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PERSPECTIVE

Zooscape ecology: a conceptual analysis of zoos and landscape ecology

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Abstract
Context Zoos are a unique landscape with fascinating connections to the principles of landscape ecology. These 'zooscapes' have a focus on managing wild species.
Objectives This article examines the multiple scales of zoos as urban green spaces, exhibit landscapes, and resources for resilience. I identify that landscape ecology can inform zoo evolution and note how zoos may provide a novel research site for landscape ecology.
Methods I provide a brief history of American zoos and insight into lingering questions within zoos, including their representations of animals and humans. Additionally, I note conceptual overlap between zoo design/function and landscape ecology literature.
Results Zoos provide habitat for native species and valued cultural ecosystem services. Zoo exhibits developed a landscape focus as modern landscape ecology emerged in the 1980s. Patches, corridors, and matrices exist within a zoo, and these facilities have value for the genetic support of fragmented populations. Zoos' strategies for disease management are increasingly relevant for global health. Simultaneously, zoos must exhibit sustainable landscapes, not just ecological simulacrums for threatened species.
Conclusions Zoos must promote humanity's continued coexistence with other species. A landscape view is essential to achieving this goal. Zoos need to model sustainable landscapes of our present and future.

Keywords Zoos · Biodiversity conservation · Landscape design · Human–wildlife interactions · Landscape sustainability

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Introduction

From its humble beginnings in the early 1980s, the field of landscape ecology has set its sights on understanding the complex relationships between ecological patterns and processes across scales (Wiens 2008). Unlike other traditional ecologies, landscape ecology has not hesitated to consider and actively engage the human presence in the natural world. Landscape ecologists have even used metrics initially developed to examine swaths of undeveloped land to examine and compare rapidly expanding metropolitan areas (Wu et al. 2011). Despite the aversion many disciplines have had to thinking across human and non-human animal divides, landscape ecology has long inhabited this conceptual space as it has worked to find more sustainable arrangements of human development amidst natural systems. Humans and animals often exist near one another and directly impact one another. Nowhere is this reality more readily apparent than in the zoo.

Landscape ecology thinking is therefore a natural fit for zoos, which historians and ecologists alike have often ignored in their analyses due to zoos' unique locus at the intersection of natural and built environments. Zoos also are well-suited to landscape ecology analyses given their stated aims of creating ways for humans to live in harmony with nature (Association of Zoos & Aquariums 2020; World Association of Zoos and Aquariums, n.d.). Landscape ecology has emerged as a sustainability-minded field as the holistic thinking of the long-term impact of land use and land change has become a major research thrust (Wu 2013b). Zoos can similarly incorporate this kind of thinking in their operation and designs to exemplify the most sustainable forms of landscape architecture.

According to zoo historian Baratay, "To tour the cages of a zoo is to understand the society that erected them" (2002, p. 13). In essence, the pattern of a zoo reflects its societal purpose and the ecological processes at play there. Landscape ecology seeks to examine the relationships between spatial pattern and flows of energy, materials, and organisms (Forman 1983). Zoos reflect our relationships with nature, with animals, and with other humans. Depending on how zoo exhibits are stylized, they can advance the unhelpful idea that we as humans are completely separate from nature, especially if they reinforce notions of a mythological, people-free wilderness (Cronon 1996). As ecologically informed exhibit design has developed, zoo exhibits have begun to more accurately represent diverse habitats (Hancocks 2001), though they have often lagged in considering the human element. Many zoo exhibits stress how humanity's actions directly jeopardize the continued survival of many species (Merlino 2006), though more zoo exhibits must go further and stress the real actions people and society as a whole can take to have a more sustainable relationship with the natural world (Fig. 1).

As public attitudes toward animals have become more considerate of their biological and social needs, so too has veterinary care in zoos improved. Animals once considered valuable only for their ability to be seen by visitors have become valued by their

Fig. 1 Depiction of the London Zoo in 1835 (Scharf 1835)

communities as individual beings with personalities and interests (Bender 2016). Zoological collections started as royal menageries that acted as physical representations of aristocratic power, but the 18th-century democratization of European countries led to the creation of the scientifically-oriented public zoological garden we recognize today (Baratay 2002). As European Empires grew, zoos sourced animals and cultural artifacts through new colonial avenues (Rothfels 2002; Bender 2016). As pre-Nazi Germany became increasingly nationalized, its zoos even touted the superiority of the country's native fauna (Mohnhaupt 2020). In the United States, American zoos brought in their own racist undertones, substituting chimp performers for black-face minstrels as racial segregation became widespread within urban areas (Uddin 2015; Bender 2016). Now, zoos have continued to struggle as they find appropriate and accurate ways to depict humans in the natural environment. One zoo hired "cultural interpreters" only to be faced with a media firestorm (Valdes 2007). In 2007, Seattle's Woodland Park Zoo hired several Western-educated Maasai men in western garb to lead tours of the zoo's new Africa exhibits and talk to guests about their lived experiences and the importance of conservation. Unfortunately, much of the zoo's marketing for the attraction focused on the guides rather than the exhibits, leading to some outcries from local academics at the University of Washington who asserted that human culture has no place in a zoo. Despite the bad press, the tours and exhibit were well received by thousands of visitors, who were often struck by the personal stories the Maasai guides shared about their lives alongside African wildlife. The Maasai guide program even received a national award from the American zoo community in 2008 (Woodland Park Zoo 2008). Perhaps, by thinking of zoos as their own miniature landscapes, we can find more just and ideal arrangements of the natural, animal, and human elements that make up the modern zoo.

In this article, I will be examining how zoos, as an often-overlooked element of the urban landscape, embody and exemplify the concepts of landscape ecology, as well as how the two fields might inform one another as they continue to develop. In my analysis, I will examine how some of the principles and research areas of landscape ecology may play out in zoos, at a variety of scales. History shows that zoo design and function has slowly broadened from an individual and species-specific approach to a more collective and ecologically informed one (Hanson 2002). By broadening further to include the human factors present in a landscape ecology approach, zoos can further their contributions to a shared sustainability mission.

Methods

To put zoos in productive conversation with the concepts of landscape ecology, I will examine zoos through three functional perspectives. The first perspective will concern zoos as urban green spaces. How have zoos provided natural spaces in urban areas throughout their history, and what value do zoos pose to native species and zoo visitors today? The second perspective will consider the campus of individual zoos as landscapes. For example, how have zoos developed the exhibit design approach of landscape immersion, and how does this mirror the development of landscape ecology as a discipline? Some special consideration of how Forman and Godron's (1981) patch/corridor/matrix framework can be applied in zoo exhibits will also be included. Finally, with the third perspective I will examine zoos as an untapped resource in the growing efforts to keep both wild populations and human society safe and healthy in a world of increasing habitat fragmentation and interspecies interaction, with special attention to the topic of emerging infectious diseases such as COVID-19.

Zoos as a unit: green spaces in the urban landscape

America's earliest zoos developed closely alongside the first major cities. The Philadelphia Zoo, traditionally considered America's first zoo, opened in 1874 after the American Civil War delayed the establishment of a facility envisioned by a local zoological society founded in 1859 (Kisling 2000). These first zoos were often created in tandem with the American Urban Parks Movement in the early 1900s (Henson 2018). Many zoos were even initially managed by cities' park departments (Braverman 2012). The famed American landscape architect Frederick Olmsted, known best for his co-design of New York City's Central Park, was one of the giants of this movement

and was even involved in the design of several major zoos (Hanson 2002). Thomas Jefferson had earlier advocated for the park movement's core concept of pastoral utopianism, leading to the idea that life in the city represented some kind of moral hazard to people, and that the consumption of a manicured, tamed nature was necessary in order to counteract those harms (Baratay 2002). To achieve this, the proper kind of nature had to be curated in these urban parks and in zoos. Ideally, these parks would provide a delicate taste of a romanticized nature, one that would be safe enough to explore but still beautiful enough to make it worth enjoying (Uddin 2015). In these early pastoral zoos, animals were organized in a very clear fashion in large typically single-species exhibits where the animal didn't overwhelm the visitor's view of the greenery (Hanson 2002). Animals were to fit within the scene, but not dominate the image as a centerpiece (Uddin 2015). The controversial founding director William T. Hornaday of the Bronx Zoo was very particular in what he allowed in his zoo. Animals were to be presented as a perfect picture, with realistic social groups and painted backgrounds. Hornaday even prohibited guest photography to ensure that the only public photos of his zoo would be carefully curated (Hanson 2002). Zoos have long considered themselves through the lens of a landscape, albeit a highly contrived and artificial one (Fig. 2).

The zoo landscape is designed for people, but for much of their history zoos have been exclusionary

Fig. 2 Early Model of National Zoo Grounds, prepared by William T. Hornaday (United States National Museum Photographic Laboratory 1888)

institutions. Some of the first formal Western zoos, such as the London Zoo, began as expensive entertainment-focused member-only institutions (Rothfels 2002). This stockholder-based zoo structure quickly fell out of favor when several institutions adhering to the model, such as the Rome Zoo, went bankrupt in the late 1800s and early 1900s (Baratay 2002). As the middle class grew in affluence, they suddenly had the time and wealth necessary to attend expanding zoological institutions, choosing to imitate the promenade of aristocrats at the zoo rather than attend the theater, an act that was considered morally degradative (Baratay 2002; Hanson 2002). Hornaday considered the Italian immigrants who collected firewood in the woods around the Bronx Zoo to be delinquents and carried a pistol with him at all times as a result (Bender 2016). While Hornaday actively killed and collected avian specimens himself, he considered immigrants who hunted native songbirds for food to be less than human and called the police in to shoot at them (Uddin 2015). Hornaday actively fought against a disordered zoo landscape. During one day of Hornaday's war against littering visitors, 126 visiting men, women, and children were arrested (Bender 2016). While segregation was present at many zoos, zoos were typically less segregated than many other urban institutions (Levy 1992; Baratay 2002; Wells 2018). Still, the racist views of their leaders were clearly visible in messaging about biological European superiority or their colonial conservation approaches. One of the most visible of these instances was the brief exhibition of Ota Benga, a young Congolese Pygmy tribesman at the Bronx Zoo in 1906 (Howard 2018). Despite this lack of a warm welcome, many minorities flocked to the zoo given few alternative sites for recreation. For decades until the 1960s, African Americans would come to roll eggs on Easter Sunday in the National Zoo because black children were excluded from the event at the White House (Baratay 2002). Zoos are mirrors of society, including collective views toward not only animals but also groups of people. As a result, zoos have actively engaged with and contributed to racist historical frameworks of science and conservation. Simultaneously, they have been an important restorative landscape for city-dwelling humans for decades. By equitably considering *all* community members in urban landscapes through inclusive frameworks such as landscape ecology, zoos may be better able to disentangle themselves from their colonial past for a more inclusive future.

Today, zoos are increasingly recognized for the value they pose to native species and human visitors as a reservoir of natural surroundings in urban settings. One recent study demonstrated the value of zoos as habitat for small mammal species (Elwell et al. 2021). The authors suggested that because zoos often are located in cities but not immediately adjacent to residential areas and additionally utilize barriers such as perimeter fencing, zoos indirectly may have smaller local populations of feral cats than that of the surrounding area (Elwell et al. 2021). This suggests that zoos act as valuable urban green spaces for native small mammals. Small mammals are not the only species to benefit from zoos, however. Zoos, with their generally significant amount of horticulture, shelter, and perennial water sources also act as stopover sites for the migration of many species of birds (Totha 2019). The Phoenix Zoo was even the site of the first known sighting of a Trumpeter Swan in the Phoenix Metro area in 2018 (12News 2018). India's Delhi Zoo has long acted as a crucial nesting ground for hundreds of wild, near-threatened Painted Storks, and one study even used the site to research the species' reproductive behavior and threats (Meganathan and Urfi 2009). Though currently underutilized, it is possible that many zoos around the world offer similar study sites for species of conservation interest.

Through cultural ecosystem services, even human beings benefit from the green space provided by zoos. Journalist Richard Louv has coined the term "nature deficit disorder," a theoretical ailment in many children today that results from a substantial disconnection from nature due to Americans' increasingly urban and technological lifestyles (Louv 2006). Studies have found that visits to the zoo can be beneficial for young children in terms of educational and moral outcomes (Fraser and Switzer 2021), though these kinds of claims often are debated (Kahn et al. 2008; Marris 2021). Some zoos have found very simple natural elements to be an especially charming part of the zoo experience. Constructed with the surplus dirt from a publicly funded excavation project in the 1930s, "Monkey Hill" at the Audubon Zoo in New Orleans, has long been—albeit somewhat falsely—credited as the tallest point in the famously low-lying city, standing a meager 26 feet above sea level

(Campanella 2014). Nearly a hundred years later, the children of New Orleans continue to find endless joy log-rolling down the hill, one of the few points of geographic elevation in the region (Campanella 2014). Sometimes, very simple elements of heterogeneity, such as relatively minor differences in plant density or elevation can make a world of difference for people's connection to the natural world.

Within the zoo: landscape ecology in exhibit design

The principles of zoo exhibit design have also changed drastically over the decades, with notable developments in the 1970s and 1980s, allowing one to draw some fascinating parallels with the history of landscape ecology. Today, landscape ecologists are continuing to study the impact of spatial planning and landscape design in order to create more sustainable landscape arrangements and uses (Milovanović et al. 2020; Hersperger et al. 2021). During the foundational period of modern landscape ecology signified by the 1983 Allerton Park Workshop (Wiens 2008), zoo exhibits were similarly developing towards a spatially aware ecological mindset. By the 1980s, American zoos began recognizing the interconnections between humans and nature and represented that through exhibit messaging (Uddin 2015). At the same time, zoos faced increasing scrutiny about animal welfare (Jamieson 1985). Zoos suddenly realized the need for change within the institution, and began developing more meaningful and effective conservation programs, though the measures for success in this area still often lack consensus. Zoos could no longer stand on the sidelines, claiming to act as "Noah's Ark" by protecting species from the storm of species extinction; the world was changing too quickly and the Zoo Ark didn't have the space necessary to protect all the creatures facing destruction (Keulartz 2015). All zoos could do was buy threatened species some extra time (Conway 2011). Zoos had to improve the care of their animals while also creating meaningful change to support species in the wild.

One meaningful innovation that helped address both of these issues was the new zoo exhibit design approach called "landscape immersion" (Hyson 2000). Seattle's Woodland Park Zoo pioneered this approach during its redesign in the late 1970s while under the directorship of David Hancocks, a zoo architect. These exhibits were a drastic change from the harshly modern, cement-forward, barred exhibits of the mid-twentieth century (Hancocks 2001). Such former "sanitary modernism" style exhibits sought to meet animals' needs without any natural features; they were bare, quick to hose down, and often placed the viewer far above the animal (Hyson 2000). Landscape immersion built in the reverse by seeking to achieve necessary biological functionality through natural forms; this school of thought contended that the best way to meet every known and unknown need of an animal was to make as accurate of a recreation of their natural habitat as possible (Braverman 2012). Consequently, landscape immersion exhibits were lushly planted and placed the animals at or above visitor eye level (Hanson 2002). Defining the term in 1975, leading zoo architect John Coe explained that a landscape immersion exhibit places the animal in the context of nature, rather than the context of architecture, and that it makes the visitor feel part of nature rather than an outside observer of it (Braverman 2012). The approach quickly became the standard for new exhibits built at American zoos in the 1980s (Hanson 2002). The rapidly growing field of ecology inspired not only landscape ecology, but also landscape immersion. The value of ecosystems was suddenly blatantly obvious, and the former architectural styles that ignored such benefits were quickly replaced by new designs that included more meaningful natural features.

Landscape immersion style exhibits provide a very direct way to consider the landscape ecology of zoo exhibits. All landscapes are made up of patches and corridors within a particular matrix (Forman and Godron 1981). Why should zoo landscapes be any different? When architects Jones and Jones were in the design process for the first major landscape immersion exhibit in America at Woodland Park Zoo, they measured tiny differences in environmental conditions at the site in order to map out microclimates (Hancocks 2001). Minor heterogeneity matters greatly when considering the scale of a zoo exhibit, which is typically much smaller than an animal's natural range. There are some unique factors present in zoos that create patch types we might not expect to find in other landscapes. One is the element of public viewing. Individual animals are differentially affected by this presence, leading to preferences in different

areas throughout an exhibit. One study measured the favored spaces for individual okapi within an exhibit, and the factors that influenced those choices (Troxell-Smith et al. 2017). Another fascinating element is that of multispecies exhibits. In the wild, animals would be able to move away from one another easily enough to find private spaces or food sources only accessible to them. Even in large, enclosed areas, this is less feasible. One way that zoos get around this is by creating species-specific barriers. Like a backyard bird feeder targeting finches as opposed to pigeons through careful perch and dispenser design, zoos create food containers that ensure only the target species can access them. In the same vein, zoos will establish barriers that only smaller or more nimble species can navigate, thus ensuring that gazelle have a space they do not have to share with giraffe, for example. Thus, even the areas that animal species are found within a zoo exhibit can take the form of small discrete patches as opposed to the large gradients we might expect in nature.

Some zoos have now even begun to experiment with the use of habitat corridors as exhibits. The Philadelphia Zoo, given its central urban location and small size, has had to become creative as it's worked to improve its exhibits. Their solution: Zoo360, a collection of mazelike passages that allow a wide number of animal species to move around the zoo for different sights, smells, and experiences (Philadelphia Zoo 2016). The trails have been continuing to expand since the first set opened in 2011: now lemurs and monkeys have access to a treetop trail and tower, great apes have a climbing path, big cats have an overhead passageway, and gorillas have an elevated walkway (Philadelphia Zoo 2016). Opened in 2014, the Indianapolis Zoo's Simon Skjodt International Orangutan Center includes a network of massive cables suspended 80 feet in the air that the great apes climb in order to visit a number of satellite areas (Beard 2014). In so doing, the zoo has utilized vertical space and corridors to maximize animal welfare by giving the animals the opportunity to choose who they spend their time with and where in the complex they prefer to reside (Beard 2014). This represents the unique spatial configuration of zoo landscapes.

For many species, the ability to travel longer distances than what is typically possible in a traditional exhibit can be a medical necessity. Captive elephants in particular can suffer from major infections in their feet if they are not walking around enough and fail to receive the proper maintenance to support their foot health (Mehren 2003). To combat this, some new elephant exhibits have provided pathways for elephants to explore and thus increase their walking distance. When the National Zoo reopened their renovated elephant exhibit in 2013, it included a one third of a mile uphill walking trail for the elephants to use to exercise and explore a different part of the zoo (Associated Press 2013). Corridors can drastically change the behavior and opportunities for many species; by thinking more about the social and ecological interconnections between animal individuals and species, zoos may be able to further expand the use of these structures in zoo exhibits.

Patches and corridors also shape visitors' experience of a zoo. As discussed, recreation areas within a zoo represent an important opportunity for people to connect with their local environment. Patches of parking lots, food venues, and animal exhibits are all connected through public pathways. As they go along, families collectively decide their path through the zoo that day. The exploratory space within a zoo offers valuable opportunities for individuals to connect with one another as groups make shared meaning through their interactions with wild animals (Clayton et al. 2009). Paths are also useful dividing tools for the sake of managing foot traffic. Careful path design allows visitors to have a more personal experience with the animals. Zoos hope that this these shared and private moments with wildness inspire visitors to act for biodiversity and sustainability.

So far, we've seen how zoos have embodied the concepts of patches and corridors, but what about matrices? Depending on the scale of concern, we could consider zoos as green space patches in a matrix of urban centers, or we could see zoo exhibits as wild patches within a matrix of public recreation space. Some zoos even blur the line between where we end and where wildlife begins. In any case, landscape ecology can contribute to a conversation about diversifying the types of patches, corridors, and matrices in zoos. What might it look like for a zoo where the matrix is wild space, and only the patches and corridors are areas and paths for people to move around in? Safari parks, which appeared in America in the second half of the twentieth century, give us some idea of what an 'inverted cage' might look like (Baratay 2002; Bender 2016). Some other facilities,

such as the Arizona-Sonora Desert Museum outside of Tucson, has used traditional zoo techniques with a beautiful backdrop with great success. By controlling sightlines, minimizing the visible barriers between visitors and animals, and by incorporating exhibit infrastructure seamlessly into the beautiful desert surroundings, the Desert Museum makes it easy to suspend disbelief to a whole new degree, and actually leaves visitors startled when they suddenly find themselves face to face with a coyote (Grazian 2015). Granted, this same effect will likely be more difficult to achieve in zoos located directly within cities, but perhaps it is still possible. More work needs to be done as we strive to create these wild spaces in city centers where they can be more easily accessed by the growing numbers of urban families.

Zoos as a resilient institution: pan situ approach and one health

Zoos may be able to model sustainable means through which people and animals can safely coexist in the Anthropocene, even as habitat loss, climate change, and pandemics prove to be existential threats to our way of life. As we begin to understand the full complicated impact of habitat fragmentation on biodiversity, it's important for us to take measures to reinforce natural systems against new anthropogenic disturbances (Wilson et al. 2016). Zoos may have some valuable approaches that have yet to be fully utilized.

Researchers are recognizing the potential catastrophes of isolated populations. Metapopulation ecology provides a means to examine the degree of interaction between two or more distinct populations (van Nouhuys 2016). Landscape genetics takes things one step further to understand how landscape structure interacts with population genetics and evolutionary change (Holderegger and Wagner 2006). Zoo animals, simply labelled as *ex situ* populations, have long been ignored in the discussion of fragmented wild *in situ* populations. Yet, in a growing number of cases, zoo populations may amount to a large portion, if not the entire population, of a threatened species (Mendelson 2018). There is a need to re-integrate zoos' captive populations within the conversation of metapopulation management in what have some have termed a "*pan-situ*" approach (Minteer and Collins 2013). There is no denying that zoo animals are an isolated metapopulation, however, in an increasingly fragmented world, wild populations are also becoming similarly limited. In such a situation, re-integrating zoo populations with wild ones through re-introduction, head-starting, and cross-fostering programs may not only supplement the continued recovery of threatened species, but it may also provide the high genetic flow necessary for species to adapt to the dynamic environment of the Anthropocene (Scharis and Amundin 2015). The Association of Zoos and Aquariums' (AZA) Species Survival Program (SSP) for Mexican Wolves recently partnered with the United States Fish and Wildlife Service (USFWS) in order to cross-foster twenty captive-born Mexican wolf pups into several wild packs in Arizona and New Mexico (Arizona Game and Fish Department 2020). By more effectively integrating captive zoo populations into wildlife management, zoos can become a genetic reservoir for wild populations. Instead of culling a particularly problematic wild animal that cannot be effectively relocated, perhaps wildlife managers can place the animal in an accredited zoo or wildlife center. There, that animal can be included in a breeding program that aims to release their offspring, ensuring that its genes can still support the species' survival in the wild. Working with the World Association of Zoos and Aquariums and the IUCN Red List, the Conservation Planning Specialist Group is seeking to make these kinds of comprehensive conservation efforts, which they term the "One Plan Approach," more widespread (Byers et al. 2013). Several endangered species, including the golden lion tamarin, have already benefited from this novel approach. Through creative and innovative partnerships, zoos can help conservationists preserve genetic diversity in wild populations even as human disruption to their habitat increases.

Zoos have long had to navigate animal health using longstanding common practices such as quarantines for animals arriving from different facilities and continents (Hanson 2002; Bender 2016). Great ape exhibits started to implement glass rather than open air bars in large part due to a growing understanding of the possibility of humans passing minor ailments that became virulent diseases in captive apes (Baratay 2002; Braverman 2012). This virological awareness in zoos has only grown as zoo veterinarians have incorporated a growing number of responsibilities, often becoming population managers, wildlife

rehabilitators, and reintroduction specialists (Braverman 2021). Some American zoos are now even part of a Center for Disease Control (CDC) sponsored program where they report any cases of West Nile virus in their bird collections. Wild birds can be expensive to monitor due to the challenge of permitting and capture while zoos regularly carry out bloodwork and examinations on their avian collections. In open air aviaries, wild birds infected with the virus can easily pass it to zoo birds. Through this monitoring network, zoos act as sentinels for local outbreaks of West Nile (Nolen 2003).

Zoos have begun to embrace the One Health concept, best described as the growing understanding that wildlife health is directly related to human public health (Braverman 2021; Sulzner et al. 2021). The One Health concept is closely related to landscape connectivity and landscape epidemiology in particular (Meentemeyer et al. 2012). Given their unique operational practices providing frequent interspecies interaction, zoos not only have the space to develop and test transdisciplinary One Health solutions, but they also have an audience that can be educated regarding the epidemiological impacts of animal–human interactions (Robinette et al. 2017). In early 2021, the AZA began the "Reduce the Risk" initiative, a joint effort between the AZA, experts in safe animal transport, and their partner, the Wildlife Trafficking Alliance (Association of Zoos & Aquariums, n.d. 2021). The goals of this initiative include advocating for new legislation (such as the Preventing Future Pandemics Act), educating the public of the dangers of the wildlife trade, and contributing to efforts to halt wildlife trafficking.

Research within the field of landscape ecology is coming to conclusions that only further encourage this public health initiative for zoos. Landscape epidemiology is emerging with a focus on the socio-ecological interactions of pathogens at a variety of scales, including the habitat conditions that put global health at risk (Cumming et al. 2015). For example, new research demonstrates that habitat fragmentation can increase the risk of future pandemics (Azevedo et al. 2020). By raising funds and public support for habitat protection, zoos can come alongside other conservation organizations, international governments, and local communities to reverse the progress of global habitat fragmentation. Other researchers in landscape ecology have recognized that pandemic risk is not only dependent on habitat fragmentation, but also the ways in which people interact with wild places and the wildlife that lives there. Bloomfield et al. (2020) found that certain behaviors brought people to the core of fragmented habitat, such as pole cutting (from large trees that nonhuman primates often reside in) along with hunting and foraging, increased the likelihood of humans encountering non-human primates. These encounters provide opportunities for zoonotic diseases to jump between the two parties, with potentially devastating impacts for both species' populations. Perhaps, through partnerships with local communities and organizations, zoos can provide the personal protective equipment and behavioral techniques necessary to reduce the risk of disease transfer when community members need to engage in these high exposure risk activities. Zoos have decades of experience establishing clear and healthy boundaries for the benefit of ourselves and wildlife. It seems like, amidst the ongoing COVID-19 pandemic, it's time to include zoo managers in the conversation around practical zoonotic disease prevention measures.

One recent editorial in *Landscape Ecology* has noted the value of green infrastructure for societal resilience to the growing risks of climate stress and public health crises (Pamukcu-Albers et al. 2021). They define green infrastructure as "a system of natural and artificial green spaces that provide ecological and social functions in urban areas" (Pamukcu-Albers et al. 2021). Zoos fit naturally into this network. As we discussed earlier, zoos represent an important ecological reservoir for many wild species in urban areas (Elwell et al. 2021). Zoos are also a clear social resource. They provide key opportunities for connections to wildlife that can foster action for conservation (Skibins and Powell 2013). Zoos may also be a very valuable site to understand the local and global relevancy of climate change and our actions to mitigate it (Grajal et al. 2017). As the pandemic has shown us, outdoor green spaces provide immensely valuable spaces for safe recreation to support good mental health (Pamucku 2021). Zoos, given their primarily outdoor situation, have proven to be an especially valuable local activity amidst the COVID-19 pandemic. The Phoenix Zoo, for example, was able to reopen for regular drive-through "Cruise the Zoo" events during the peak of COVID-19 lockdowns (AZ Family 2020).

The One Health principle ties together zoos' mission to serve their visitors, care for their animals, and support global conservation efforts.

Even beyond the One Health principle, zoos pose an important forum to discuss the proper relationship between humans and the natural world. The wildness of zoos is constructed and artificial, and the zoo itself is ultimately built for people (Hancocks 2001; Rothfels 2002). By embracing rather than concealing the human-ness inherent in the institution, zoos can provide a space to explore what more environmentally sustainable landscapes might look like, both in terms of our environmental ethics and geography. Zoos must bring a human-aware sustainability approach into their design and operation (Cerezo and Kapsar 2018; Norton 2018). As landscape sustainability science suggests, not all landscape patterns are equally effective at contributing to global biodiversity, ecosystem services, and human wellbeing (Wu 2021). Landscapes are complex, with unique interactions between scalar levels and often unpredictable disturbances from outside the systems (Wu 2013a). As zoos create architecture and exhibits, they can model green infrastructure to a wide public audience. For example, the Cincinnati Zoo constructed their Hippopotamus exhibit (home of the famous prematurely born hippo "Fiona") with a cistern to collect 400,000 gallons of rainwater, as well as a series of advanced and natural filtration systems, for use in exhibits around the zoo. Signage in the exhibit communicates to the public how various natural components, such as tilapia fish in the hippo pool, all contribute to clean water for the hippos and human viewers to enjoy (Meek 2017). By applying landscape ecology principles, zoos can not only illustrate ecosystem function and biodiversity, but also human wellbeing and flourishing.

Conclusions

As this discussion has demonstrated, it is useful to consider the implications that landscape ecology has on social institutions, since doing so can lead to new ideas and innovations of significant value. In this analysis, we have (1) identified the value of zoos within cities for urban wildlife and human recreation; (2) created a vision of zoo exhibits as landscapes with unique forms of heterogeneity and novel patch dynamics; and (3) recognized zoos' ability to contribute to landscape sustainability, biodiversity resilience, and public health in response to habitat fragmentation.

Early American zoos were myopically focused on creating picturesque landscapes of pastoral wilderness (Baratay 2002). This was often an overly narrow lens, in large part influenced by patriotic ideals of the wilderness, but it stressed animals' existence within an environmental context (Hancocks 2001; Hanson 2002). In the mid-twentieth century, zoo animals were deprived of that context and generally exhibited as specimens within markedly unnatural surroundings (Hyson 2000). Since the 1980s, zoo animals have been frequently exhibited with a greater focus of their ecological roles and needs (Hanson 2002). Yet, the landscapes presented by many of these exhibits omit any reference to a key species: *Homo sapiens*. Human presence and impact on the landscape is largely omitted. Zoos must engage in the Anthropocene and provide examples of sustainably coupled socioecological systems within their exhibits (Grazian 2015). They must demonstrate how human society can develop with minimal harms to the environmental systems upon which we and all other species depend (Norton 2018). Just as human society is no island, zoos are no ark. In order to preserve species in such an interconnected world, zoos must collaborate with diverse institutions and disciplines to address broad sustainability challenges (Cerezo and Kapsar 2018). Zoos must become more than a collection of enclosures; they must engage in the larger ecological and human community. Through new transdisciplinary partnerships with zoos, landscape ecologists may find that 'zooscapes' are an example of novel, human-influenced landscapes that can assist in the preservation of endangered species and threatened ecosystems. By carefully applying landscape ecology principles in planning and design within zoos, we can create sustainable zooscapes that not only display wild animals, but also contribute to landscape sustainability.

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References

12News (2018). Photos show what might be 1st trumpeter swan sighting in Phoenix. 12news.Com. https://www.12news.com/article/news/local/valley/photos-show-what-might-be-1st-trumpeter-swan-sighting-in-phoenix/75-509278019

Arizona Game and Fish Department (2020) Mexican wolf population gets genetic boost with a record 20 captive-born pups cross-fostered into wild packs. https://www.azgfd.com/mexican-wolf-population-gets-genetic-boost-with-a-record-20-captive-born-pups-cross-fostered-into-wild-packs/

Associated Press (2013) National Zoo opens elephant center after overhaul. The Mercury. https://www.pottsmerc.com/national-zoo-opens-elephant-center-after-overhaul/article_bf1b5aaa-84d2-58f1-8203-49020bad1adb.html

Association of Zoos & Aquariums (n.d.) Reduce the risk. https://www.aza.org/reduce-the-risk. Accessed 28 Feb 2022

Association of Zoos & Aquariums (2020) Strategic plan. AZA. Org. https://www.aza.org/strategic-plan?locale=en

Association of Zoos & Aquariums (2021) AZA launches new initiative aimed at zoonotic disease threats. https://www.aza.org/aza-news-releases/posts/aza-launches-new-initiative-aimed-at-zoonotic-disease-threats?locale=en

AZ Family (2020) New "Cruise the Zoo" lets you visit Phoenix Zoo from the comfort of your car | Coronavirus in Arizona | azfamily.com. https://www.azfamily.com/news/continuing_coverage/coronavirus_coverage/new-cruise-the-zoo-lets-you-visit-phoenix-zoo-from-the-comfort-of-your-car/article_cc910146-8fe3-11ea-a1d3-53d13856d64b.html

Azevedo JC, Luque S, Dobbs C, Sanesi G, Sunderland TCH (2020) The ethics of isolation, the spread of pandemics, and landscape ecology. Landsc Ecol 35(10):2133–2140

Baratay É (2002) Zoo: a history of zoological gardens in the West. Reaktion Books, London

Beard SJ (2014) A look inside the International Orangutan Center at the Indianapolis Zoo. https://www.indystar.com/story/news/local/2014/05/16/interactive-international-orangutan-center/9182315/

Bender DE (2016) The animal game: searching for wildness at the American zoo. Harvard University Press, Cambridge

Bloomfield LSP, McIntosh TL, Lambin EF (2020) Habitat fragmentation, livelihood behaviors, and contact between people and nonhuman primates in Africa. Landsc Ecol 35(4):985–1000

Braverman I (2012) Zooland: the institution of captivity. Stanford University Press, Stanford

Braverman I (2021) Zoo veterinarians: governing care on a diseased planet. Routledge, New York

Byers O, Lees C, Wilcken J, Schwitzer C (2013) The One Plan approach: the philosophy and implementation of CBSG's approach to integrated species conservation planning. WAZA Mag 14:2–5

Campanella R (2014) Monkey Hill, which turns 80 this summer, isn't the highest spot in New Orleans, but it's one of the most beloved. NOLA.Com. https://www.nola.com/entertainment_life/home_garden/article_dbdf317c-651c-5c8c-985e-d9fbf1eb66a9.html

Cerezo A, Kapsar KE (2018) Zoo conservation Disembarks: stepping off the ark and into global sustainable development. In: The ark and beyond. University of Chicago Press

Clayton S, Fraser J, Saunders CD (2009) Zoo experiences: conversations, connections, and concern for animals. Zoo Biol 28(5):377–397

Conway W (2011) Buying time for wild animals with zoos. https://doi.org/10.1002/zoo.20352

Cronon W (1996) The trouble with wilderness: or, getting back to the wrong nature. Environ Hist 1(1):7–28

Cumming GS, Abolnik C, Caron A, Gaidet N, Grewar J, Hellard E, Henry DAW, Reynolds C (2015) A social–ecological approach to landscape epidemiology: geographic variation and avian influenza. Landsc Ecol 30(6):963–985

Elwell E, Leeson C, Vaglio S (2021) The effects of a zoo environment on free-living, native small mammal species. Zoo Biol 40(4):263–272

Forman RTT (1983) An ecology of the landscape. Bioscience 33(9):535–535

Forman RTT, Godron M (1981) Patches and structural components for a landscape ecology. Bioscience 31(10):733–740

Grajal A, Luebke JF, Kelly L-AD, Matiasek J, Clayton S, Karazsia BT, Saunders CD, Goldman SR, Mann ME, Stanoss R (2017) The complex relationship between personal sense of connection to animals and self-reported proenvironmental behaviors by zoo visitors. Conserv Biol 31(2):322–330

Grazian D (2015) American zoo: a sociological safari. Princeton University Press, JSTOR. https://doi.org/10.2307/j.ctvc77m4k

Hancocks. (2001). *A different nature: The paradoxical world of zoos and their uncertain future*. University of California Press.

Hanson E (2002) Animal attractions. Princeton University Press, JSTOR. https://doi.org/10.2307/j.ctv39x66f

Henson PM (2018) american zoos: a shifting balance between recreation and conservation. In: The ark and beyond. University of Chicago Press

Hersperger AM, Grădinaru SR, Pierri Daunt AB, Imhof CS, Fan P (2021) Landscape ecological concepts in planning: review of recent developments. Landsc Ecol 36(8):2329–2345

Holderegger R, Wagner HH (2006) A brief guide to landscape genetics. Landsc Ecol 21(6):793–796

Howard M (2018) Ota Benga (1883–1916). https://www.blackpast.org/global-african-history/benga-ota-1883-1916/

Hyson J (2000) Jungles of eden: the design of American Zoos. https://www.semanticscholar.org/paper/Jungles-of-Eden%3A-The-Design-of-American-Zoos-Hyson/a8c3487b9d8bb6d7eb309f03c1782f8bb8405a19#paper-header

Jamieson D (1985) Against zoos. https://as.nyu.edu/content/dam/nyu-as/faculty/documents/Zoos_Revisited.pdf

Kahn PH, Saunders CD, Severson RL, Myers OE, Gill BT (2008) Moral and fearful affiliations with the animal world: children's conceptions of bats. Anthrozoös 21(4):375–386

Keulartz J (2015) Captivity for conservation? Zoos at a crossroads. J Agric Environ Ethics 28(2):335–351

Kisling VN (2000) Zoo and aquarium history: ancient animal collections to zoological gardens. CRC Press, Boca Raton, FL

Levy PB (1992) Let freedom ring: a documentary history of the modern civil rights movement. Praeger, New York
Louv R (2006) Last child in the woods: saving our children from nature-deficit disorder, Rev., 1. pbk. Algonquin Books of Chapel Hill, Chapel Hill
Marris E (2021) Opinion | The case against zoos. The New York Times. https://www.nytimes.com/2021/06/11/opinion/zoos-animal-cruelty.html
Meek K (2017) The world's most sustainable hippo exhibit | Cincinnati zoo blog. http://blog.cincinnatizoo.org/2017/11/20/the-worlds-most-sustainable-hippo-exhibit/
Meentemeyer RK, Haas SE, Václavík T (2012) Landscape epidemiology of emerging infectious diseases in natural and human-altered ecosystems. Annu Rev Phytopathol 50(1):379–402
Meganathan T, Urfi AJ (2009) Inter-colony variations in nesting ecology of Painted Stork (*Mycteria leucocephala*) in the Delhi Zoo (North India). Waterbirds 32(2):352–356
Mehren KG (2003) The elephant's foot: prevention and care of foot conditions in captive Asian and African elephants. Can Vet J 44(7):591
Mendelson J (2018) Frogs in glass boxes: responses of zoos to global amphibian extinctions. In: The ark and beyond. University of Chicago Press
Merlino (2006) Zoolex exhibit—tiger mountain. https://www.zoolex.org/gallery/show/817/
Milovanović A, Milovanovic Rodic D, Maruna M (2020) Eighty-year review of the evolution of landscape ecology: from a spatial planning perspective. Landsc Ecol 35:1–21
Minteer BA, Collins JP (2013) Ecological ethics in captivity: balancing values and responsibilities in zoo and aquarium research under rapid global change. ILAR J 54(1):41–51
Mohnhaupt JW (2020) The zookeepers' war (Frisch S, Trans.). Simon Schuster Paperbacks. https://www.simonandschuster.com/books/The-Zookeepers-War/J-W-Mohnhaupt/9781501188503
Nolen RS (2003) Nation's zoos and aquariums help track West Nile virus. American Veterinary Medical Association. https://www.avma.org/javma-news/2001-11-15/nations-zoos-and-aquariums-help-track-west-nile-virus
Norton B (2018) Zoos and sustainability: can zoos go beyond ethical individualism to protect resilient systems. In: The ark and beyond. University of Chicago Press
Pamukcu-Albers P, Ugolini F, La Rosa D, Grădinaru SR, Azevedo JC, Wu J (2021) Building green infrastructure to enhance urban resilience to climate change and pandemics. Landsc Ecol 36(3):665–673
Philadelphia Zoo (2016) Philadelphia Zoo's Zoo360 trails provide animals more room to roam (plus more ways for visitors to see 'Em) [Sponsor Content]. Philadelphia Magazine. https://www.phillymag.com/sponsor-content/philadelphia-zoo-animal-trails/
Robinette C, Saffran L, Ruple A, Deem SL (2017) Zoos and public health: a partnership on the One Health frontier. One Health 3(C):1–4
Rothfels N (2002) Savages and beasts the birth of the modern zoo. Johns Hopkins University Press, Baltimore
Scharf G (1835) Zoological Gardens. Regent's Park. [Lithograph]. The British Museum. https://www.britishmuseum.org/collection/object/P_1862-1108-577
Scharis I, Amundin M (2015) Cross-fostering in gray wolves (*Canis lupus lupus*). Zoo Biol 34(3):217–222
Skibins JC, Powell RB (2013) Conservation caring: measuring the influence of zoo visitors' connection to wildlife on pro-conservation behaviors. Zoo Biol 32(5):528–540
Sulzner K, Fiorello C, Ridgley F, Garelle D, Deem SL (2021) Conservation medicine and One Health in zoos: scope, obstacles, and unrecognized potential. Zoo Biol 40(1):44–51
Totha A (2019) Urban refuge: why zoos are important green spaces for migrating birds. April/May 2019, 46(4 & 5)
Troxell-Smith S, Watters J, Whelan C, Brown J (2017) Zoo foraging ecology: preference and welfare assessment of two Okapi (*Okapia johnstoni*) at the Brookfield Zoo. Anim Behav Cognit 2017:187–199
Uddin L (2015) Zoo renewal: white flight and the animal ghetto. University of Minnesota Press, Minneapolis, pp 1–287. https://doi.org/10.5749/minnesota/9780816679119.001.0001
United States National Museum Photographic Laboratory (1888) National Zoological Park, Relief Model of Rock Creek Park and Zoo Grounds [Black-and-white photographs]. Smithsonian Institution Archives Capital Gallery, Washington. https://www.si.edu/object/national-zoological-park-relief-model-rock-creek-park-and-zoo-grounds%3Asiris_arc_399328
Valdes M (2007) A misguided use of zoo guides? The Seattle Times. https://www.seattletimes.com/seattle-news/a-misguided-use-of-zoo-guides/
van Nouhuys S (2016) Metapopulation ecology. In: Encyclopedia of life sciences. https://doi.org/10.1002/9780470015902.a0021905.pub2
Wells CW (2018) Environmental Justice in Postwar America. University of Washington Press; JSTOR. http://www.jstor.org.ezproxy1.lib.asu.edu/stable/j.ctvcwngjr
Wiens JA (2008) Allerton Park 1983: the beginnings of a paradigm for landscape ecology? Landsc Ecol 23(2):125–128
Wilson MC, Chen X-Y, Corlett RT, Didham RK, Ding P, Holt RD, Holyoak M, Hu G, Hughes AC, Jiang L, Laurance WF, Liu J, Pimm SL, Robinson SK, Russo SE, Si X, Wilcove DS, Wu J, Yu M (2016) Habitat fragmentation and biodiversity conservation: key findings and future challenges. Landsc Ecol 31(2):219–227
Woodland Park Zoo (2008) Zoo wins national award for Maasai Journey. https://blog.zoo.org/2008/09/zoo-wins-national-award-for-maasai.html
World Association of Zoos and Aquariums (n.d.) About WAZA - WAZA. https://www.Waza.Org/. https://www.waza.org/about-waza/. Accessed 5 Jan 2022
Wu J (2013a) Landscape sustainability science: ecosystem services and human well-being in changing landscapes. Landsc Ecol. https://doi.org/10.1007/s10980-013-9894-9
Wu J (2013b) Key concepts and research topics in landscape ecology revisited: 30 years after the Allerton Park workshop. Landsc Ecol 28(1):1–11

Wu J (2021) Landscape sustainability science (II): core questions and key approaches. Landsc Ecol. https://doi.org/10.1007/s10980-021-01245-3

Wu J, Jenerette GD, Buyantuyev A, Redman CL (2011) Quantifying spatiotemporal patterns of urbanization: the case of the two fastest growing metropolitan regions in the United States. Ecol Complex 8(1):1–8