In Press (*Restoration Ecology*). March 22, 2020

A World of Possibilities: Six Restoration Strategies to support the United Nation's Decade on Ecosystem Restoration

Authors and addresses: James Aronson[1, 6], Neva Goodwin[2,] Laura Orlando[3,] Cristina Eisenberg[4], and Adam T. Cross[5]
[1] Center for Conservation and Sustainable Development, Missouri Botanical Garden, 4344 Shaw Blvd, St Louis, Missouri 63110
[2] Economics in Context Initiative at the Global Development Policy Center, Boston University, Boston, Massachusetts 02215
[3] Boston University School of Public Health School, Boston, Massachusetts 02118
[4] College of Forestry, Forest Ecosystems and Society, Oregon State University, Corvallis, Oregon 97331
[5] ARC Centre for Mine Site Restoration, School of Molecular and Life Science, Curtin University, GPO Box U1987, Bentley WA, Perth 6102, Australia
[6] Corresponding author: James Aronson, Center for Conservation and Sustainable Development, Missouri Botanical Garden, 4344 Shaw Blvd, St Louis, Missouri 63110, USA. Tel: +1-617-449-8399. E-mail: ja42014@gmail.com

Author contributions: JA, NG and LO conceived the paper; JA, NG, LO, CE and ATC all authors contributed to the writing and editing.

Abstract. Ecological restoration is practiced worldwide as a direct response to the degradation and destruction of ecosystems. In addition to its ecological impact it has enormous potential to improve population health, socio-economic wellbeing, and the integrity of diverse national and ethnic cultures. In recognition of the critical role of restoration in ecosystem health, the United Nations declared 2021-2030 as the Decade on Ecosystem Restoration. We propose six practical strategies to strengthen the effectiveness and amplify the work of ecological restoration to meet the aspirations of the Decade: (1) incorporate holistic actions, including working at effective scale; (2) include Traditional Ecological Knowledge (TEK); (3) collaborate with allied movements and organizations; (4) advance and apply soil microbiome science and technology; (5) study and show the relationships between ecosystem health and human health; and (6) provide training and capacity-building opportunities for communities and practitioners. We offer these in the hope of identifying possible leverage points and pathways for collaborative action among interdisciplinary groups already committed to act and support the UN Decade on Ecosystem Restoration. Collectively, these six strategies work synergistically to improve human health and also the health of the ecosystems on which we all depend, and can be the basis for a global *restorative culture*.

Key Words Eco-cultural restoration, EcoHealth, ecocide, ecological restoration, ecosystem restoration, public health, human health, soil microbiomes, Traditional Ecological Knowledge (TEK).

Implications for Policy

- Improving ecosystem health through holistic ecological restoration and related activities will ameliorate significant health and wellbeing problems among people locally, regionally, and globally.
- Capacity-building will be greatly enhanced through the development of an international network of restorative action sites.
- Health professionals, landscape and urban planners and designers, and others can advance the goals of the UN Decade by joining restoration efforts and collaborating with restoration ecologists.
- Including indigenous people and practices in restorative activities brings an immense depth of knowledge and experience to the work and is crucial to success in many circumstances.
- Advancement and better application of the science and technology of soil microbiomes and biocrusts in the context of ecological restoration and allied restorative activities is urgently needed.

Introduction

Several global ecological assessments since 2010 culminated in the inspiring United Nations General Assembly declaration of a Decade on Ecosystem Restoration (2021 to 2030) in March 2019 (https://www.decadeonrestoration.org/what-decade) and a full draft strategy was posted on-line in late February 2020 (https://www.decadeonrestoration.org/get-involved/strategy), with a call for public comment. The draft strategy brilliantly presents the Decade's approach to achieving its goals with a clear vision and "theory of change" that defines "inter-related and overlapping barriers" and three main "pathways" to action: generating a global movement, fostering political support, and building technical capacity. It will be up to the global community to respond and so, to begin, we offer six specific strategies that could provide a framework for action for governments, NGOs, and other organizations during the United Nations (UN) Decade on Ecosystem Restoration, and help turn around our current trajectory – from destruction and loss to rebuilding and renewal. We intend to expand on each of these six strategies with a series of follow-up papers in this journal.

Let's start with an overview of the global context for the Decade. In May 2019, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) issued a terrifying report that one million species of plants and animals would go extinct "on our watch" (Díaz et al. 2019). According to Berkeley Earth, a non-profit research organization, the year 2019 was the second warmest year on Earth since record keeping began in 1850, surpassed only by 2016. The highly influential Global Footprint Network, founded in 2003 to "advance the science of sustainability", released data in 2019 showing that Earth Overshoot Day, the day "that humanity is now using 'Nature' 1.75 times as fast as the planet's ecosystems can regenerate," occurred on July 29 of that year.

As many readers of *Restoration Ecology* and members of the Society for Ecological Restoration (SER) already know, uplifting news and encouraging reports were shared at the 8th World Conference on Ecological Restoration held in September 2019 in Cape Town, South Africa. More than 850 participants from 65 countries attended, including top-level policy makers in the

United Nations Environment Programme (UNEP) and the Food and Agriculture Organization (FAO) -- the two UN agencies charged with jointly leading the Decade's implementation.

However, participants at the SER meeting in Cape Town did not have to look far to find environmental disaster and ominous trends: severe drought threatened lives and livelihoods a few hundred kilometers east, in the Karoo region of South Africa, while further afield deforestation accelerated in the Amazon, and some of the worst heat waves and wildfires in recorded history were raging in Australia, Bolivia, and California. The year ended with the December meeting of the UN Climate Change Convention's COP 25 falling depressingly short of the need for action. In light of these and other rampant environmental stressors, such as war and chemical pollution, it feels appropriate to employ the frightening, but accurate, term *ecocide* to human actions. And yet, we hold the possibility of healing through an ecosystems approach to health, for which we use the rich and promising term *EcoHealth*. [Among the many competing and conflicting uses of the term "EcoHealth", we combine the simple contraction of ecosystem health (e.g., Rapport 2007) with that of Berbés-Blázquez et al. (2014) who used it as an abbreviation of "an ecosystems approach to health."]

The terrible human-driven crises of our time -- climate change, mass extinction, food and fresh water shortages -- can be termed *ecocide* because the tidal wave of disasters we can see coming toward us, or are already experiencing, are bound up with the ways in which humans have degraded and destroyed so much of the natural world. Yet amid these challenges we live in a world of possibilities. Ecological restoration has "come of age" via new technology and improved and strengthened standards since its founding as a scientific discipline and its emergence as an international movement in the 1980s and 1990s. We believe that the work of ecological restoration is at least as critical to human wellbeing as, for example, electrification or a modern communications system; it is our best hope for beginning to make the U-turn so desperately needed, away from the despair of continuing loss, toward hope of a healthy world for our children and grandchildren.

However, on its own, *ecological restoration* is not enough ['the process of assisting the recovery of an ecosystem that has been damaged, degraded or destroyed', as defined in the most-widely used definition, Society for Ecological Restoration International Science & Policy Working Group 2004; available here, in English and in ten other languages as well; and in the SER Guidelines, V.2; Gann et al. 2019; available here]. At large spatial scale across mosaic landscapes the ecological restoration of degraded lands and ecosystems is inevitably intertwined with myriad other human behaviors. These include ongoing efforts focused on conservation, habitat, biodiversity and ecosystem management, and the struggle against climate change. Piecemeal, project-by-project efforts parochially addressing localized degradation are not turning the tide of ecosystem collapse. We propose a more integrated, holistic approach, and adopt the term "ecological restoration and allied restorative activities" used by Aronson et al. (2017), Cross et al. (2019), and Gann et al. (2019). We also sometimes refer to this combination or "family" of restorative activities as "ecological restoration writ large".

Six Strategies to Advance Ecological Restoration

Anticipating the January 2021 kick-off of the UN Decade on Ecosystem Restoration, we advocate the following six inter-linked, ecological restoration strategies.

(1) Be holistic, interdisciplinary and inclusive, especially when working on large-scale restorative action plans in mosaic landscapes. Ecological restoration is not just a branch of conservation science, as it was often conceived in the early 1990s (e.g., Towns and Ballantine 1993). Nor is it all about ecosystem services. Instead, it is about saving native biodiversity (both in terms of the species richness, functionality, connectivity, and resilience of locally indigenous ecosystems) to the greatest possible extent and maintaining and replenishing natural capital, which includes native biodiversity and well-functioning ecosystems (Aronson et al. 2007; Blignaut et al. 2014). Dramatic declines in human health are increasingly being linked to comcomitant decline in biodiversity and the quality and quantity of ecosystem services (Ford et al. 2015). Ecological restoration that is designed to be holistic aims to provide human health and welfare benefits for those who participate and live in or near the sites where activities are undertaken as well as regionally and globally (Clewell and Aronson 2013). Critical to a holistic approach is working at an effective scale, with an interplay of social, cultural and ecological complexities. For example, a caribou migration route of 1000–2000 kms may be blocked by one major highway or wall, requiring a very specific and detailed action to remedy the detailed obstacle and achieve the larger goal. Conversely, it may be impossible to achieve the survival of a trans-equatorial migratory bird species unless a linked sequence of actions is taken at a global scale. The 1000 km long Gondwana Link program in south-western Australia is made up of a significant number of smaller detailed projects and programs, operating at a diversity of scales but through arrangements that ensure a level of aggregation across the range of specific achievements (Bradby et al 2016). In such programs it is critical that not all involved are consumed by the complexity of the larger picture, nor focused on a purely local achievement. Our understanding of how to achieve and support such synergies is in its early stages (Curtin 2015), and will require careful development.

(2) Include and respect all valid ways of knowing, particularly Traditional Ecological Knowledge (TEK), in the planning and execution of ecological and related restorative activities on the 25–28% of lands owned and managed by Indigenous people globally (Garnett et al. 2018), as well as on other lands where flora and fauna co-evolved with traditional use of the land and its resources by Indigenous people. We encourage federal land managers to consider national-scale incorporation of TEK into land management decisions; for example, we note that federal agencies in Australia, the U.S. and Canada are broadening application of TEK to all lands where Indigenous people once had a presence (including on Bureau of Land Management land in the U.S. that is not now owned by Indigenous communities). *Eco-cultural restoration* is a key concept that is being applied and rapidly developed (Eisenberg et al. 2019; cf. Martinez 2003), building on the principle that eco-cultural relationships and long-term anthropogenic factors (e.g., climate change, land use changes, and many more) must be addressed in all eco-cultural restoration and human health restorative efforts. Specifically, it also advocates that Indigenous peoples displaced and otherwise abused through colonialization require reconnection to their own lands and histories. Inclusion includes accepting a broad spectrum of communication methods, from rigorous data through to stories and oral traditions.

(3) Those engaged in ecological restoration and related activities should work closely with movements and organizations that are not necessarily engaged directly with ecological restoration, but that strive toward similar goals for human and ecological health or where cooperation on seemingly unrelated goals can lead to synergistic or multiplier benefits. These include academic societies, governments, nonprofits, multilateral agencies, and corporations working to, for example, advance regenerative agriculture and other climate-resilient production systems; improve urban health and revitalize urban communities through ecosystem health; improve population health; end the use of fossil fuels; integrate landscape and urban design and planning into ecosystem restoration; and improve the quality of drinking water and protect aquatic ecosystems. One example is the EcoHealth Alliance, a global nonprofit that conducts and promotes "cutting-edge scientific research into the critical connections between human and wildlife health and delicate ecosystems" in order to "develop solutions that prevent pandemics and promote conservation."

(4) Advance and better apply the science and technology of soil microbiomes and biocrusts, and the microbial communities and invertebrate assemblages of freshwater and marine sediments, in the context of ecological restoration and allied restorative activities. In the past 15 years the underground component of terrestrial ecosystems, including invertebrates and the myriad soil microbes, has emerged as an exciting research field (Wardle et al. 2004). There is clear evidence that extractive land use over long periods greatly affects soil conditions, and depletes below-ground biodiversity (Wardle et al. 2004; Myers et al. 2013). The impact of degraded soil microbiomes on human health are now being explored and tested (Wall et al. 2015), and new scientific discoveries illustrate the encouraging possibility of restoring soil biodiversity so as to ameliorate soil health, ecosystem health and human health, in rural and in urban areas (Breed et al. 2017; Liddicoat et al. 2017, Robinson et al. 2018; Liddicoat et al. 2020). This strategy may be especially relevant in the vast areas of arid, semi-arid and desertified lands worldwide that have already been significantly or completely degraded, and are often strongly reliant upon microbial communities for maintaining productivity through the provisioning of key ecological functions such as nutrient cycling (Soussi et al. 2016; Neilson et al. 2017; Moreira-Grez et al. 2019).

(5) Significantly increase on-site training and capacity building opportunities at ecological restoration and restorative action sites for early career professionals, community leaders, practitioners, administrators, and academics. The numbers of competent restoration scientists, managers, restoration entrepreneurs, and practitioners is insufficient to meet global ecological challenges. Additionally, current teaching strategies may not be providing these professionals with the breadth of cross-disciplinary knowledge required for ecological restoration; restoration scientists need training in a broad range of disciplines from taxonomy and hands-on organismal biology and physiology to microbial ecology, population biology, and soil and marine science. People seeking training, conceptual grounding, and inspiration can find it not only in classrooms and workshops, but also through expanded opportunities to engage in on-site, hands-on participation at long-term restoration and restorative action sites (e.g., Aronson et al. 2010).

(6) Highlight, study, and communicate the intricate linkages between restoring ecosystem health and the improvement of physical, mental, social, and cultural health of local and global human populations, along with the general wellbeing and sustainability of communities, nations, and

society (Robinson et al. 2018; Mills et al. 2017; Amberson et al. 2016; Aronson et al. 2016; Speldewinde et al. 2015; Elmqvist et al. 2015).

Figure 1 situates Strategies 1 through 6 within the general idea of this paper. It cites industrial agriculture, silviculture, and urbanization among the ways that human actions are harming ecosystems, and proposes that restorative action is required to address ecological degradation in areas impacted upon by these industries (for example, farms and ranches, and in the water catchment areas in and around cities). There are, of course, many other types and areas of ecosystem impairment, which need to be addressed in the places where they occur: ecosystem restoration is strikingly place-based.

We propose these six strategies for consideration not only by restoration practitioners and scientists but also by planners, farmers and ranchers, policy-makers, investors, administrators, health professionals, and the strategists and leaders of the UN Decade on Ecosystem Restoration.

[Insert Figure 1 near here]

While place-based and site-specific restoration activities are obviously essential to healing and re-enabling impaired sites and ecosystems, Figure 1 adds a second concept to the needed healing: public health education, research, and practice. This begins with the obvious but as yet largely unproven logic: if degraded ecosystems cause (as they are known to cause) serious health problems among people in their vicinity, can we not anticipate that improved ecosystem health will ameliorate (or at least cease to exacerbate) those same health problems (Aronson et al. 2016; Robinson et al. 2018; Liddicoat et al. 2020)? Work is needed to prove this proposition by integrating health professionals, both in public heath and clinical research and practice, into ecological restoration planning and projects. Health research should be conducted at established restoration sites, ideally where ongoing ecological monitoring, evaluation and capacity-building are undertaken over suitable periods of time. Both quantitative and qualitative data can show health changes from restoration activities and help establish public policies and practices that maintain the ecological conditions that support the health of populations, particularly the disadvantaged and vulnerable.

The six strategies outlined above can be folded into an EcoHealth approach to ecological restoration. Most practitioners and theorists of ecological restoration will be familiar with some or all of the foregoing strategies. The major new theme advanced here concerns the linkages between the health of human populations and cultures (including human wellbeing in a socio-economic context) and the health of ecosystems. Taken together these strategies can be the basis for the *restorative culture* that is needed to transition away from ecocide and towards EcoHealth (Cross et al. 2019; www.ecohealthglobal.org).

The driving force of a restorative culture, in which environmental and human health co-benefit, must be a spiritual, cultural and philosophical connection of society to nature. To achieve this connection we need to take care of courselves, beginning with a break from the historical dichotomy of ‘humanity vs. nature’, and come to terms with the fact that humanity *is* nature.

Taking care of one means taking care of the other. The UN Decade on Ecosystem Restoration suggests UNEP and FAO aspire to achieve such a connection through the genesis of a global movement towards transformative change in our way of understanding the world and the place of humans, and human economies, within it. Language in the declaration emphasizes the fundamental linkages between ecosystems and sustainable development, poverty alleviation, and human wellbeing; key concepts of a restorative culture. While it remains to be determined how the Decade will actually be planned and implemented, a draft strategy is being developed and is anticipated for completion by June 2020. Already it is inspiring to see the United Nations aims for the Decade, such as to "connect initiatives working in the same landscape, region, or topic, to increase efficiency and impact," dovetailing with the strategies we emphasize.

The application of technologies and practices that have caused so much ecological degradation will need to be abandoned or rethought, and entrepreneurial energy redirected into economic engines driving the protection and restoration of ecosystems. There remains a considerable disconnect between business and restoration enterprise, and ecological knowledge. For example, we must radically shift from large-scale industrialized monoculture systems of agriculture to methods that conserve, enhance, and complement biodiversity both above and below ground. Such techniques will need to limit the use of synthetic chemical poisons for the control of pests and weeds, improve the livelihoods of farmers, respect cultural practices and food traditions, and adopt agroecological principles of food sovereignty and justice. Other areas such as urban design and water management will require equally radical shifts, and these changes may require championing by governments and regulators through economic incentives or other facilitatory measures.

A restorative paradigm requires an approach of humility rather than hubris. It must accept the unpredictability and surprises inherent in open, nested ecosystems and landscapes of great functional and spatial complexity (see Falk 2017; Blignaut & Aronson 2019). There is still a yawning gap between what we aspire toward in restoration ecology, and what we can expect to actually achieve in one or two human lifespans with our current scientific understanding and technology (Moreno-Mateos et al. 2012, Moreno-Mateos et al. 2017). Furthermore, caution must be applied when setting and meeting ambitious goals (i.e., afforestation targets) to ensure that well-intentioned activities do not result in deleterious environmental outcomes (e.g., the afforestation of grasslands), and that terms such as ‘ecosystem restoration’ are not misused to disguise low aspirations (Cross et al. 2018).

Nevertheless, there are reasons to hope for rapid and continued growth in shared wisdom as well as knowledge. The growth of knowledge about soils and subterranean biodiversity is extremely heartening. The lessons and concepts embedded in the deep roots of Traditional Ecological Knowledge are increasingly being listened to by people and institutions with the power to act. There are cumulative lessons from efforts focused on conservation, habitat and ecosystem management, and climate change resilience. Along with the ratcheting up of concern about the climate emergency immediately facing the Earth there is growing awareness of the importance of ecosystem services and renewable natural capital, including biodiversity and the ecosystem goods and services that flow from soil health and ecosystem health (de Groot et al. 2010; Bullock et al. 2011; Blignaut et al. 2014). There are many potential partners for a movement in which concepts of ecosystem restoration are expanded to include all the places where people live. For all of this, the UN Decade on Ecosystem Restoration provides a powerful platform.

The context for this paper

The strategies summarized above will be laid out in a series of short papers, written under the auspices of the EcoHealth Network (EHN), which was founded in 2017 to build synergies to foster a rapid increase in the amount and effectiveness of ecological restoration throughout the world (http://www.ecohealthglobal.org/). The mission of this organization is to accelerate understanding and awareness among scientists, policy makers, practitioners and the general public of the feasibility and potentially enormous benefits of ecological restoration, for human health and for the ecosystems on which we depend. Many different forms of restorative actions are being investigated and tried across the world. To strengthen and broaden the impact of these actions, and to speed adoption of effective restorative practices globally, EHN is creating an interactive network of sites that will address key gaps in science, education, and outreach. Combining social, economic, and ecological perspectives, EHN will focus especially on two related knowledge gaps: 1) soil responses to restoration; and 2) the relationships between ecosystem health and human health. However, we are also committed to addressing and applying all six of of the strategies presented in this paper.

We argue that ecological restoration is the most powerful way to truly connect these two entities – ecosystem health and human health – both in theory and in practice. The papers in the series following this introduction will be curated by EHN, and written by a variety of authors including members of the EHN Steering Committee and other members of the network and from allied organizations who are helping to build the EcoHealth Network and forge a transition to a restorative culture.

The authors of this series hope to contribute to the growing literature that bridges the divide between the theory of ecological restoration and its practical on-the-ground application. This is especially important in light of the UN commitment, and the commitments that are being solicited, and are forthcoming, from nations in response to the UN Decade on Ecosystem Restoration. Some ambitious responses, inevitably, come more from good will than familiarity with the concepts of ecological restoration. Such approaches can result in wasted effort and resources, for example where narrow emphasis is placed upon a single action such as large-scale tree planting without adequate consideration of the whole ecosystem and its functioning. In these cases, consideration should be paid to whether the tree species being planted (and their provenance) are appropriate to the soil and the climate to ensure that many - if not all – do not die, and avoid species with any potential to become dangerously invasive and harmful to ecosystem health and, therefore, to human health and wellbeing. Indeed, evidence suggests that afforestation can be profoundly deleterious to biodiversity, ecological functioning and ecosystem productivity if it is poorly planned or undertaken in the wrong context (e.g., where tree planting is undertaken in grassland ecosystems; Nosetto et al. 2005; Berthrong et al. 2009; Veldman et al. 2015). Locations selected for restorative actions should optimize all of the potential benefits of the activities to be undertaken. To continue our tree planting example, proper site selection could integrate with regenerative farming systems, providing shade, improvig water retention, and possibly yielding additional income sources to people on farms or grasslands (Perfecto et al.

2019). Importantly, there should be prior consultation with all of the groups who may be affected, including Indigenous peoples.

There are myriad ways in which the important intentions of the Decade on Ecological Restoration can be put into practice. They can be applied to wetlands, waterways, and coastal regions; to grasslands, whose huge potential for withdrawing carbon from the air and storing it in the soil is only just beginning to be recognized; to industrial and commercial sites; and to cities, where ecological restoration has especially obvious and visible implications for human health – for example, by improving water and air quality, or through improving mental wellbeing by reconnecting people with nature and green spaces. The linkages to regenerative agriculture are strong, and need to be better integrated into public policy. We hope that the strategies laid out in this, and the following series of papers, will inform and inspire many nations, cities, organizations and individuals who can contribute to the critical work of ecological restoration writ large in this critical decade for humans and other life on Earth.

A growing wave of public awareness, led in many cases by young people, is recognizing that climate change represents perhaps the most acute emergency humankind has ever faced. We must all insist upon appropriate action — from ourselves, our local and national governments, and all organizations, including businesses and non-profits. The Decade of Ecological Restoration provides a conceptual framework for the crucial "restore" aspect of the action required.

Acknowledgements

The authors warmly thank Keith Bradby, Martin Breed, Anthony Mills, Philip Weinstein, and Levi Wickwire for discussions and very helpful comments on previous drafts, and Margaret Palmer and two anonymous reviewers for their advice and assistance in revising the manuscript.

References

Amberson S, Biedenweg K, James J, Christie P (2016) "The Heartbeat of Our People": Identifying and measuring how salmon influences Quinault tribal well-being. Society & Natural Resources, 29, 1389–1404. doi.org/10.1080/08941920.2016.1180727

Aronson J, Aguirre N, Muñoz J (2010) Ecological Restoration for Future Conservation Professionals: Training with Conceptual Models and Practical Exercises. Ecological Restoration 28, 175–181.

Aronson J, Blatt CM, Aronson TB (2016) Restoring ecosystem health to improve human health and well-being: physicians and restoration ecologists unite in a common cause. Ecology and Society 21 (4), art. 39: doi.org/10.5751/ES-08974-210439

Aronson J, Blignaut J, Aronson T (2017) Conceptual frameworks and references for landscape-scale restoration: reflecting back and looking forward. Annals Missouri Botanical Garden 102, 188–200. doi.org/10.3417/2017003

Berbés-Blázquez M, Oestreicher JS, Mertens F, Saint-Charles J (2014) Ecohealth and resilience thinking: a dialog from experiences in research and practice. Ecology and Society 19: 24. doi.org/10.5751/ES-06264-190224

Berthrong ST, Schadt CW, Pineiro G, Jackson RB (2009) Afforestation alters the composition of functional genes in soil and biogeochemical processes in South American grasslands. Applied Environmental Microbiology 75, 6240–6248.

Blignaut JN, Aronson J (2019) Developing a restoration narrative: A pathway towards system-wide healing. Ecological Economics.168, 106483. doi.org/10.1016/j.ecolecon.2019.106483

Blignaut, JN, Aronson J, de Groot R (2014) Restoration of natural capital: A key strategy on the path to sustainability. Ecological Engineering 65, 54-61.

Bradby K, Keesing A, Wardell-Johnson G (2016) Gondwana Link: connecting people, landscapes, and livelihoods across southwestern Australia. Restoration Ecology 24, 827-835.

Bullock J, Aronson J, Rey Benayas JM, Pywell R, Newton A (2011) Restoration of ecosystem services and biodiversity. Trends in Ecology and the Environment 26, 541–549.

Clewell AF, Aronson J (2013) Ecological Restoration: Principles, Values, and Structure of an Emerging Profession. 2nd Edition. Island Press, Washington, D.C.

Cross AT, Young R, Nevill P, McDonald T, Prach K, Aronson J, Wardell-Johnson G, Dixon KD (2018) Appropriate aspirations for effective post-mining restoration and rehabilitation: a response to Kaźmierczak et al. Environmental Earth Sciences 77, 256.

Cross AT, Neville PG, Dixon KW, Aronson J (2019) Time for a paradigm shift towards a restorative culture. Restoration Ecology 27, 924–928.

Curtin CG (2015) The Science of Open Spaces – Theory and Practice for conserving large complex systems. Island Press, Washington DC.

Díaz S, Settele J, Brondízio ES, Ngo HT, Agard J, Arneth A, Balvanera P, Brauman KA, Butchart SH, Chan KM, Garibaldi LA, Ichii K, Liu J, Subramanian SM, Midgley GF, Miloslavich P, Molnár Z, Obura D, Pfaff A, Polasky S, Purvis A, Razzaque J, Reyers B, Chowdhury RR, Shin Y-J, Visseren-Hamakers I, Willis KJ, Zayas CN (2019) Pervasive human-driven decline of life on Earth points to the need for transformative change. Science 366,1327eaax3100.doi:10.1126/science.aax3100

de Groot R, Fisher B, Christie M, Aronson J, Braat L, Haines-Young R, Gowdy J, Maltby E, Neuville A, Polasky S, Portela R, Ring I (2010) Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation. In: TEEB Foundations: The

Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Edited by Pushpam Kumar. Earthscan, London and Washington, D.C. pp 9–40.

Elmqvist T, Setälä H, Handel S, van der Ploeg, S, Aronson J, Blignaut J, de Groot R (2015) Benefits of restoring ecosystem services in urban areas. Current Opinion in Environmental Sustainability 14, 101–108. doi.org/10.1016/j.cosust.2015.05.001

Falk DA (2017) Restoration ecology, resilience and the axes of change. Annals of the Missouri Botanical Garden 102, 201–216.

Ford A, Graham ESH, White PCL (2015) Integrating human and ecosystem health through ecosystem services frameworks. EcoHealth 12, 660–671. doi.org/10.1007/s10393-015-1041-4.

Eisenberg C, Anderson CL, Collingwood A, Sissons R, Dunn CJ, Meigs GW, Hibbs DE, Murphy S, Kuiper SD, SpearChief-Morris J, Little Bear L, Johnston B,Edson CB (2019) Out of the Ashes: Resilience to extreme wildfire, prescribed burns, and indigenous burning in ecosystems. Frontiers in Ecology and the Environment 7, 436. doi:10.3389/fevo.2019.00436

Gann G, McDonald T, Walder B, Aronson J, Nelson, CR, Eisenberg C, et al. (2019) International principles and standards for the practice of ecological restoration. Restoration Ecology 27, S3–S46. doi: 10.1111/rec.13035

Garnett ST, Burgess ND, Fa JE, Fernández-Llamazares Á, Molnár Z, Robinson CJ, Watson JEM, Zander KK, Austin B, Brondizio ES, Collier NF, Duncan T, Ellis E, Geyle H, Jackson MV, Jonas H, Malmer P, McGowan B, Sivongxay A, Leiper I (2018) A spatial overview of the global importance of Indigenous lands for conservation. Nature Sustainability 1, 369 – 374. doi: 10.1038/s41893-018-0100-6

Liddicoat C, Waycott M, Weinstein P (2017) Environmental Change and Human Health: Can Environmental Proxies Inform the Biodiversity Hypothesis for Protective Microbial–Human Contact? BioScience 66, 1023–1034.

Liddicoat C, Sydnor H, Cando-Dumancela C, Dresken R, Liu J, Nicholas, NJC, Gellie, Mills JG,Young JM, Weyrich LS, Hutchinson MR, Weinstein P, Breed MF (2019) Naturally-diverse airborne environmental microbial exposures modulate the gut microbiome and may provide anxiolytic benefits in mice. Science in the Total Environment 701, 134684. doi.org/10.25909/5caaf18c3450d

Martinez D (2003) Protected areas, indigenous peoples, and the Western idea of nature. Ecological Restoration 21, 247–250.

Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: Synthesis. Millennium Ecosystem Assessment Series. Washington, DC: Island Press

Mills JG, Weinstein P, Gellie NJC, Weyrich LS, Lowe AJ, Breed MF (2017) Urban habitat restoration provides a human health benefit through microbiome rewilding: the Microbiome Rewilding Hypothesis. Restoration Ecology 25, 866–872.

Moreira-Grez B, Tam K, Cross AT, Yong JW, Kumaresan D, Farrell M, Whiteley AS (2019) The Bacterial Microbiome Associated With Arid Biocrusts and the Biogeochemical Influence of Biocrusts Upon the Underlying Soil. Frontiers in microbiology 10, 2143.

Moreno-Mateos D, Power ME, Comín FA, Yockteng R (2012) Structural and functional loss in restored wetland ecosystems. PLoS Biology, 10, e1001247.

Moreno-Mateos D, Barbier EB, Jones PC, Jones HP, Aronson J, McCrackin ML, Meli P, Montoya D, Rey Benayas JM (2017) Anthropogenic ecosystem disturbance and the recovery debt. Nature Communications 8, 14163. doi:10.1038/ncomms14163.

Myers SS, Gaffikin L, Golden CD, Ostfeld RS, Redford K, Ricketts T, Turner WR, Osofsky SA (2013) Human health impacts of ecosystem alteration. Proceedings of the National Academy of Sciences 110, 18753–18760.

Neilson JW, Califf K, Cardona C, Copeland A, Van Treuren W, Josephson KL, Knight R, Gilbert JA, Quade J, Caporaso JG, Maier RM (2017) Significant impacts of increasing aridity on the arid soil microbiome. mSystems 2, e00195-16.

Nosetto MD, Jobbágy EG, Paruelo JM (2005) Land-use change and water losses: the case of grassland afforestation across a soil textural gradient in central Argentina. Global Change Biology 11, 1101–17.

Perfecto I, Jiménez-Soto ME, Vandermeer J (2019) Coffee Landscapes Shaping the Anthropocene: Forced Simplification on a Complex Agroecological Landscape. Current Anthropology 60, no. S20, S236-S250. doi:10.1086/703413

Rapport DJ (2007) Sustainability Science: an ecohealth perspective. Sustainability Science 2, 77–84. doi:10.1007/s11625-006-0016-3

Robinson JM, Mills JG, Breed MF (2018) Walking Ecosystems in Microbiome-Inspired Green Infrastructure: An Ecological Perspective on Enhancing Personal and Planetary Health. Challenges 9, 40. doi:10.3390/challe9020040

Samson F, Knopf F (1994) Prairie conservation in North America. BioScience 44, 418–421.

Society for Ecological Restoration International Science & Policy Working Group (SER) (2004) The SER International Primer on Ecological Restoration. www.ser.org & Tucson: Society for Ecological Restoration International.

Soussi A, Ferjani R, Marasco R, Guesmi A, Cherif H, Rolli E, Mapelli F, Ouzari HI, Daffonchio D, Cherif A (2016) Plant-associated microbiomes in arid lands: diversity, ecology and biotechnological potential. Plant and Soil, 405, 357–370.

Speldewinde, P. C., Slaney, D., & Weinstein, P. (2015) Is restoring an ecosystem good for your health? Science of The Total Environment, 502, 276–279.doi.org/10.1016/j.scitotenv.2014.09.028

Towns DR, Ballantine WJ (1993) Conservation and Restoration of New Zealand Island Ecosystems. Trends in Ecology & Evolution 8, 452–457.

Turner NJ, Ignace MG, Ignace R (2000) Traditional ecological knowledge and wisdom of aboriginal peoples in British Columbia. Ecological Applications 10, 1275–1287.

Wardle DA, Bardgett RD, Klironomos JN, Heikki S, van der Putten WH, Wall DH (2004) Ecological linkages between aboveground and below-ground biota. Science 304, 1629–1633.

Veldman JW, Overbeck GE, Negreiros D, Mahy G, Le Stradic S, Fernandes GW, Durigan G, Buisson E, Putz FE, Bond WJ (2015) Where tree planting and forest expansion are bad for biodiversity and ecosystem services. BioScience 65, 1011–1018.

Figures:

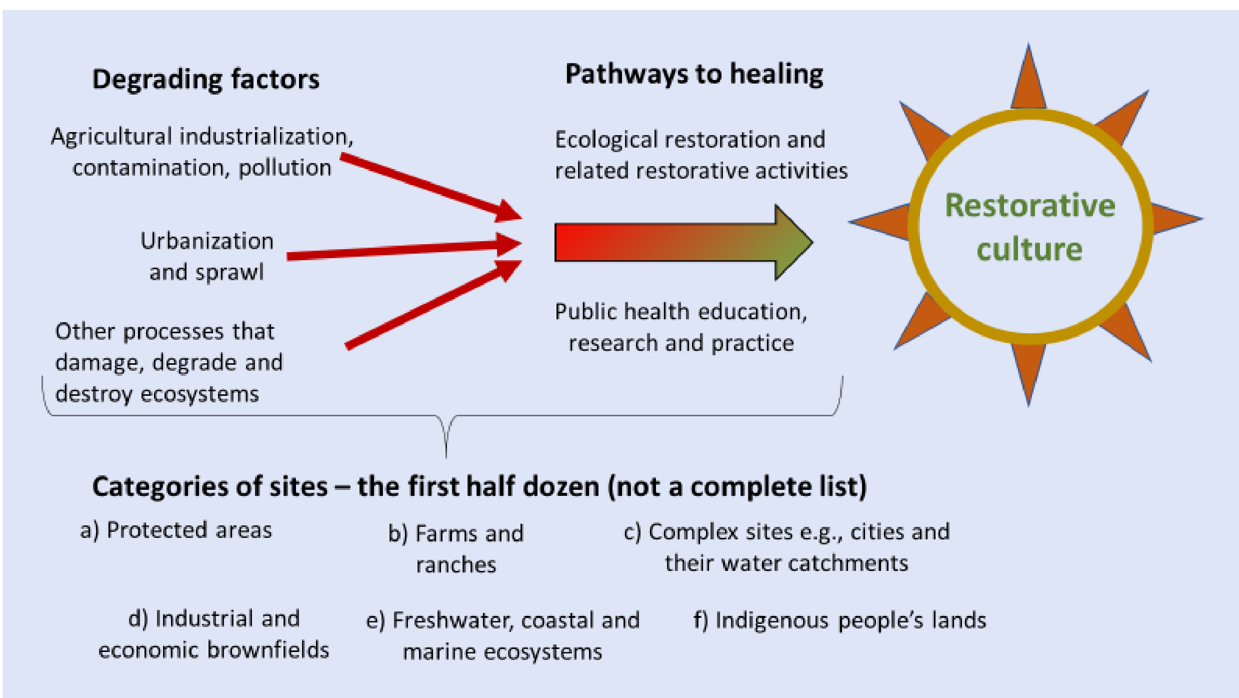

Figure 1. Schematic flow chart identifying the impact of some of the major drivers of environmental and ecological degradation on ecosystems and potential pathways to a restorative culture, as well as a partial list of sites where ecological restoration and related restorative activities are needed. Sites could be categorised on the bases of socio-environmental bases (e.g., Protected areas), socio-economic bases (e.g., Farms and ranches), or both (e.g., Indigenous people's lands), but the crucial inter-related linkages both within and among them must be recognised. For example, although the social, ecological and economic context and the drivers of degradation acting upon Freshwater, coastal and marine ecosystems will likely differ from those of Complex sites such as cities, many cities exhibit strong land-water links as a result of location in coastal areas or along waterways and there may be opportunities for translational learnings between these site categories. Note that Drylands (being the arid and semi-arid lands representing ca. 40% of the emerged lands on Earth), as well as Forests (including boreal, temperate, and tropical forest ecosystems) and Grasslands of all types, are additional examples of categories of sites that could potentially be included as well.