Compendium of Scientific and Practical Findings Supporting Eco-Restoration to Address Global Warming

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About Biodiversity for a Livable Climate

Biodiversity for a Livable Climate, https://bio4climate.org, is a 501(c)(3) non-profit founded in 2013 whose mission is to support the restoration of ecosystems to address global warming. We are:

● ***A think tank***, creating research and reports (such as this Compendium), and presenting conferences on the science and practice of eco-restoration with speakers from around the world.

● ***An educational organization***, offering presentations, courses and materials, including over 200 videos of speakers (with over 330,000 views on YouTube) from our numerous public presentations 13 conferences since November 2014 (https://bio4climate.org/conferences), with many restoration and climate-positive examples from both scientists and practitioners.

● ***An advocate*** that reaches out to other organizations to encourage and facilitate the incorporation of eco-restoration as a climate solution into their own messaging and actions. We seek to connect to other groups and projects to help nourish and advance their own growth, and carry messages among groups to collaboratively learn and build on each other's efforts, and occasionally facilitate the emergence of new groups. Since climate affects everyone, every organization has to deal with it in its own way, and we strive to help with the transition.

● ***An activist group*** that engages in non-partisan political processes. For example, we helped shepherd a bill through the legislative process in 2017 to establish a Maryland Healthy Soils Program.

● ***A co-founder of the EcoRestoration Alliance,*** a growing organization of individuals and organizations (currently 120 around the world) actively involved in regenerating ecosystems to address the biodiversity and climate crises (http://ecorestorationalliance.net/).

We are a small 501(c)(3) non-profit with a major impact in addressing climate, and we rely on your generous contributions! Please go to https://Bio4Climate.org/Donate to join our monthly donor program, or to make a one-time donation, all tax deductible. Many thanks!

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collection of article summaries and commentary that will grow as new literature becomes available and as older literature is re-discovered.

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Conversion table

hectares vs. acres	1 ha ≈ 2.5 ac
megagrams vs. tons	1 Mg = 1 metric ton
teragrams vs. tons	1 Tg = 1 million metric tons
petagrams vs. gigatons	1 Pg = 1 billion metric tons (1 Gt)
weight[1] carbon vs. weight CO_2	12/44
parts per million CO_2 vs. weight of carbon[2]	1 ppm CO_2 ≈ 2 Gt carbon

[1] We refer to carbon in soils and biomass, etc. by weight of carbon; atmospheric carbon may be referred to by weight of carbon *or* by weight of CO_2, a frequent source of confusion.

[2] ppm is a volume measurement; 1 ppm in the total volume of earth's atmosphere is approximately equal to 2 gigatons of carbon by weight – and yes, this can be confusing too. Moving 1 ppm CO2 from the atmosphere results in 2 Gt carbon added to soils or other carbon sinks.

How culture shapes how we relate to nature

In this section, we explore how culture and religion influence the way humans relate to nature. Author Robin Wall Kimmerer suggests that our creation stories orient our cultural understanding of what land is and inform our treatment of nature. Kimmerer is descended both from the Potawatomi people of the western Great Lakes region and European immigrants to North America.

In her popular book *Braiding Sweetgrass*, she tells the Potawatomi story of Falling Sky Woman, an immigrant to Earth from another world, who owes her life to the animals who cradled her fall from the sky, held her above the water, and helped her create land. In this story, animals are people's teachers, and land is a sacred place of interrelationships and of belonging. In the Christian creation story imported to the Americas by Europeans, by contrast, the Garden of Eden is a place of conflict, where fruit is forbidden, an animal - the snake - acts deceptively, and people are banished from the garden paradise.

To the extent that these stories shape our sense of how to relate to the natural world, they lead us in very different directions. Indeed, many have pointed to Christianity as fostering a cultural understanding of humans as being separate from nature, a belief that has encouraged the ecological destructiveness of the modern era. Conradie et al. [2017] point out that the countries with the highest historic carbon emissions are those where Christianity helped to legitimize capitalism and consumerism through ideas such as the prosperity gospel, the belief that physical health and financial success are signs of God's favor. On the other hand, Christianity can also be viewed as a source of guidance on stewardship of nature. Eco-theology (the study of the ecological crisis in relation to God and religion) delves into Christian teachings, revealing both those that alienate us from nature and those expressing ecological wisdom.

Like that of the Potawatomi, many of the world's many spiritual practices embrace the idea that humans are part of nature. In China, Daoist tradition values biodiversity as a measure of societal affluence, while the loss of species is a sign of societal decline. When a Daoist theocratic state was established around 200 AD, half of the governing rules related to nature, with statements such as "you should not dry up wet marshes." The Chinese government today is exploring ways to encourage the spread of Daoist thought throughout the population in order to build an "ecological civilization."

Similarly, traditions such as Shinto in Japan maintain "sacred forests," where Gods are believed to dwell and which are honored by neighboring communities. In Guinea Bissau, observing how sacred forests are passionately protected by communities that practice animist religions, the government has encouraged the propagation of "community forests" in non-animist communities, modeled after sacred forests. Public outreach about the multiple values and uses for a community forest, including sustainable gathering of wild fruit, is meant to change people's mindsets and halt logging. Traditional animists, who see their own identity as inseparable from that of the forest and its

guardian spirit, forbid cutting trees; they enter the forests only for sacred rituals. In Rwanda, sacred forests are valued in part for the medicinal plants that grow in the forest and are collected by traditional healers.

Whether spiritually motivated or not, many indigenous cultures live in ways that reflect a sense of connectedness to other living species. While western society speaks in terms of “natural resources,” referring to materials, animals and plants gathered (mined or killed in large numbers) for human usage, many indigenous communities have traditions of exchange and reciprocity with living creatures. In the book Lo-TEK, Watson [2020] offers examples of socio-ecological systems that weave intimate knowledge of local flora and fauna with spiritual beliefs and practices, and where particular species play significant roles in people's lives.

Watson presents the Khasis of northern India, who build living bridges and ladders out of the living roots of the rubber fig tree (*Ficus elastica*) that can last for centuries, are able to withstand the force of the monsoonal rains, and grow stronger over time. The Khasi protect the forests that grow along the river where this species grows. So central is the rubber fig tree that the Khasi origin stories feature this species stretching between Earth and heaven.

In telling the stories of indigenous technologies like the fig bridge, Watson highlights the symbiotic role humans can have with other species in the ecosystems they inhabit. Conserving nature can be a participatory activity that benefits humans as much as it does the rest of nature. Even initiatives like Nature Needs Half, which advocates for allowing natural ecosystems to deploy without disruption over half of the surface of Earth, stresses that local human communities can and should be a part of these ecosystems. It’s only the extractive, exploitative industries that should be expelled from natural areas.

Encouragingly, if cultural ideas shape our behavior in fundamental ways, then changing some of our ideas can change our behaviors. As mentioned earlier, many people today see humans as being separate from nature, and also separate from one another. Authors Bristow et al. [2022] argue that this limitation can be addressed through the practice of mindfulness and compassion. By becoming more attentive to the present moment and to the suffering of others, we can better connect with our own emotions, with other people, and with the living biosphere. Doing such leads us to engage in positive action, rather than retreating into reactive habits such as consumption in an effort to achieve satisfaction. Bristow et al. argue that human will is the main ingredient missing from beneficial climate action, and that this can be addressed by encouraging the practice of mindfulness and compassion at every level of human institution.

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Summaries of selected articles on how people relate to nature

Daoism in China's Climate Change Policy, Martin Palmer 2022

In 2009, Daoists of the White Cloud Temple (the headquarters of the Chinese Daoist Association) framed the burning of fossil fuels in terms of the balance of yin and yang forces. From this perspective, we are taking yin materials—cold, dark, earthy—and by burning them recklessly we are turning them into yang—fiery, atmospheric, and volatile. We have shifted them to where they do not belong and as a result the earth is out of harmony, explains Martin Palmer, former Secretary General of the Alliance of Religions and Conservation (ARC), quoting the Daoists of the White Cloud Temple.

Daoism values acting in harmony with natural forces rather than seeking to oppose or conquer them. This form of action is evoked in a key Daoist phrase, "wu wei," or the action of non-action. (The English-language concept of "going with the flow," is a very rough equivalent). It is linked to the Daoist view that humans approach nature for one of two reasons: to exploit it or to observe and learn from it.

Protection of nature is woven into Daoist texts both ancient and modern. When a Daoist theocratic state was set up around 200 AD, fully half of a book of 180 precepts on governance related to nature, with statements like, "you should not dry up wet marshes." Palmer, described this as the oldest listing of environmental actions of any faith. In 2003, the Chinese Daoist Association affirmed that:

> Daoism has a unique sense of value in that it judges affluence by the number of different species. If all things in the universe grow well, then a society is a community of affluence. If not, this kingdom is on the decline.[3]

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Daoism is a non-interventionist religion, whose practitioners lead by example and do not seek converts. This is a foundational aspect of its approach to nature, yet it raises doubts in some about

[3] https://fore.yale.edu/World-Religions/Daoism/Statements

its capacity to address the scale of current environmental problems. Nevertheless, Palmer sees it as an invaluable resource and increasingly influential in both China and the larger world.

In a public online lecture organized by the Manchester China Institute, Palmer summarized how the ideas described above — the balance of yin and yang forces, the concept of "wu wei," or actionless action, and the diversity of species as a measure of true wealth — shape Daoist understandings of nature. He pointed to practical measures undertaken by Daoist temples, as well as the Chinese government's engagement with Daoist institutions and ideas as hopeful developments, in the effort to transform civilizations to deal with climate change.

About 120 temples have formed a "Daoist Ecological Protection Network," which promotes "green pilgrimage" practices and teaches ecological principles to visitors. Daoists host hundreds of thousands of urban young people every year on trips to reconnect with nature. Palmer also mentioned an ARC study which showed that there is more biodiversity in the nature sanctuaries that surround Daoist temples than in China's national parks, since, unlike park rangers, the monks don't leave the mountain at night, and their presence helps ward off poachers. Daoists founded a university focused on sustainable architecture, and have engaged in reforestation to halt the advance of the Gobi Desert.

In 1993, there were only a few hundred Daoist temples left in China. Today, there are around 9,000, and Daoists are major civil society partners in the Chinese government's efforts to create an "ecological civilization."[4] This extraordinary revival was spurred by the government's recognition of the ecological devastation wrought by rapid industrialization, and its turn to Daoism as a source of ecological values rooted in Chinese culture.

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Lo-TEK: Design by Radical Indigenism, Julia Watson 2020

Lo-TEK is a visually rich exploration of technological innovations that offer promise for meeting the greatest design challenges of today. These range from building climate-resilient homes and infrastructure, to coping with water scarcity, to feeding growing human populations while restoring soil fertility, reversing desertification, and halting mass extinction. What differentiates *Lo-TEK* from other books on cutting-edge design is that the technologies were all developed by indigenous peoples, and some have been in use for millennia. By reframing these resilient, sustainable systems as the creative innovations that — in the long view — they undoubtedly are, Watson seeks to overturn modern biases that dismiss them as "low-tech," primitive, and outmoded.

[4] For the number of temples: https://www.sixthtone.com/news/2019/taoist-monks-find-new-role-as-environmentalists.

“Indigenous communities…hold a global bank of eco-intelligence” (the “TEK,” or Traditional Ecological Knowledge, of Lo-TEK) [Watson: 2020, 399]. In contrast to the energy- and capital-intensive “hard” technologies favored by modernism, Lo-TEK infrastructures are “local, inexpensive, handmade, and easily constructed soft systems,” that amplify mutually beneficial interactions between species.” [Watson 2020: 21]. They point to the human capacity to foster “species symbiosis” rather than displacing or destroying other species.

Watson features eighteen case studies of socio-ecological systems that weave intimate knowledge of local flora and fauna with spiritual beliefs and practices. Most revolve around “cultural keystone species” — species particularly “salient” to a people, “identified by its significance in their diets, materials, medicines, languages, traditions, histories, and spiritual practices” [Watson 2020: 23].

In ecology, a keystone species is one that is critically important to the survival of an ecosystem. A number of other species depend on it, such that if it were to disappear, the system would change drastically and possibly collapse. By extension, a cultural keystone species is one which holds this same centrality in a human cultural system. Its disappearance forces drastic cultural changes, and possibly collapse. For example, the 19th-century extermination of the buffalo by white settlers eliminated an ecological keystone species that was simultaneously a cultural keystone species for Plains Indians, shattering the spiritual, socio-economic, and ecological systems that were woven around it. Though Watson does not draw this out explicitly, the overlapping of ecological and cultural keystone species can help to illuminate the disproportionate role that indigenous peoples play in ecosystem conservation.

For example, the Khasis of northern India create living bridges and ladders out of the roots of the rubber fig tree (*ficus elastica*). For designers of “cities where flooding and sea level rise is inevitable, and infrastructures are continually failing,” this “responsive, productive, adaptable, and resilient” infrastructure is a model for working with nature’s forces [Watson 2022: 63]. In rugged mountains, the Khasis “have developed the only bridges able to withstand the force of the monsoonal rains” and swift tropical decomposition [Watson 2020: 47]. Over thirty years, they train secondary root systems to grow through the hollowed-out trunks of betel-nut trees. The bridges can last for centuries, and grow stronger over time. The rubber fig is a cultural keystone species. Khasi origin stories feature a fig tree stretching between earth and heaven. Khasis protect sacred forests along streambanks through taboos on cutting or plucking leaves. This “sanctified area has ensured the survival of the rubber tree, the future of living innovation, [and] the cultural heritage of the tribe” [Watson 2020: 61].

Lo-TEK is a book of such marvels. Rice terraces that enable productive farming on almost-vertical slopes [Watson 2022: 76]. Floating cities that help clean water while providing biodegradable habitat [Watson 2022: 288]. Forest gardens that use fire, polyculture, and natural succession to enrich the soil and enhance biodiversity [Watson 2022: 126]. Living fences that grow forests and wildlife corridors in the desert [Watson 2022: 227].

Alongside case studies, Watson provides maps listing dozens more in four biomes: forests, mountains, deserts, and wetlands. Many of these are threatened: by agribusiness, logging, mining, tourism, urban expansion, aquifer depletion. And sustainable indigenous practices such as swidden agriculture in South America and nomadic pastoralism in Africa were long misunderstood by science, blamed for environmental problems, and deliberately suppressed. The early conservation movement "removed stewards [from the land], erased knowledge, and ignored resilient technologies that had been mitigating climate challenges for thousands of years," thereby "displacing millions of indigenous peoples and accelerating the mass extinction of species" [Watson 2022: 397]. Correcting these mistakes, and properly valuing and learning from the techniques that humans have developed for living symbiotically with other species, is the urgent work of designing for a future.

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Tradition and taboo keep Guinea-Bissau's forests standing, Shyrock (from Mongabay News) November 2019

Sacred forests are scattered around Guinea-Bissau, especially in the northwest region and across the Bijagos archipelago. These forests are highly valued by local communities who see their own identity as being deeply intertwined with the forests. Locals scoff at the concept of the trees having any sort of monetary value.

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Sacred forests are more common in communities with traditional animist belief systems and less common in the predominantly Muslim eastern parts of the country. No survey has been done to determine how many there are or the area they cover. There are estimated to be hundreds, each with its own characteristics — men only, women only, or open to all — and uses, such as coming of age ceremonies and prayers. They all share one rule: No tree may be chopped down in a sacred forest. Traditionalists believe killing a tree will result in the death of the perpetrator at a time and through a method chosen by the forest's spirit.

Guinea-Bissau has struggled with political stability since gaining independence in 1974. As a result, environmental protection efforts have suffered. Conservation efforts have used the sacred forests to

their advantage, as they are often included within the boundaries of national protected areas. Between 2013 and 2015, illegal logging was rampant until a moratorium decreased the scale of the illegal logging significantly. The moratorium was set to expire in 2020, and although there were some efforts to extend the moratorium, others opposed the extension, citing national economic needs. It appears the moratorium was lifted in 2021, and there does not appear to be published information about the impact to forests.

The government and various non-governmental organizations introduced the concept of community forests. The idea is to get local communities to take responsibility for the forests and watch over them similar to the way the sacred forests are protected. Public outreach about the multiple values and uses for forests, including sustainable gathering of wild fruit, has been key in transforming people's mindsets. When the article was written, there were 27 community forests covering 64,370 acres, which was about 1.3% of the forest in the country. The goal is to have at least 10% of the nation's forest land be community forests.

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Assessment of traditional ecological knowledge and beliefs in the utilization of important plant species: The case of Buhanga sacred forest, Rwanda, Irakiza *et al*. 2016

This article discusses the roles that customs, beliefs, and traditional knowledge play in the preservation of biodiversity in forested areas of Rwanda. Historically, forests were used for various rites, materials for arts and crafts, and traditional medicine. The medicinal and other uses of particular species and associated spiritual beliefs help protect the forest.

The Buhanga sacred forest, located north of the capital Kigali, covers approximately 33 hectares (82 acres). This forest is mostly surrounded by land used for agricultural purposes: subsistence farming and coffee, tea, and pyrethrum (chrysanthemum) plantations. This study was conducted as a way to lift up the traditional values and uses associated with the forest in the face of modern pressures and threats to it. For example, the Rwandan genocide of 1997 – 1998 resulted in many refugees settling in forest areas, including the Buhanga sacred forest, and an increase in damage to those natural areas—trees felled for firewood, land cleared for farming--until the refugees were resettled. This damage highlighted the need for comprehensive plans, involving local communities, for managing resources.

The authors conducted an ethnobotanical survey of the Buhanga sacred forest in May, 2008. The survey included interviews with elders regarding rituals and beliefs surrounding the forest, and traditional healers regarding the use of medicinal plants. The field survey found 45 plant species used by the local communities, 38 of which were used for medicinal purposes. Most of the plants, 29 species, were collected in the wild, 9 were cultivated, the rest were found in farm plots or beside roads. Leaves, the most frequently used part of the plants, can be heavily harvested without

destroying the plant. Although the medicines are made on an as-needed basis and the threat of over-harvesting is low, some plants have become scarce and one of the recommendations was to work with healers to domesticate additional species.

The authors note that: “the integral success of the traditional ecological knowledge into biodiversity conservation depends on active participation of the knowledge holders, such as indigenous communities and institutions.” In other words, to ensure local protection, sacred forests and their component species need to be actively recognized, valued and used locally – such as in sustainably harvesting plant parts to treat important health problems.

Christianity: an ecological critique of Christianity and a Christian critique of ecological destruction, Conradie 2017

Some point to Christianity as a major source of problematic beliefs about human separation from and dominion over non-human nature that have contributed to the ecological destructiveness of the modern era. Others hold that Christianity contains important resources for resisting ecological destruction, and that its global reach and the number and power of its adherents make it an indispensable force for confronting climate change and environmental crises.

Christian eco-theology—systematic reflection about both God and the ecological crisis—moves in both directions, critiquing Christianity in the light of ecological concerns, and drawing on Christian resources to address global environmental problems. According to Conradie, “a far-reaching ecological reformation of the various Christian traditions is…underway” [Conradie 2017: 70]. However, this reformation is “’slow work,’” highly fragmented among multiple Christian groups with differing interpretations of the core texts, traditions, and sources of authority [Conradie 2017: 71].

The countries responsible for the greatest historic carbon emissions are those in which “Christianity was influenced by the advent of the industrial revolution,” and provided “tacit legitimation of neo-liberal capitalism and consumerist aspirations” [Conradie 2017: 71]. This persists in movements such as the “prosperity gospel,” the belief that physical health and financial success are signs of God’s favor.

Yet, “an ecological reformation is currently taking place in all the main branches of Christianity.” The sheer number and variety of eco-theological reflections (more than 10,000 books, articles and essays) make an overview difficult. Instead Conradie highlights some of the major tensions within the movement [Conradie 2017: 73]. One such tension is between an attitude of trust that sacred texts hold answers to our present-day dilemmas, and a critical reading of these texts. The former focuses on the “ecological wisdom” of selected biblical texts, while the latter finds anthropocentrism and religious alienation from the earth embedded in them.

> For example, while some bemoan our failure to respond to the call to 'stewardship' [of the earth] in Genesis 1:28, others trace the root causes of environmental destruction to the 'successful' collective response in Abrahamic traditions [Christianity, Islam, and Judaism] to 'subdue' the earth and to 'rule' over it. [Conradie 2017: 73].

Christians also hold deep differences over the ecological significance of God's purported transcendence of the natural, physical, or material world. They debate the relation of nature to grace (or, God's redemptive action), of faith to science, and of Christianity to other religions. Ecofeminist critiques of "interlocking dualisms based on the binaries of male/female, culture/nature, soul/body, transcendence/immanence, and heaven/earth," and the contribution of these dualisms to the "subjugation of the land and other forms of life for the sake of human needs and desires" have been taken on board by some Christian theologians. Yet others see these critiques as contradicting basic Christian distinctions between Creator and created, and they are at odds with patriarchal dominance in both scriptural texts and church leadership.

Given this multiplicity, Conradie claims that no adequate map of Christian eco-theological perspectives is possible. Rather than a map, he offers the metaphor of a "journey from an unacceptable present" into a "daunting future." The travelers go forward together "with some sense of a destination and purpose," while drawing on varying sources of inspiration, "including authoritative sacred texts, tradition, reason and contextual experience," recognizing the need for "diverse companions" as they respond to "a looming catastrophe beyond imagination" [Conradie 2017: 77].

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Reconnection: Meeting the Climate Crisis Inside Out, Bristow, Bell & Wamsler 2022

The dangers of the climate crisis increase with every year. Humans possess the scientific knowledge needed to address it. Yet we have so far failed to enact changes at the necessary scale to avert catastrophe. Why? The authors argue that sustainability research and policies have focused on external (material and technical) solutions, while ignoring the inner (emotional, psychological, and neurophysiological) dimensions of change. They seek to remedy this by drawing out the implications for sustainability of a growing body of scientific research on mindfulness and compassion.

Mindfulness — intentional, open, and curious attention to present-moment experience — and compassion — an "inner motivational system that combines the capacity to engage with and feel moved by suffering, with a will to help" – are evolved natural capacities that can be strengthened with training [Bristow 2022: 10]. This can help to overcome the "shared mindset of

separateness" from nature and one another that lies at the root of the climate crisis, and that also fosters a sense of powerlessness which leads to inaction [Bristow 2022: 5, 6].

Mindfulness and compassion practices guide us to recognize the connectedness of our physical, psychological, and emotional states and our interdependence with others and the living world. Rather than responding to the enormity of climate change with shutdown, empathic burnout, and reactive habits of consumption, such practices enable us to "stay with the trouble" and experience the difficult emotions that arise from recognizing a painful reality. They help us reclaim our attention from digital distraction, restore our emotional and bodily intelligences, expand our senses of self and community, connect to nature, and return our nervous systems to calm after threat activation. This enables us to cultivate a deep psychological resilience that can contribute to a "regenerative spiral of individual and planetary wellbeing" [Bristow 2022: 6].

Training in mindfulness and compassion can also help shift our attitudes around consumption as a measure of happiness, giving us the ability to "reorient our 'wanting'" toward more sustainable sources of life satisfaction [Bristow 2022: 7].

> [C]ultivating mindfulness and compassion strengthens intrinsic values - ends that are inherently rewarding…such as bonds with friends and family, nature-connection, self-acceptance and concern for others…in contrast to extrinsic values such as external approval, wealth and material success, which are associated with lower satisfaction…Hence, mindfulness and compassion training show potential to support a shift to less resource-intensive lifestyles. [Bristow 2022: 59].

In and of themselves, mindfulness and compassion will not solve the climate crisis. "Climate change is a physical reality demanding political and practical solutions. But the wanting, co-creating, negotiating, and enacting of those solutions depends wholly upon inner capacities of the human mind and heart that have hitherto been absent from mainstream theories of change" [Bristow 2022: 61]. Among a number of specific recommendations addressed to governments, public institutions, and NGOs, the authors urge "consideration of inner human capacities" such as mindfulness and compassion… "be incorporated into policy thinking through systematic integration - modifying existing processes and structures at all levels and across all sectors of society" [Bristow 2011: 62].

Protecting Half the Planet and Transforming Human Systems are Complementary Goals, Crist et al. 2021

The conservation initiative known as "Nature Needs Half," or "Half Earth," aims to preserve biodiversity, halt mass extinction, and mitigate climate change by reserving at least half of the planet for wild nature, in areas off-limits to corporations and extractive industries. Some critics raise social

justice concerns, worrying that such large-scale conservation would hurt poor communities living near the preserves and worsen food insecurity. Others fear the Half-Earth movement does not confront economic systems which drive both injustice and ecosystem degradation. The authors respond that, rather than being at odds with one another, the conservation of natural systems at the requisite scale and the downscaling and transformation of human systems into more just and ethical communities go hand in hand.

Rather than being at odds with one another, the conservation of natural systems at the requisite scale and the downscaling and transformation of human systems into more just and ethical communities go hand in hand.

Protected areas must be designed in partnership with the communities living near them. Indigenous peoples are among the strongest protectors of natural lands; this role must be recognized and supported. Since human communities differ in the way their needs, traditions, and priorities mesh with local ecosystems, the design of conservation areas will differ as well.

To conserve half the Earth for natural ecosystems, human systems must be transformed and downscaled. This entails economic transformation into a sustainable degrowth system, supported by changes such as a shorter work week, reduced consumption, and production of more durable goods. Richer countries must transfer accumulated wealth to poorer countries to support the transition to a renewables-based energy regime. Food production must shift from globalized monoculture and factory farming practices to more localized agro-ecological methods. We can revamp food production

> into a modest subsystem of the planet….[T]he landscapes and seascapes of food can be transformed to interface supportively with wild nature, sustain pollinators and other wildlife, build healthy soils, accommodate a reduced number of livestock, eschew synthetic pesticide and fertilizer pollutants, and take wild fish and other marine life with a lighter hand. [Crist 2021: 5].

To decrease the pressures that human consumption places on natural systems, we must also limit human population growth. This can be achieved in ways that strengthen human rights and social justice, by investing in the education of women and girls, making family planning services and sexual education universally available, and ending child marriage.

The human system transformations required to sustain biodiversity, cool the planet, and halt mass extinctions lead toward more just human societies. They also point towards an expanded ethical

recognition of the rights and intrinsic value of nonhuman life. The Nature Needs Half initiative seeks a symbiosis in which the needs of both human and nonhuman life are supported. This requires changing our vision of the future from one in which the bulk of the planet is dedicated to human use, with islands set aside for wild nature, to one in which natural systems govern much of the surface of the planet, with certain areas set aside for intensive human habitation. Rather than accepting a "chaotic and impoverished world…dangerous for us all" we can achieve "justice and well-being for both people and other species" [Crist 2021: 1].

This requires changing our vision of the future from one in which the bulk of the planet is dedicated to human use, with islands set aside for wild nature, to one in which natural systems govern much of the surface of the planet, with certain areas set aside for intensive human inhabitation.

Farming communities in Botswana coexist with elephants, by Albertinah Matsika

Even though the Kalahari Desert covers over 75% of Botswana, the northern region houses the Okavango Delta, one of the world's largest inland deltas. This perennial water source provides a wide variety of habitats and nourishment for many wildlife. The Okavango Delta is protected internationally and locally through bodies such as the International Union for Conservation of Nature (IUCN), designation as a World Heritage Site and a Ramsar site, and local Wildlife Management Areas designations.

As a result, there is high diversity and abundance of fauna, increasing the likelihood of human-wildlife conflict (HWC). For instance, the elephant population of Eastern Okavango was estimated to be 15,429 in 2015 [Songhurst et al., 2016], close to the human population there, 16,306 in 2010 [Statistics Botswana, 2011]. Human-elephant conflict (HEC) occurs mainly when elephants enter fields to consume agricultural crops. "Crop raiding" by elephants can devastate farmers, who depend on their harvest for food for the year. In addition, elephants may also charge when they feel threatened, maiming or killing people, and they sometimes damage property.

However, non-profit organizations such as Ecoexist actively work in the area to find and foster long-term, cheap, and easily adaptable mitigations for realizing human-elephant coexistence. Ecoexist (i) conducts applied elephant-related research, (ii) coordinates elephant awareness

workshops for communities and farmers, (iii) advocates and advises on land use and planning, (iv) tests, disseminates and monitors HEC mitigation measures, and (v) facilitates an elephant-friendly economy to benefit communities living with elephants.

Ecoexist helps policymakers, farmers, and other relevant stakeholders gain a greater understanding of short-term or long-term interaction with elephants. On a short-term basis, Ecoexist assists stakeholders in ensuring safety around elephants and elephant corridors, monitoring elephant movements, decoding elephant behavior, and responding accordingly to avoid adverse interactions.

In long term outputs, Ecoexist helps farmers practice elephant-resilient farming intended to reduce their vulnerability to crop loss. The organization recommends, for example, conservation practices for improving soils and yields over small spaces and planting early-maturing crops, both of which allow farmers to better protect their fields during the growing season. Ecoexist also teaches people how to deter elephants from farms and homes. Elephants favor the same foods preferred by people, such as cereals and melons, which are sweet, nice, high caloric, and high in water content. Thus, growing crops that deter elephants is encouraged. This includes: chili peppers, which irritate elephants' keen sense of smell; legumes, which have tannins that elephants don't like; or ground nuts, which are too cumbersome to dig up, can deter elephants. When raiding fields, elephants know they are stealing, so they capitalize on time when inside the farms by grabbing standing crops, rather than taking the time to dig.

Ecoexist also assists in strengthening key public services for communities that contribute to elephant conservation. This includes incentivized scholarships for students from elephant-friendly communities, a guaranteed market for produce grown through elephant-aware agriculture, and provision of facilities such as public transportation between villages and drinking water access for people in communities living with elephants.

I joined Ecoexist as a PhD fellow in collaboration with the Botswana University of Agriculture & Natural Resources (BUAN). As a conservation practitioner, it is very interesting to work with communities. My main role was to explore different cropping strategies for reducing human-elephant conflict, particularly crop raiding. I evaluated how crops of different maturity timelines and alternative crops influenced the farmers' vulnerability to elephant crop raiding in the Eastern Okavango Panhandle.

Farmers prefer to grow cereals to meet their household staple food demands. For many, farming is the only source of sustenance for their households, so elephants raiding your farm means no food until the next cropping season, and that's assuming rains will be good enough for you to harvest sufficiently. One important aspect agreed on by many scientists was that elephant crop raiding is tied to rainfall or water availability. They come for people's crops towards the beginning or intensification of the dry season: that's when the grass is dry, contains more roughage, and is neither appealing nor nutritious. So they turn to people's farms because their crops will still be supple, highly nutritious, and high in water content.

My study proposed early-maturing crops to make the most of a short rainy season. However, farmers do not seem to like these alternative varieties much because they say they do not taste as good as their traditional varieties. However, traditional varieties take almost twice as long to be ready for harvest and that increases the vulnerability and chances of food loss by elephants at the farms. In cases where farmers did not like early varieties, we explored other possibilities, such as growing more legumes and fewer cereals, or growing the cereals and watermelons within a buffer of processed or unprocessed chili on the edges to deter elephants from accessing their main crop.

Many now adopt such strategies after seeing better results from fellow farmers. Looking at the long-term data, many farmers are still holding on to the traditional staple crops, while trying alternative crops alongside the staple crop. There is clear change in the choice of crops and cropping methods as a means of adapting to high elephant numbers, and it helps to reinforce these new practices with ongoing input and consultation. Community awareness workshops have significantly assisted people in staying safe despite high elephant numbers.

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Grassland Ecosystems

The history of humanity is interwoven with that of grass, although the latter has been around much longer than humans. Grasses originated as far back as the age of dinosaurs some 65 million years ago [Prasad 2011, Bredenkamp 2002], and then became widespread toward the end of the Miocene period (24 to 5 million years ago). Grasslands expanded in eastern Africa starting 10 million years ago, becoming dominant two to three million years ago.[5]

Then, between 6 and 7 million years ago, the first hominids appeared in Africa, evolving into *Homo sapiens* only a few hundred thousand years ago. Our species' history overlaps in time and space with the evolution of grassland ecosystems. In fact, *Homo sapiens'* evolution seems to have been driven by landscape diversity encompassing both forest and grasslands as well as climatic changes that forced our ancestors to learn to adapt to multiple conditions.[6]

Grasslands are open grassy landscapes, in the case of savannas sparsely populated by trees, and also encompassing shrublands. Grasslands are generally found in areas too dry for forest, although climate is not the only factor influencing their global distribution; disturbance regimes like fire and grazing also play a key role. The world's natural native grasslands include such major ecosystems as North American prairie, the pampas of South America, the Asian steppe, and the savannas and grasslands of eastern and southern Africa, including the Serengeti. Australia also hosts native grasslands.

[5] https://www.earth.columbia.edu/articles/view/3283/
[6] Ibid.

By contrast, the grasslands in western Europe were created and maintained by clearing forests. Many such anthropogenic secondary grasslands are considered semi-natural because they are biodiverse and allowed to develop according to natural processes, while others are considered "improved" in the sense that they are intensively managed for fodder production through cultivation, fertilization, irrigation, and use of non-native cultivars, i.e., plants bred for desired traits. Unlike the latter type, semi-natural grasslands provide a wide range of ecosystem services as do their natural counterparts [Bengtsson 2019].

The establishment of grasslands on Earth is also intertwined with the development of large herbivores. Over the past 40 million years, ungulates developed continuously, growing teeth and larger molars suitable for chewing tough grasses, as well as long, slender legs and hard hooves for running through the plains.

Grasses developed rhizomes and a growth point at the base of the leaf as ways to manage ungulate herbivory (ingestion of plant matter) [Retallack 2013]. In Africa, spiny plants (with thorns as a defense against browsing) proliferated on the savanna. Around the same time bovids diversified into species with different feeding strategies in relation to thorns. In turn, the influx of bovids and other herbivores helped develop the savanna by limiting woody vegetation growth [Charles-Dominique 2016]. In addition to herbivory, fire also plays a role in maintaining grasslands by burning and suppressing tree saplings.

Fast forward to the dawn of agriculture 10,000 years ago, a moment as monumental in human history as our emergence from the forested home of ape ancestors. Here too grasslands played a formative role by providing us with the species – all grasses – from which we would develop many of our primary crops, such as wheat, corn, rice, oats, and sugarcane. Grasslands have provided us with a great deal over time, including thick, fertile soils which we plowed to plant crops. Perhaps even our modern adoration of lawns as a ubiquitous landscape feature is an unconscious nod to our savanna-tied origins.

Intact grasslands today are sites of incredible biodiversity. Grassy biomes in the tropics boast more megafauna than tropical forests, while the two biomes are comparable in terms of overall vertebrate diversity; tropical forests are richer in vascular plant species than tropical grassy biomes [Murphy 2016]. Healthy grasslands are also important carbon sinks with carbon stored safely in the soil, rather than in burnable, edible aboveground biomass.

Yet despite the significance of grasslands in human history, in terms of the planet's present condition in the face of climate breakdown and biodiversity collapse, grasslands are highly threatened. Grasslands cover about 40% of global land surface, and nearly half are degraded [Bardgett 2021]. Threats, which are accelerating, include overgrazing; under-grazing (allowing woody encroachment and limiting light and nutrient cycling); conversion to crops, forestry, or built infrastructure; climate change (such as through drought); invasive species; intensive management (use of fertilizer and non-native seed, tilling); and altered fire regimes [Bardgett

2021]. Twenty percent of historical grasslands have been converted to crop production [O'Mara 2012].

To be protected, though, grasslands must receive further attention. They have multiple important functions that are mutually reinforcing. As well-managed grazing pasture, grasslands can improve food security, while storing and sequestering carbon, regulating water flow and quality, supporting pollinators, birds and other wildlife, and offering recreation, among other functions valued by humans. When grazing is managed in a way that livestock deposit manure, churn the soil, and then leave plants plenty of time to recover before being grazed again, this can improve the productivity of the whole system. This will benefit wildlife as well as dairy and meat production and the livelihoods sustained by ranching and pastoralism. Grazing management that mimics the movement of wild ungulate herds can regenerate grasslands, while poor grazing management degrades these ecosystems.

The following articles present a brief overview of what grassland ecosystems are, where they grow, what their ecological and social value are, how they are threatened, and how livestock grazing can play a role in their regeneration. These articles build on the selection we presented in the grasslands section of Compendium v1n1 (July 2017).

Summaries of selected articles on grassland ecosystems

What controls the distribution of tropical forest and savanna? Murphy & Bowman 2012

The authors cited long-standing research that climate, and especially rainfall, is the major driver of global forest distribution. Yet certain areas with ample rainfall host savanna biomes, rather than forests, while some drier areas are forested. Why? What other factors are at play that might cause trees to coexist with grasses in a savanna instead of forming a closed canopy that excludes grasses, as in a forest? Forests and savanna biomes dominate the tropics, and are globally important centers of biodiversity, yet the ecological processes influencing their distributions have not been fully explored. This paper proposes a unique model to explain the relative distribution of forests and savannas throughout the tropics.

A simple comparison of the climatic zones and tropical forest distribution showed that climate alone could not be a cause of the change from savanna to forest. The authors argue that the distribution is an interactive result of many variables in addition to climate, including local species composition, soils, nutrient availability, drainage, topography, and fire. Consequently, this study proposed a model based on the alternative stable state theory and tree growth-fire interactions to explain the relative distribution of forest and savanna throughout the tropics.

The alternative stable state theory explains that contrasting ecosystems (such as savanna vs. forest) can exist under identical environmental conditions due to positive feedbacks maintaining the system in its current state. The closed canopy of a forest increases humidity and decreases the temperature and wind within the forest, inhibiting fire. By contrast, savanna grass is flammable and fully exposed to wind and heat, making fires more likely. High fire frequencies in grassy savannas limit the recruitment of tree saplings that tend to be easily killed by fire, inhibiting forest encroachment into the savanna.

The authors found that the interaction between tree growth rates and fire frequency determines the likelihood of a forest canopy forming to displace savanna. The better the conditions for fast tree growth, including water and nutrient availability, and the lower the fire frequency, the more likely savanna could switch to forest. In other words, the multiple factors influencing vegetation type of a given area are dynamic and interacting.

On the origin of northern and southern hemisphere grasslands, Bredenkamp, Spada & Kazmierczak 2002

This article distinguishes between primary climatic grasslands, where the climate is too dry or cold for forests, and secondary anthropogenic grasslands that were caused by deforestation and subsequent livestock grazing.

Grasses are believed to date back to the Oligocene (33.9 million to 23 million years ago) in Eurasia and Africa. Prior to this in the Eocene (56 to 33.9 million years ago), the world was almost totally forested. Natural grasslands often grow in the interior of continents, where there is a wide seasonal temperature range and long annual dry seasons. Poor soil drainage can also prevent tree growth in grasslands. However, the key factors vary by region:

> Whereas the absence of trees in the Eurasian steppes and North American prairies seems to be controlled by macroclimatic aridity and insufficient drainage in the soil, trees are absent in the southern African grassland due to low temperatures and frost during the dry season [Bredenkamp 2002: 224].

Prairie lands are abundant in western North America, where the tallgrass prairie in the eastern part of the grasslands range developed 11,000 years ago. In the more moist eastern tallgrass prairie area, forest encroachment is believed to have been prevented by regular fire disturbance. Large herbivores have co-evolved with grasses here and in Africa, resulting in grasses' capability to regrow from the base of the leaf.

> The grasses are well adapted to defoliation by both herbivory and fire: they generally do not have chemical defenses while intercalary meristems[7] at base of leaves ensure continued growth after top parts of leaves were removed [Bredenkamp 2002: 217].

Just as dry areas within forested regions transition into grassland patches, more moist areas, such as floodplains, river valleys and ravines in dry environments can be woodland or forest.

In contrast to primary grasslands, central and western European grasslands are secondary, or human-made. Grassy biomes exist on the continent only because forest has been cleared and the land continuously maintained for grazing or other non-forested purposes. If left unmanaged, most of the land in Europe (apart from areas such as dunes, salt marshes, or high alpine elevations) would revert to forest. Interestingly, secondary grassland exists in southern Africa as well, even where climatic conditions are suitable for primary climax grasslands. When the land is degraded due to overgrazing or plowing, different species develop and become dominant in a secondary grassland, "which is totally different from the climatic climax grassland" [Bredenkamp 2002: 226].

The underestimated biodiversity of tropical grassy biomes, Murphy, Andersen & Parr 2016

Tropical grassy biomes (grasslands and savannas) have not received as much conservation attention as forests, often due to a misconception that they are nothing more than degraded forests. While some tropical grassy biomes (TGBs) are anthropogenically derived, many are ancient, primary ecosystems with spectacular biodiversity and endemism. There are clear ecological and evolutionary differences among regions dominated by grassy biomes, making these areas critical for global biodiversity conservation. While appreciation of TGBs and the threats they face is growing, there remains a poor understanding of their biodiversity values on a global scale.

The objective of this paper was to compare species richness between TGBs and tropical forest biomes, and among different TGBs. The authors analyzed the existing global dataset of mammals, birds, amphibians, and vascular plants and found that TGBs have lower vascular plant diversity compared to tropical forests, but comparable levels of vertebrate species richness, when accounting for the effect of differences in rainfall, latitude and biogeographical region (continent). Tropical forests are renowned for their exceptional diversity of trees, yet more megafauna occur in open savannah than in forests. Species richness of threatened amphibians and endemic species was lower in TGBs than in tropical rainforests.

[7] Intercalary meristems are tissues that promote the growth of the plants by elongating the nodes and internodes present at the leaves and stems.

The authors also compared biodiversity levels among TGBs, finding that the Neotropics (Southern Mexico, Central and South America and the Caribbean) and Afrotropics (Africa south of the Sahara) had more diverse vertebrate species richness compared to TGBs in Australia and Asia. The Cerrado and Llanos ecoregions in the Neotropics, as well as certain parts of southern and Central Africa, and dry tropical forests of Indochina have the greatest variety of both vertebrates and vascular plants. The Indomalayan TGBs (South and Southeast Asia) have high concentrations of threatened birds and mammals (threatened due to high human population densities and land-cover conversion in the region).

Large-scale land-cover conversion is the most severe threat to TGB biodiversity, especially in high-rainfall areas. Greater amounts of rainfall make these areas most suitable for agriculture and plantation silviculture, leading to high human population densities. The biodiversity consequences of land-cover conversion are likely to be severe because TGBs in low-rainfall biomes are likely to be species-poor. Woody thickening and forest encroachment, mainly aggravated by reductions in fire frequency, were identified as another critical threat to the biodiversity of TGBs.

The role of grasslands in food security and climate change, O'Mara 2012

Earth's terrestrial area is classified into different ecosystem types. The major group "Grasslands," which encompasses Open or Closed Shrublands, Woody and Non-woody Savannas, and Grasslands, covers an estimated 37% of the earth's terrestrial area (excluding Greenland and Antarctica). Grassland also occupies an area classified as cropland, where it is used for livestock grazing or hay and silage production; much of this is anthropogenic rather than natural (climatic) grassland.

Twenty percent of the world's native/natural grasslands have been converted to crop production, especially those grassland areas with higher average rainfall, while grazing remains on more marginal grasslands.

This article argues that grass-based meat and dairy production have a key role to play in increasing global food supply for a growing human population. Moreover, increasing food production through improved grazing-land management can be achieved in tandem with carbon sequestration and land degradation reversal.

> Ruminants are efficient converters of forages and poor-quality feeds into humanly edible energy and protein, and grassland-based food production can produce food with a comparable carbon footprint as mixed systems. Grasslands are a very important store of carbon, with more carbon stored in global grasslands than in global forests, and they are continuing to sequester carbon. There is considerable potential to increase this further

through grazing land management (e.g. through managing grazing intensity, improved productivity, etc.) and restoration of degraded grasslands [O'Mara 2012: 1269].

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Savannas are vital but overlooked carbon sinks, Dobson et al. 2022

The United Nations Climate Change Conference announced a decision to stop global deforestation by 2030. With respect to protection of savanna ecosystems, however, which cover an area 3 million square kilometers greater than the area covered by tropical forests, the decision is more of a political achievement than an ecological one. The decision did not include savannas despite savannas being as important carbon sinks as tropical forests. The Serengeti plains annually remove enough carbon dioxide from the atmosphere to neutralize all emissions from the region, including those from airline flights from the region. Savannas also provide ecological services to both wildlife and people, and yet savannas are as threatened as forests.Therefore, there is a need to hasten the inclusion of savannas in global protections.

Grasslands and savannahs in the UN Decade on Ecosystem Restoration, Dudley et al. 2020

Grasslands and savannas cover a third of the Earth's land surface and provide many ecosystem services such as biodiversity, soil stabilization, carbon sequestration, and water security. The authors advocate for improving awareness about the status of global savannas and grasslands and the importance of their conservation, and urgently call for the inclusion of grassland and savanna restoration as a key component in the UN Decade on Ecosystem Restoration. The Decade aims to ensure the restoration of all types of ecosystems around the world, but has overemphasized forest restoration at the expense of other ecosystems. In some cases, natural savannas are wrongly converted to forest in the name of eco-restoration.

Grasslands and savannas cover a third of the Earth's land surface and provide many ecosystem services ranging from biodiversity, soil stabilization, carbon sequestration, and water security.

At present, there is work to be done identifying important natural and semi-natural areas to achieve savanna and grassland restoration successfully. Simple and affordable methods such as eliminating pressures and allowing natural recovery, improving fire and grazing management, direct seedling, and enhancement planting and irrigation could potentially quicken the restoration process. Yet there is still much to be learned about grasslands and savannas and the authors argue that growing this knowledge base should be one of the goals for the coming decade.

Grasslands—more important for ecosystem services than you might think, Bengtsson et al. 2019

Grasslands, either natural or semi-natural, have multiple uses and benefits. They can produce food through livestock grazing and simultaneously offer other important ecosystem services, including water supply and flow regulation, carbon storage, erosion control, cultural values, pollination, and biological control of agricultural pests. Yet, the role of grassland systems in food security is not well appreciated and their capacity to deliver multiple ecosystem services (ES) is understudied. It is perhaps unsurprising, therefore, that the global extent of grasslands has rapidly declined over the past century, largely due to conversion to croplands.

This paper focused on semi-natural and natural grasslands (as opposed to “improved” grasslands used for fodder production and characterized by plowing land to plant non-native grasses needing fertilizer and irrigation). In contrast to the latter, natural and semi-natural grasslands are biodiverse and capable of delivering multiple ecosystem services. The study found that both northwestern Europe (NE) and southern Africa (SA) presented a high societal demand for essential grassland services, especially regulating water flow and quality, provisioning dairy and meat products, biological pest control, and recreation. However, in NE, due to the limited area of semi-natural grasslands, demand for these grassland ecosystem services far outstripped supply, suggesting that more land should be devoted to semi-natural grasslands in the region. Natural and semi-natural grasslands in SA are more extensive, and the services they supply are well balanced with regional demand. This points to the importance of protecting existing grasslands in SA.

Grazing management that regenerates ecosystem function and grazing land livelihoods, Teague & Barnes 2017

This article reviews research on multi-paddock grazing management with respect to the effect on the ecosystem function of grazing land. The authors explain how differences in grazing management affect the productivity and ecosystem services of grazing land. Traditionally, the stocking rate, or number of grazing animals per unit area, is viewed as the key management tool, so that when stocking rates are low enough land degradation can be avoided. However, even when the land's carrying capacity is not breached, continuous grazing in a single large paddock or pasture is problematic because the animals tend to favor certain plants and patches.

> This repeated preferential consumption of preferred plants and patches results in uneven impact, such that even at low stocking rates localized undesired changes in plants and soil take place, with these patches persisting and expanding, progressively degrading the landscape [Teague & Barnes 2017: 78].

Multi-paddock rotational grazing has the potential to avoid the problems of continuous grazing, yet when not adaptively managed, the authors stress, rotational grazing too can lead to land degradation. This happens when "paddocks have been grazed for too long and not enough time has been allowed for plants to recover from grazing" [Teague & Barnes 2017: 78].

Instead, Teague and Barnes recommend Adaptive Multi-Paddock grazing management (AMP), which uses many paddocks and a short grazing period, followed by a sufficient recovery period during the growing season. The timing and animal numbers are determined according to the current, local conditions, rather than according to a predetermined schedule or regime.

> Many farmers around the world have used AMP grazing management to restore ecosystem services and productivity on degraded rangelands in areas with less than 250 to 1,500 mm of annual precipitation. Many of these ranches in drier areas were initially so bare of vegetation that they would have been classified as desertified. Improved management has been shown to reverse the causal mechanisms of degradation by decreasing bare ground, increasing water infiltration rates, enhancing soil carbon, enhancing soil fertility, increasing soil and ecosystem community biodiversity, and restoring the dominance of the most productive plant species. These functions are all strongly linked to shifts in soil microbial and biological community composition, carbon cycling and nitrogen cycling [Teague & Barnes 2017: 78].

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