for the aggregation of populations. The combination of larger human populations, and livestock to sustain them, led to changes in the structure of vegetation communities around settlements. Thus, there was a shift over time in landscape use from economies based in hunting and gathering, to early herders, and finally settled pastoralists. These later pastoral groups engaged in ecosystem engineering by partitioning livestock into different pastures and allowing herd animals to stay near settlements for longer periods of time—leading to vegetation changes, pasture degradation, and nitrification of soils. Changes in the landscape may have been one of the many driving forces that forced a change in settlement patterns during the Late Bronze Age, where populations moved into smaller settlements dispersed across the steppe.

Foddering and Water Management in the Semi-Arid Steppe During the Final Bronze Age

In drier zones of Central Asia, such as the semi-arid steppe, landscape and livestock management strategies were essential to the growth and support of human populations (**Figure 2**). During the Final Bronze Age (1500–1000 cal BCE) in the uplands of central Kazakhstan, colloquially called Saryarka, pastoralists constructed locales that housed more densely aggregated populations than seen elsewhere on the steppe at that time. For example, the ancient site of Kent, a regional center with 130 pithouses, is surrounded by smaller settlement clusters dating to the same period, forming a proto-urban locality with a population in the low thousands (Evdokimov and Varfolomeev, 2002; Varfolomeev, 2011; Beisenov et al., 2014). Located in a relatively marginal zone in the semi-arid steppe, Kent is situated in a microclimatic pocket in a sheltered valley with year-round water that improves local forage considerably in comparison to the surrounding steppe. Contemporary vegetation data suggest that rain-fed agriculture is possible in patches across the landscape, typical of mosaic ecosystems (Klein et al., 2012; Eisfelder et al., 2014). Aggregated populations had economies based on pastoral products such as meat and milk from sheep and goats (Outram and Kasparov, 2007; Outram et al., 2012; Haruda, 2018). Human diets were supplemented by low levels of millet consumption (Ananyevskaya et al., 2018) suggesting that groups engaged in limited cultivation or agricultural production; although this has not been proven definitively through recovery of archeobotanical remains.

There is some evidence that pastoralism was already supported by significant investment in landscape alteration by this stage, as waterways were altered with construction techniques similar to those used to create Final Bronze Age (Begazy-Dandebaevsky) structures in other parts of the region (Margulan, 1979, fig. 188; Parzinger, 2014). These waterways consist of stone-lined channels used to re-direct water and snowmelt across the

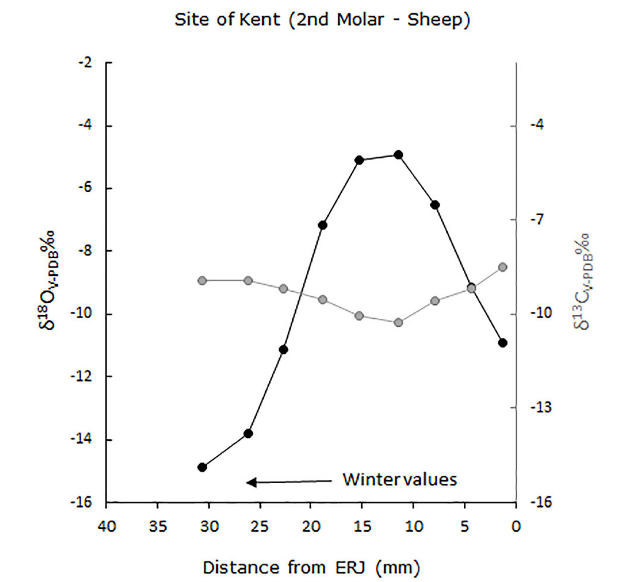

FIGURE 4 | A sheep tooth from the site of Kent in central Kazakhstan indicates that foddering was taking place (modified from Ventresca Miller et al., 2020).

landscape to supply either cultivated crops or pastures. This had the effect of improving soil fertility, carrying capacity, and enlarging ruminant herds (Love and Eckert, 2006), potentially providing sustenance for humans and livestock. Additionally, canals may have impeded animals from entering fields, serving a dual purpose to protect crops or pasture for later use. The reshaping of water resources, through irrigation, channels, or reservoirs, is common across ancient Central Asia (Parzinger, 2014) and in the modern era enables the use of otherwise marginal landscapes for agricultural and pastoral production (Robinson et al., 2016). Contemporary pastoralists often use concrete Soviet-period irrigation systems to enhance plant growth in pastures that are then harvested as fodder to increase commercial livestock production (Kerven et al., 2011).

Human modification of landscapes to increase growth of crops or pasture in the steppe is an important way to facilitate resilient economies, necessary when population density is high, as in the Final Bronze Age across Saryarka. As the consumption of domesticated crops was relatively minimal during this period (Ananyevskaya et al., 2018), the alteration of waterways increased the productivity of rangelands and cultivated fields. Sheep at Kent were closely managed, with evidence that they were foddered during the winter with grasses cut at the end of the summer months (Ventresca Miller et al., 2020). Foddering of sheep in the winter increased their health and fecundity, allowing for an extension of birth seasonality, while revealing an unexpected intensity in animal management practices (Ventresca Miller et al., 2020). Sheep teeth from the site have low oxygen isotope values that coincide with high carbon isotope values, demonstrating that they were provided with feed (**Figure 4**). Further, recent zooarcheological research has shown that domesticated sheep herds developed functional (skeletal morphological) adaptions to local environments that accrued through generations (Haruda et al., 2019).

Pastoralists in the semi-arid steppe of central Kazakhstan engaged in distinct forms of ecosystem engineering, as this area has less rainfall and forage availability than in the northern regions. During the Late Bronze Age, local populations grew, and sustainable lifeways were supported by the occupation of diverse microclimatic ecotopes such as river valleys. Human populations were sustained using limited agriculture, as well as innovations in pasture management that included the alteration of waterways and foddering. Furthermore, by allowing herds to graze locally, sheep responded in kind, developing skeleton morphology that was distinct from other sheep in the region and is indicative that long-distance mobility was not required to keep animals alive and pasture resources in good condition.

Mountain Pastoralism and Agro-Pastoral Foothills During the Bronze and Iron Ages

Mosaic environments in the mountains and foothills of southeastern Kazakhstan promoted a mix of pastoral and agricultural endeavors (**Figure 2**). Archeological research in southeastern Kazakhstan provides strong evidence for the presence of the region's first domesticated grains by the mid-third millennium cal BCE (Frachetti et al., 2010; Spengler et al., 2014; Doumani et al., 2015). Ecosystems were engineered through agro-pastoral practices, including vertical transhumance and the adoption of cultigens to diversify dietary intake and sustain growing populations (Ullah et al., 2019). Research shows that when pastoralism intensified and farming began, the region was covered in spruce and juniper forests with deforestation occurring (c. 1850 BCE) alongside potential shift toward a cooler climate (Beer et al., 2018). At the transition from the Bronze to Iron Ages, pastoral and agro-pastoral populations inhabited diverse ecologies along an altitudinal gradient in the Tian Shan. Deforestation was a key element of landscape modification in the foothills, supporting increased pasturage, with the long-term use of areas by domestic herds leading to the creation of nutrient-rich ecological pockets favored by livestock (Spengler et al., 2013b; Spengler, 2014). Simultaneously, there is evidence for wild taxa that preferred closed forest environments, suggesting a mosaic environment was present (Roberts et al., 2019). Cattle proportions remain low in this region throughout prehistory, while sheep and goats formed the majority of domesticated herd animals; however, preference for animals in this region was guided not just by ecological variables but by a complex interplay of cultural and social values (Haruda, 2018).

The site of Turgen, a high-altitude mountain encampment (1900 masl), had rectangular pithouses featuring central hearth features and storage pits located between houses (Goryachev, 2004). The site had at least two occupations dating to the Late Bronze and Early Iron Ages (Ventresca Miller et al., 2020). Sheep from this site were managed using different strategies that changed over time, with Bronze Age sheep being guided from high-altitude summer pastures to the semi-arid steppe, or low-altitude foothills, in the winter months. This is supported by

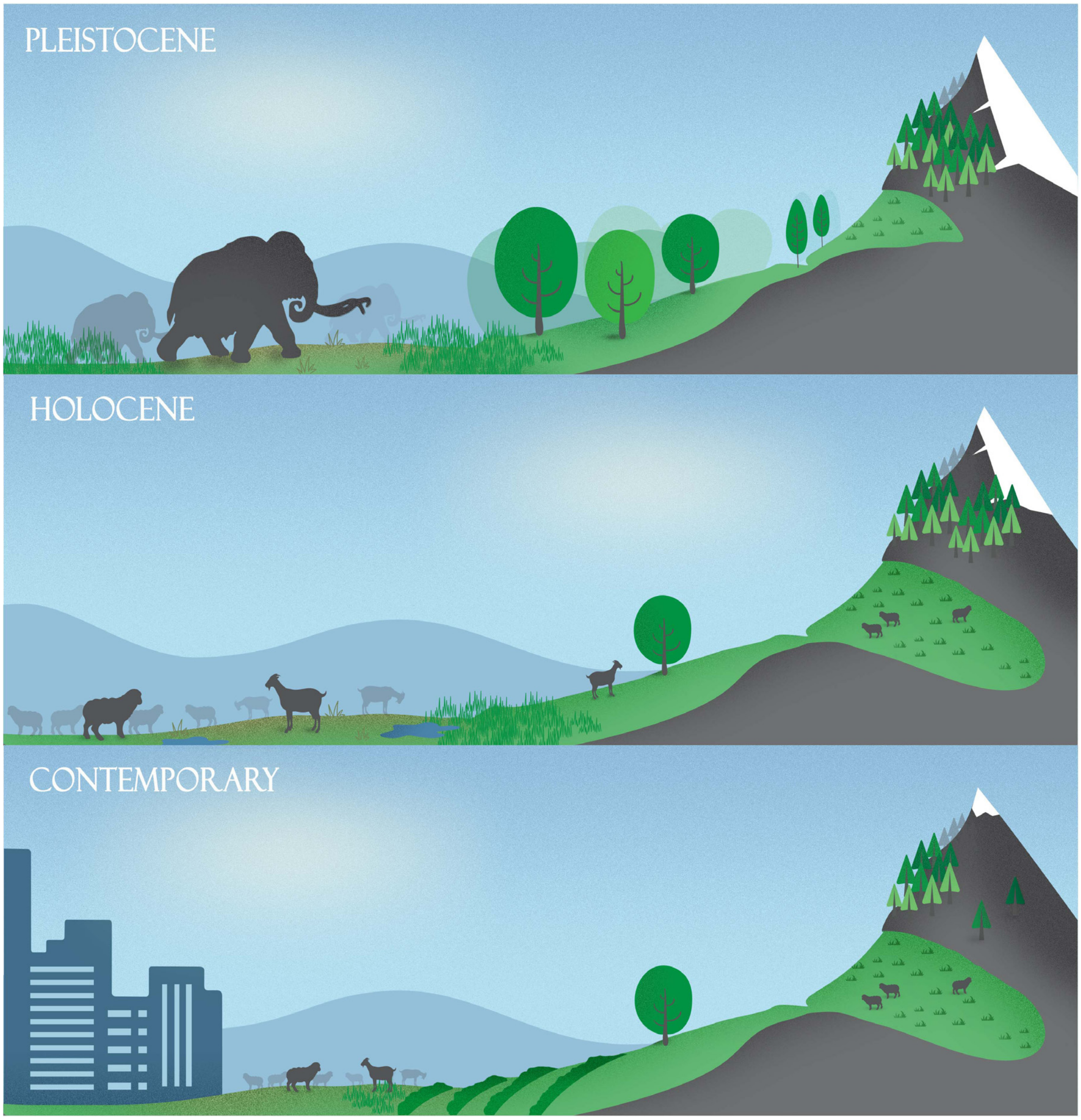

FIGURE 5 | Changes in ecosystem engineering and landscape impact through time.

studies of modern pastoralists who engage in similar activities to increase predictability of resource availability (Ferret, 2013, 2018). In the Early Iron Age, sheep exhibit a very different management strategy (Ventresca Miller et al., 2020). Sheep ingested vegetation that was ^{13}C-enriched, indicating that they were foddered with C_4 plants such as domesticated millet during the winter, while consuming a mix of millet and fresh graze in the summer.

This suggests that by c. 550 cal BCE, populations at the small encampment of Turgen had regular access to millet, which was plentiful enough to fodder sheep (Ventresca Miller et al., 2020). Allowing animals to graze stubble after harvest has a dual purpose of clearing the fields of remaining stalks and chaff while allowing livestock to manure the fields (Chang, 2017). There are several potential niche construction behaviors for this site: (a) human populations modified the landscape to cultivate and maintain millet at the site, (b) pastoralists directed herds to lower altitudes in the winter to graze on stubble, and (c) they may have imported millet fodder from lowland fields for their animals. As the site is at an elevation above the growing threshold for most crops, it is unlikely that millet was grown at this elevation, yet paleobotanical studies have not been undertaken to clarify ecological impacts to this landscape. However, this combination of agriculture as well as high-altitude pastoralism implies significant modification of the landscape. At Iron Age sites (400 BCE to 100 CE) in the Talgar region, these is evidence for year-round occupation with a dual system of seasonal transhumance of livestock alongside crop production (Chang, 2017; Schmaus et al., 2018; Ullah et al., 2019). Analyses of the locations of archeological sites from this period along the Talgar fan indicate that instead of being located near the floodplain, most are located near ephemeral channels that derive water from seasonal rainfall on the adjacent hills (Ullah et al., 2019). These relatively small changes to the landscape can have profound impacts on sedimentation and downstream erosion, with evidence for dramatic changes (Ullah et al., 2019).

In the foothills of the Tian Shan, pastoralists engaged in long-term adaptations to a unique mosaic environment. Vertical transhumance of livestock was an important part of the herding system, which played a role in the area for several millennia. This local adaptation was employed in parallel with the early introduction of agriculture into the region (Spengler et al., in press). It may be that cultivation in the floodplain and foothills fits well with vertical transhumance, as livestock are moved into high altitude pastures when domesticates are being sown in the low altitude steppe (Chang, 2017). In early periods, ecosystem engineering included vertical transhumance of livestock and cultivation of domesticated plants (Spengler et al., 2013a; Spengler, 2014). By the Iron Age, the ecosystem was heavily modified to include farming, the alteration of waterways, and the harvesting of millet chaff for fodder or allowing livestock to graze on stubble. Alterations to the local ecosystem allowed for population growth and inequality, with strong evidence for hierarchical societies by 100 CE.

DISCUSSION AND CONCLUSION

The archeological record of northern Central Asia demonstrates that pastoralists in this region have been engineering ecosystems, both intentionally and unintentionally, for thousands of years. While this record transforms our understanding of the behaviors of ancient societies once seen as small-scale and marginal, it also holds important insights into contemporary pastoral practices in the region that have yet to be fully examined. Our case studies have shown that ancient pastoralists modified environments to varying degrees across different biogeographical zones. Vegetation communities across Eurasia have likely been altered dramatically through time by grazing—whether by herds of megafauna during the interglacial phases of the Pleistocene or domesticated livestock during the Holocene—resulting in the significant alteration of regional ecosystems (**Figure 5**). During the Holocene, the growth of human populations and the adoption of domesticated livestock led to significant reshaping of the landscape, as the presence of multiple domestic and wild species greatly increased the scale of habitat modification. Bronze Age pastoral populations varied in their land use strategies based on environmental contexts, primarily dependent on topographic and ecological differences (Bendrey, 2011; Outram et al., 2012). The earliest evidence from the Trans-Urals points to the appropriation by herders and their livestock of land previously occupied by wild herbivores. Wild herbivores occupied a realized niche that was primarily based on grasslands and provided the same fundamental ecosystem services as domesticated ruminants. Herding animals in these grasslands is sustainable over long timescales if livestock are moved between disparate pastures to prevent overgrazing. However, with increasing population growth among settled pastoralists (Ventresca Miller et al., 2018), the landscapes around these sites would have been increasingly degraded (Stobbe et al., 2015), which may have led to abandonment. As the archeological record attests, modern conservation strategies in the Trans-Urals should include the movement of herds to new pastures on a regular basis to combat overgrazing. This is especially true for areas in close vicinity to smaller cities or towns, where nearby pastures are quickly exhausted due to overuse. Further, herds can graze on stubble in agricultural fields after harvest, which allows for the fertilization of these areas through manuring.

In drier zones, archeological data demonstrate that Final Bronze Age communities utilized innovations in landscape management such as irrigation and foddering to increase animal survival rates and provision aggregated human populations (Ventresca Miller et al., 2020). Engineering of semi-arid steppe ecosystems is heavily dependent on consistency of rainfall, which allows this diverse subsistence system to be productive. Contemporaneous ancient settlements were situated in well-watered valleys, at the base of granite outcrops, and in the semi-arid steppe suggesting that different land-use strategies were possible (Margulan, 1979; Evdokimov and Varfolomeev, 2002; Varfolomeev, 2011). Waterways were altered, through the construction of small dams that slowed the flow of surface water (Margulan, 1979, fig. 188; Parzinger, 2014). The harvesting of rainwater and snowmelt in these zones increased the productivity of the land, allowing for domesticated crops or pasture to grow. Additionally, canals may have impeded animals from entering fields, serving a dual purpose to protect crops or pasture for later use. Recommendations for semi-arid zones are complex and dependent on a range of environmental factors that change relative to the proximity of water. In drier periods, it is likely that pastoralists moved longer distances, decreased herd size, favored arid-adapted taxa such as sheep and goat, and/or dispersed in order to find new pastures.

In the mountain foothills, pastoralists used vertical transhumance to access high quality pasture throughout the year, and this tradition continued both before and after the advent of agriculture to the present day. Agriculture and pastoralism were adaptations to mosaic environments, located along ecotones that encouraged vertical transhumance of livestock. Livestock were moved to high altitude pastures in the summer months and to low-elevation semi-arid open steppe pastures in the winter. Further, the foddering of livestock in the winter with millet stubble, either through direct grazing of livestock or collection, occurred much earlier than previously suggested (Ventresca Miller et al., 2020). Conservation recommendations for the mountainous zones include vertical transhumance from high altitude summer pastures to wintering in the low-altitude steppe. This can be combined with foddering regimes, either from pastures cut at the end of the summer, agricultural stubble, or allowing livestock to graze in fields.

The archeological evidence for pastoralism across the Kazakh steppe serves as a foundation for discussions in contemporary conservation regarding the restoration of "lost ecologies," particularly in light of modern industrial pastoralism. Conservation measures for steppe and mountain-steppe landscapes in Eurasia are contextualized as efforts to encourage extensive pastoral movement, while dealing with the constrained pastoral mobility that currently exists. Studies of ancient livestock management strategies have called into question the prevalence and uniformity of long-distance herding strategies, and the part it played in Central Asian societies. Sedentary or semi-sedentary lifeways were prominent in the past with pastoral practices varying based on cultural choice and environment (Chang, 2017; Haruda, 2018; Ventresca Miller et al., 2018, 2019; Haruda et al., 2019). As modern ecologists focus on the restoration or rewilding of grasslands through the re-introduction of wild species to increase biodiversity, a secondary discussion should focus on how animal husbandry might also contribute to grassland ecology. Future directions in conservation should be specific to each ecological region, taking into account herd makeup, water availability, and traditional and archeological evidence for past livestock management strategies.

Importantly, in the modern era, an increase in infrastructure development and land conversion to crops has greatly affected wild fauna in Central Asia through habitat fragmentation and loss, alongside other anthropogenic effects (Kamp et al., 2016). Rapid urbanization and the support of growing populations, such as that seen in Kazakhstan, can be a selective force that changes the composition of animal communities and offers challenges to the maintenance of biodiversity. Urbanization is not a new phenomenon in the region, as pastoralists have engaged in various behaviors to build sustainable economies while supporting dense human populations since the Bronze Age. However, a focus on how and why particular strategies and niche-constructing behaviors succeeded, and failed, might provide a way forward for ensuring the provisioning of modern urban populations in global markets. Our findings indicate that while pastoralism is often understood as a specialized and highly mobile economy, it in fact comprises a diverse set of practices under the umbrella of livestock-based subsistence. When necessary, or useful, many Central Asian pastoral societies could engage in more extensive mobile pastoralism to mitigate climatic, ecological, or social issues. The primary barriers to shifts in the extent of herd movement are connected to regional population density, grassland productivity, availability of water and pasture, and capitalization costs of long-distance movement.

Archeological studies of pastoralism in Central Asia instruct us not only about the past, but also hold great potential to inform contemporary discussions of conservation, sustainability, and stakeholder engagement across this expansive, as well as ecologically and politically diverse, region. To meet such challenges, archeologists must reach out, both cross-disciplinarily and beyond the research community. Archeologists must ensure that their research findings are published not only in specialized disciplinary journals, but also in broader ecological, sociological, and conservation-related venues. They must also work closely with those studying contemporary environments, environmental change, and pastoralism in the regions they investigate. We demonstrate that ancient pastoralists acted as ecosystem engineers to encourage those engaged in development and planning goals to move away from notions of ecological systems in balance and instead to showcase a deep time approach to ecology as a complex system in which human lifeways are well integrated. This enables greater opportunities for contextualizing modern practices and patterns into longer timeframes, and for examining the sustainability of different approaches to pastoralism through time in a given region. Finally, archeologists must aim to draw on their understanding of the long-term interplay between climate change on the one hand, and pastoralist economic activities on the other, to contribute to understanding, predicting, and mediating the impacts of ongoing climate change on pastoralist economies and communities globally. Such engagement is key to the future of archeology and to ensuring that archeological insights into the Anthropocene find relevance and application in the modern world, in the context of ecosystem engineering by pastoralists as well as many other aspects of human behavior.

AUTHOR CONTRIBUTIONS

AV, NB, PR, and RS devised the study. AV, RS, AH, BM, and SW provided the archeological and historical context. SR provided contemporary ethnographic information. AV, RS, and AH wrote the manuscript, with comments from BM, SW, SR, PR, and NB.

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