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

Volume 4, Number 1, July 2020

NOTE: Citations in our text are in brackets. The format is [lead-author year: page number (if a specific quote is referenced)].

CONTACT: Biodiversity for a Livable Climate
P.O. Box 390469
Cambridge, MA 02139, USA
compendium@bio4climate.org
(781) 674-2339

About Biodiversity for a Livable Climate

Biodiversity for a Livable Climate, bio4climate.org, is a 501(c)(3) non-profit founded in 2013 whose mission is to support the restoration of ecosystems to reverse 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 185,000 views on YouTube) from our 12 conferences since November 2014 (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.

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 www.Bio4Climate.org/Donate to join our monthly donor program, or to make a one-time donation, all tax deductible. Many thanks!

Suggested Citation

Compendium of Scientific and Practical Findings Supporting Eco-Restoration to Address Global Warming, Vol 4 No 1, July 2020, https://bio4climate.org/resources/compendium/. This is a collection of article summaries and commentary that will grow as new literature becomes available and as older literature is re-discovered.

Acknowledgements

Current contributors to this collection are co-editors Hannah Lewis and Adam Sacks, writers Hannah Lewis, Ajibona Tolulope and Mayanka Dutta, and reviewer Fred Jennings. The value of the contributions from our many speakers and collaborators cannot be overstated. We invite our readers to review our collection of conference videos on the program page of each of our thirteen conferences (https://bio4climate.org/conferences/) as of May 2020.

We are most appreciative of the support from our sponsors over the past six years. In particular, the 11th Hour Project provided significant funding for our first two years, and the new and important institution that it helped create, the Regenerative Agriculture Foundation, is continuing its strong moral and financial support. We are also pleased to acknowledge generous conference sponsorship from the Organic Consumers Association, Regeneration International, the Virgin Earth Challenge, Bristol Community College, the Tufts Institute of the Environment, Janelia Foundation, Margaret Roswell, the Overbrook Foundation and Foundation Earth. Additional important support has been kindly provided by the Nutiva Foundation, the Rockefeller Family Fund, the Savory Institute, Irving House and the Bionutrient Food Association. We also gratefully acknowledge support from several institutions, including Tufts University, Harvard University, Bristol Community College, and the University of the District of Columbia.

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

Introduction

In a fitting juxtaposition, 2020 has brought us both the Covid-19 pandemic and the eve of the United Nations (UN) Decade of Ecosystem Restoration (2021-2030). As we have learned from infectious disease research, ecosystem degradation drives the emergence of novel human diseases that become pandemic. In this issue of the compendium we delve into research examining the connection between biodiversity loss and infectious disease, along with another set of articles on how best to restore the increasingly dangerous degraded lands that surround us. Perhaps a decade of restoring ecosystems as if our lives depend on it will deliver us to a gentler world come 2030.

Biodiversity loss and pandemics

The subject of infectious disease became both fascinating and uncomfortably relevant with the global breakout of Covid-19 in early 2020. Are bats to blame, hunting and selling of wild game or seafood markets? It turns out that the destruction of nature is the root problem, according to the UN environment chief and lead scientists for the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES). “Covid-19 is nature sending us a message,” writes the UN environment chief and colleague [Dasgupta & Anderson 2020]. They continue:

[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 is approximately equal to 2 gigatons 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 sink.

> In fact, it reads like an SOS signal for the human enterprise, bringing into sharp focus the need to live within the planet's means. The environmental, health and economic consequences of failing to do so are disastrous [Dasgupta & Anderson 2020].

> "Covid-19 is nature sending us a message. In fact, it reads like an SOS signal for the human enterprise, bringing into sharp focus the need to live within the planet's means. The environmental, health and economic consequences of failing to do so are disastrous." - Sir Partha Dasgupta & Ingar Anderson

An April 2020 IPBES article [Settele 2020] echoes this alert:

> As with the climate and biodiversity crises, recent pandemics are a direct consequence of human activity – particularly our global financial and economic systems, based on a limited paradigm that prizes economic growth at any cost.
>
> … Our actions have significantly impacted more than three quarters of the Earth's land surface, destroyed more than 85% of wetlands and dedicated more than a third of all land and almost 75% of available freshwater to crops and livestock production [Settele 2020].

"With more than 70% of all emerging diseases affecting people having originated in wildlife and domesticated animals," the IPBES team explains, "activities that bring increasing numbers of people into direct contact and often conflict with the animals that carry these pathogens" lead to pandemics [Settele 2020].

A study [Rulli 2017] linking forest fragmentation with outbreaks of Ebola virus disease in West and Central Africa bears out this assessment. The authors stress that infectious disease emergence is among the many dangers stemming from ecosystem destruction.

> The impact of forest loss on ecosystems and the services they provide is often evaluated in terms of habitat destruction, losses of biodiversity, carbon stock and emissions, land degradation, or altered climate and hydrologic conditions. This study, however, highlights that deforestation and forest fragmentation potentially have another important class of externalities associated with global health and zoonotic[3] disease outbreaks [Rulli 2017: 5].

[3] Zoonotic diseases are those which are transmissible from animals to humans.

Using satellite data on forest cover change from 2000 to 2014, these researchers found that all 11 sites of the first human Ebola infections since 2004 occurred in close proximity (within 25 km) to areas with higher rates of forest fragmentation than the regional average. Similarly, the closer one approached to the centers of first infection, the greater the fragmentation.

What is forest fragmentation? It is the cutting of forest into isolated patches and irregular shapes, resulting in greater lengths of edge between forested and non-forested areas. The increased length of forest perimeter in turn increases contact between humans and the wildlife that are potential disease agents, which would not otherwise be crossing our paths.

In addition to increasing human-wildlife contact, forest fragmentation favors some species while harming or obliterating others, throwing the whole system out of balance. Various studies have shown that the animals that thrive in degraded ecosystems are the same ones that constitute reservoirs of diseases communicable to humans. For example, in the case of West and Central Africa, the species suspected in the emergence of Ebola in humans include gorillas, chimpanzees, duikers (similar to an antelope) and a handful of bat species, all of which have been observed to increase in density following forest disturbance.

> In addition to increasing human-wildlife contact, forest fragmentation favors some species while harming or obliterating others, throwing the whole system out of balance.

> Thus, it could be argued that while disturbance by deforestation destroys the habitat of specialist[4] species, generalists – possibly including reservoirs of some zoonotic pathogens – thrive, thereby further enhancing the risk of infection in human populations close to the forest margins [Rulli 2017: 5].

A similar observation was made in North America. The white-footed mouse, an extremely "competent" host for Lyme Disease – meaning highly capable of harboring and transmitting the Lyme bacteria – does well in degraded forests, while many less competent hosts require more diverse, intact forests to thrive. Opossums, for instance, do poorly in impoverished ecosystems and also do not transmit the Lyme bacterium as readily as mice do. Furthermore,

[4] Specialist species have specific, limited requirements for food and habitat, while generalists are more adaptable and can make do on a variety of food resources and environmental conditions.

opossums kill ticks attempting to feed on them, making them a poorer host for the tick vector[5] as well.

There may be a direct link between a species' susceptibility to habitat degradation and its quality as a disease host[6]. Among vertebrates,

> resilience in the face of disturbances that cause biodiversity loss, such as habitat destruction and fragmentation, is facilitated by life history features such as high reproductive output and intrinsic rates of increase. Vertebrates with these features tend to invest minimally in some aspects of adaptive immunity; we hypothesize that this may make them more competent hosts for pathogens and vectors [Keesing 2010: 650].

The loss of less-competent disease host species, or of predators, for example, that would otherwise control a competent host population, thus allowing the latter to flourish, can create an "amplification effect." The resulting higher concentration of competent hosts increases the likelihood of vector contact with infected hosts, thus increases disease transmission.

The amplification effect was observed also in the case of West Nile Virus (WNV) in North America in 2003-2004 [Ostfeld 2009]. Counties with higher passerine (perching) bird diversity were found to have lower human incidence of WNV disease, presumably due to lower concentrations of the bird species that were the primary disease reservoirs. With higher bird diversity, mosquito vectors were less likely to get infected due to a greater prevalence of uninfected birds upon which to feed.

With higher bird diversity, mosquito vectors were less likely to get infected due to a greater prevalence of uninfected birds upon which to feed.

Given multiple studies of particular disease systems like the ones described above indicating that biodiversity inhibits the spread of disease, another group of scientists [Civitello 2015] wanted to know how broadly and generally the amplification effect applies. Were these disease systems special cases, or do they suggest an inherent relationship between biodiversity and disease? Inverse of the amplification effect, "the dilution effect hypothesis

[5] Vectors are organisms that can transmit a disease from an animal to a human or between humans.
[6] A host is an organism that can be infected by a given disease; from a virus' perspective, a host organism is a suitable habitat.

suggests that diverse ecological communities limit disease spread via several mechanisms. Therefore, biodiversity losses could worsen epidemics that harm humans and wildlife" [Civitello 2015: 8667], the authors state to contextualize their research. They analyzed 202 studies of biodiversity and parasite abundance, and found "overwhelming evidence of dilution, which is independent of host density, study design, and type and specialization of parasites" [Civitello 2015: 8667]. From these results, it can be inferred that biodiversity generally limits infectious disease.

This message has not gone unheard by some in the public health field. An article [Granter 2016] published in the American Society of Clinical Pathology argues for health practitioners to become aware of the human health implications of environmental destruction, stating that:

> Knowledge and prowess with infectious diseases for diagnosticians must be incorporated back into training with a reimagined lens crafted from the information we have gained by studying our environment, its destruction, and the ultimate resulting human infections [Granter 2016: 645].

A research team that included ecologists and a Center for Disease Control staff member [Kilpatrick 2017] analyzed the inclusion of biodiversity conservation among key public health tools. Without further research, the authors remain hesitant to recommend conservation generally as a public health tool (except insofar as exposure to nature boosts human wellbeing). However, they suggest that targeted interventions, such as reintroducing top predators to control host populations, installing bat or owl boxes to increase predation of mosquitos (vectors) or rodents (hosts) could be feasible public health interventions against infectious disease.

In their IPBES letter, Settele and colleagues [2020] recommend the adoption of a "One Health" approach to public health. This concept recognizes the fundamental interdependence of humans, animals, plants and our shared environment, and stresses the importance to human health of the overall health of nature. Some assessments paint that interdependence in even starker terms: "Zoonoses [human diseases of animal origin] reveal that environmental stewardship is not simply related to public health; in many cases, they are the same," writes science journalist Ferris Jabr [2020].

In their IPBES letter, Settele and colleagues [2020] recommend the adoption of a "One Health" approach to public health. This concept recognizes the fundamental

interdependence of humans, animals, plants and our shared environment, and stresses the importance to human health of the overall health of nature.

Indeed, humans are not the only species to experience disease epidemics. Bovine tuberculosis, honeybee varroasis, rabbit hemorrhagic disease virus, herpes virus in pilchard fish, West Nile virus in birds, and amphibians worldwide ravaged by a fungal disease are a few examples of how other species suffer. The underlying factors causing livestock, wildlife and human epidemics are anthropogenic environmental change driven by globalization of agriculture, commerce and human travel, all of which spread disease. Habitat destruction and toxic pollution are additional factors [Daszek 2001].

Compendium readers will be aware that biodiverse, intact ecosystems provide multiple vital functions. Healthy ecosystems absorb stormwater, forestall drought, generate rain, cool the air and land, purify air and groundwater, and pollinate crops, for example, not to mention contributing to human psychological wellbeing by providing recreational opportunities and beauty. What pandemics like Covid19 have now made us aware of is that biodiversity also plays a key role in limiting the emergence and spread of infectious disease.

Biodiversity loss and pandemics article summaries

Anthropogenic environmental change and the emergence of infectious diseases in wildlife, Daszak, Cunningham & Hyatt 2001

Humans are not the only species to suffer global pandemics. Planetwide, fungal disease ravages amphibians, just as honeybees are ravaged by varroasis. A herpes virus caused mass mortality of pilchard fish off the coast of Australia and New Zealand in 1995, and seals from Antarctica to the Caspian Sea have contracted canine distemper viruses, for which domestic dogs are also hosts.

The authors point to multiple anthropogenic environmental changes as the underlying causes of disease emergence among wildlife, livestock and humans.

> Emerging infectious diseases (EIDs) are defined as diseases that have recently increased in incidence or geographic range, recently moved into new host populations, recently been discovered or are caused by newly-evolved pathogens [Daszak 2001: 103].

Two major known causes of disease emergence in wildlife are (1) “spillover” of livestock disease into wild populations; and (2) pathogen pollution, which stems from the global transport of domestic and wild animals, and contaminated products and materials. In addition, habitat destruction and fragmentation, and toxic pollution, are likely to contribute to disease emergence, although these factors hadn’t been as well studied (at least at the time of the writing in 2001).

The authors conclude with the following observation:

> We have described a group of wildlife diseases that can be classified as emerging in the same way as human EIDs. These represent a link in the chain of emergence of human and domestic animal diseases, with pathogens, habitats and environmental changes shared between these populations. Parallels between causes of emergence across these groups of diseases demonstrates an important concept: that human environmental change may be the most significant driver of wildlife, domestic animal and human EIDs [Daszak 2001: 112].

Effects of species diversity on disease risk, Keesing, Holt & Ostfeld 2006

This review article describes the potential mechanisms by which biodiversity affects disease risk. The authors explore the mechanisms at play in simple systems with only host and pathogen, as well as in more complex systems that include a vector species and/or multiple hosts. The reduction of disease risk by increased diversity is called the “dilution effect.” The opposite, termed the “amplification effect,” is when disease risk increases. “Both models and literature reviews suggest that high host diversity is more likely to decrease than increase disease risk” [Keesing 2006: 485].

The mechanisms by which diversity affects disease risk are as follows:

Encounter reduction: An additional species (such as a predator) suppresses the movement of host species or vector species, thereby reducing contact between susceptible hosts and infected hosts or vectors. (Alternatively, if the presence of a different species causes host species to clump together more among their own kind, then transmission could increase in an *encounter augmentation*.)

Transmission reduction: An additional species in a system (such as a prey) reduces host stress, boosting immune system response and lowering pathogen load. An added species could also modify host behavior in a way that reduces the duration of their encounters and thus limits transmission.

Vector or susceptible host [population] regulation: The addition of any species that reduces birth rates or increases death rates, limiting overall population, among hosts susceptible to the pathogen or among pathogen vectors. Transmission rates may be reduced, for example, with the addition of host species predators or with the addition of species that attract vectors (ticks, for instance), but then groom themselves in a way that kills many vector individuals.

Infected host mortality: An added species outcompetes infected hosts for resources or targets infected hosts for predation.

Recovery augmentation: The addition of a prey species as an added resource for host species could, for example, increase full recovery rates of host species, creating a dilution effect, or, by contrast, increase the longevity of sick hosts in an amplification effect.

When there are many hosts for a particular pathogen, some species transmit the disease more readily than others. Often, the species that most effectively spread the disease (the most competent reservoirs) are present in species-poor, degraded ecosystems, meaning that any additional host species is likely to dilute the presences of the more contagious species.

> One key question in multi-host disease systems is whether the most competent reservoir is present in species-poor communities. If so, species added to these communities have, by definition, lower (if any) reservoir competence and thus have the potential to decrease disease risk. If the most competent reservoir is not present in species-poor communities, by contrast, then an increase in diversity could include the addition of the most competent reservoir itself, which is likely to result in an amplification of disease risk. Ostfeld & Keesing (2000b) considered evidence that the most competent reservoir for a variety of vector-borne zoonoses was typically present in species-poor communities [Keesing 2006: 495].

Biodiversity loss and the rise of zoonotic pathogens, Ostfeld 2009

West Nile Virus is an infectious disease that arrived in New York City in 1999, and subsequently spread across the country to the west coast. It is transmitted to humans from passerine (perching) birds via mosquito vectors. This study tested the dilution effect hypothesis, which posits that greater diversity (of birds in this case) reduces the concentration of species that are the primary disease reservoirs (American robin, American crow, blue jay, western scrub jay, common grackle, house finch, and house sparrow), thus reducing vector contact with infected individuals, and ultimately transmission to humans. The study analyzed the incidence of human infection during 2003-2004, and found that biodiversity was indeed associated with reduced WNV infection rates among humans.

> For all 3 years, the county-level human incidence of WNV disease was strongly, and significantly, negatively correlated with bird diversity within that county [Ostfeld 2009: 41].

Similar results are reported for studies of the dilution effect of biodiversity on Lyme disease risk. Furthermore, having collected data on the competence of various mammalian hosts to infect ticks with Lyme disease, as well as each host species' average tick burden, the authors state that "we can project the number of ticks that will feed on them and the proportion of those ticks that will become infected" [Ostfeld 2009: 42].

> We conclude from these studies that high vertebrate diversity is negatively correlated with human risk of exposure to Lyme disease. Furthermore, knowledge of the species composition of these communities, beyond simple measures of species richness or evenness, strongly enhances our ability to predict risk [Ostfeld 2009: 42].

In summary,

> Evidence for a protective dilution effect of high diversity has been obtained for numerous infectious diseases of humans, wildlife, and plants. The weight of evidence suggests that protection against exposure to infectious diseases should be added to the list of utilitarian functions of biodiversity [Ostfeld 2009: 42].

"Evidence for a protective dilution effect of high diversity has been obtained for numerous infectious diseases of humans, wildlife, and plants. The weight of evidence suggests that protection against exposure to infectious diseases should be added to the list of utilitarian functions of biodiversity [Ostfeld 2009: 42].

Impacts of biodiversity on the emergence and transmission of infectious diseases, Keesing et al. 2010

This paper contextualizes reduced transmission of infectious disease as one of the many ecosystem services provided by biodiversity. Changes in biodiversity affect infectious disease transmission by changing the abundance of the host and/or vector; the loss of non-host species may increase the density of host species, increasing the encounter rates between pathogen and host.

Often, the species that remain when biodiversity is lost are those which are better pathogen hosts, while the lost species tend to be more resistant to infectious disease.

> In several case studies, the species most likely to be lost from ecological communities as diversity declines are those most likely to reduce pathogen transmission [Keesing 2010: 648].

For example, the white-footed mouse, which are high-quality hosts both for the bacteria causing Lyme Disease and for the tick vectors, are abundant in both biodiverse systems and impoverished systems, while opossums, a poorer host for the Lyme bacterium that also kill/eat most ticks attempting to feed on them, do poorly in lower-biodiversity conditions.

> Therefore, as biodiversity is lost, the host with a strong buffering effect - the opossum - disappears, while the host with a strong amplifying effect - the mouse - remains [Keesing 2010: 650].

There may be a causal link between a species' susceptibility to biodiversity loss and its quality as a disease host. Among vertebrates,

> resilience in the face of disturbances that cause biodiversity loss, such as habitat destruction and fragmentation, is facilitated by life history features such as high reproductive output and intrinsic rates of increase. Vertebrates with these features tend to invest minimally in some aspects of adaptive immunity; we hypothesize that this may make them more competent hosts for pathogens and vectors [Keesing 2010: 650].

Biodiversity also affects the emergence of infectious disease, such as the evolution of a new strain of pathogen in the same host (due to antibiotic resistance, for example), and the spillover to a new host species. Pathogen establishment in humans from other animal hosts is related to mammal species richness (a larger source pool), and land-use change (such as deforestation), which increases contact between humans and pathogen hosts. The pathogen then becomes an epidemic due to the new host species' density (domesticated animals and humans).

The authors recommend preserving biodiversity by protecting natural habitat, while also preserving microbial diversity within organisms by limiting the use of antimicrobial agents. A diverse microbiome within an organism serves as a buffer against pathogens.

Biodiversity inhibits parasites: Broad evidence for the dilution effect, Civitello et al. 2015

> Human activities are dramatically reducing biodiversity, and the frequency and severity of infectious disease outbreaks in human, wildlife, and domesticated species are increasing. These concurrent patterns have prompted suggestions that biodiversity and the spread of diseases may be causally linked. For example, the dilution effect hypothesis proposes that diverse host communities inhibit the abundance of parasites through several mechanisms, such as regulating populations of susceptible hosts or interfering with the transmission process. Thus, diverse communities may inhibit the proliferation of parasites, thereby promoting the stability of ecological communities and ecosystem services (e.g., nutrient cycling, carbon sequestration, and natural product production) [Civitello 2015: 8667].

This meta-analysis concludes that as a general rule across ecosystems, biodiversity inhibits parasitism. Previous studies had focused on particular host-parasite systems, and found that greater host diversity dilutes, or limits, the spread of disease. "Consequently, anthropogenic declines in biodiversity could increase human and wildlife diseases and decrease crop and forest production" [Civitello 2015: 8667].

Where the Wild Things Aren't: Loss of Biodiversity, Emerging Infectious Diseases, and Implications for Diagnosticians, Granter 2016

This status-quo-challenging editorial is written for the American Society of Clinical Pathology, a group seemingly unrelated to the Bio4Climate community. The authors suggest that medical training in pathology over-emphasizes oncology at the expense of an adequate coverage of infectious disease, even though "between 1940 and 2004, a total of 335 human infectious diseases 'emerged,' and 60% of these were zoonotic" [Granter 2016: 645]. Having explained biodiversity loss as a factor driving disease rates, the authors make a plea for diagnosticians to become aware of the human health implications of environmental destruction.

> Knowledge and prowess with infectious diseases for diagnosticians must be incorporated back into training with a reimagined lens crafted from the information we have gained by studying our environment, its destruction, and the ultimate resulting human infections. As loss of habitat, habitat fragmentation, and consequent biodiversity loss continue unabated, tools and skills will need to be in the hands of all diagnosticians if we hope to minimize the effect of these infections as they continually emerge [Granter 2016: 645].

This paper provides a particularly clear explanation of how biodiversity loss increases human infection risk.

> The relationship between loss of biodiversity and human disease was first illustrated by Lyme disease. Its cause, the *Borrelia burgdorferi* bacterium, has the opportunity to encounter numerous vertebrate hosts - in one study estimated to be at least 125 species - in a diverse and healthy ecosystem. The potential hosts vary tremendously in their ability to harbor and transmit the bacteria, that is, their “reservoir competence.” Studies estimate the white-footed mouse infects more than 90% of ticks that complete their blood meal. While a few other hosts, such as eastern chipmunks and short-tailed shrews, are moderately competent, most tick hosts are marginally competent or dead-end hosts that are highly unlikely to transmit the infection. Since the white-footed mouse tends to thrive in impoverished ecosystems lacking biodiversity, infected ticks and, consequently, risk of human infection show a strong negative relationship with biodiversity. Because a diverse ecosystem with a range of vertebrate hosts - including many incompetent and dead-end hosts - “dilutes” the representation of the white-footed mouse and reduces human infection risk, this phenomenon has been termed the dilution effect [Granter 2016: 644].

“Because a diverse ecosystem with a range of vertebrate hosts - including many incompetent and dead-end hosts - “dilutes” the representation of the white-footed mouse and reduces human infection risk, this phenomenon has been termed the dilution effect” [Granter 2016: 644].

Conservation of biodiversity as a strategy for improving human health and wellbeing, Kilpatrick et al. 2017

This article very pragmatically addresses the question of whether biodiversity conservation could be an effective public health tool against infectious disease emergence and transmission.

Determining whether biodiversity conservation is an effective public health strategy requires answering four questions: (1) Is there a general, causal relationship between host biodiversity and disease risk? (2) If the link is causal and negative for most pathogens, does the increased diversity of pathogens with more diverse host communities result in net total increase or decrease in infectious disease burden? (3) Is the net benefit of biodiversity conservation greater than the net benefit of diversity-degrading processes (agricultural land-use change and wild animal harvesting)? (4) Are conservation interventions feasible and cost-effective compared to standard public health approaches (vaccines and treatments)?

Regarding the first question, experimental and observational research shows that increased biodiversity is associated with reduced disease burden.

> Overall, the available data suggests that there is some correlational support in many zoonotic systems for a dilution effect, and that some species or species groups are more important than others in transmission [Kilpatrick 2017: 4].

The dilution effect hypothesis originated to explain the Lyme disease system. Greater numbers of hosts that are less "competent" (at spreading Lyme disease) – opossums, birds, raccoons and skunks – dilutes the transmission of Lyme bacteria to larval ticks by more competent hosts – white-footed mice, eastern chipmunks and shrews. Changes in community diversity affect, for example, host-vector encounter rates and host and vector abundances.

However,

> much more research is needed to show that observed correlations are causal and to identify the mechanisms by which diversity is influencing disease risk [Kilpatrick 2017: 4].

The possibility of confounding factors in observational field studies is high because the same disturbances that change host diversity alters other aspects of transmission as well. For example, an ecosystem disturbance may, in addition to decreasing host diversity, also increase vector abundance, making it difficult to discern the proximate cause of increased disease rates. The authors note that the dilution effect may well *cause* decreased disease rates – more research is needed to determine this. But they caution that *if* the dilution effect turns out not to be the direct cause of decreased disease rates in any given pathogen system, then interventions to increase host diversity could be in vain with respect to that desired outcome.

Examples of potential conservation interventions to improve public health include preserving or restoring forest land, reintroducing top predators to control host populations, installing bat or owl boxes to increase predation of mosquitos (vectors) or rodents (hosts). Our still limited understanding of the mechanisms driving disease incidence patterns, however, make it difficult to predict outcomes for broad-scale land-use interventions, according to the authors. They argue instead that more targeted interventions aiming to reduce populations of key hosts in transmission may be more feasible public health tools than general land preservation. Even this, however, requires “deep understanding of both disease and population ecology.”

Further research to address this knowledge gap may be worth the investment, both for human wellbeing and for the planet. Exposure to nature has been shown to improve human mental and physical health and wellbeing, the authors note, regardless of biodiversity’s potential to reduce infectious disease. Furthermore,

> If diverse communities can be shown to provide net benefits to human wellbeing, this could provide a powerful motivation for preserving Earth’s remaining biodiversity [Kilpatrick 2017: 7].

The nexus between forest fragmentation in Africa and Ebola virus disease outbreaks, Rulli et al. 2017

Ebola virus disease outbreaks in West and Central Africa have been linked to spillover from potential disease reservoirs such as bats, apes, and duikers (an antelope-like animal). Spillover has been thought to be related to population density, vegetation cover, and human activities such as hunting, poaching, and bushmeat consumption. In this study, forest data from satellites coupled with disease outbreak records identify a nexus between forest fragmentation and Ebola.

The researchers identified 11 sites of the first human infection of Ebola from a wild species having occurred since 2004. Changes in forest cover between the year 2000 (baseline year) and the years of first infection for each of these outbreaks were determined using high-resolution satellite data on tree cover. All 11 centers of infection were found to be located in forested areas where the rate of forest fragmentation was greater than the regional average. Similarly, forest fragmentation decreased with increasing distance from the centers of infection.

> All 11 centers of infection were found to be located in forested areas where the rate of forest fragmentation was greater than the regional average.

> The centers of first infection … tend to occur in areas where on the outbreak year the average degree of forest fragmentation (e.g., within a 25 km, 50 km or 100 km distance from the infection center) was significantly higher than in the rest of the region [Rulli 2017: 2].

Furthermore, eight of the 11 centers of infection were located in fragmentation “hotspots,” meaning within a cluster of highly fragmented forest areas.

Bats are the commonly accepted host to filoviruses such as Ebola and tend to increase in population in fragmented habitats. The geographic distribution of potential bat hosts was consistent with the distribution of the zoonotic niche of Ebola. A decline in the population of insectivorous bats and an increase in the frugivorous (fruit-eating) bat species as a result of forest fragmentation was observed. Reshaping forest boundaries, habitat disruption, and biodiversity loss may enhance the likelihood of zoonotic infection by increasing the abundance of a particular species and thus the prevalence of that species’ pathogens.

> The fact that spillover tends to occur in hotspots of forest fragmentation rather than in clearcut areas suggests that chances of human interactions with host wildlife are higher in areas where human encroachment leaves forest fragments that provide habitat for reservoir species [Rulli 2017: 5].

Pressure on land and its products is increasingly pushing people into forested areas. Given the danger of zoonotic disease outbreak, any evaluation of the costs, risk, and benefits of forest loss and fragmentation should include global health considerations.

Habitat fragmentation, biodiversity loss and the risk of novel infectious disease emergence, Wilkinson 2018

Habitat loss reduces biodiversity, which leads to infectious disease emergence. The way a habitat is fragmented (how many patches it is divided into, how those patches are shaped, and what the distance is between them) further affects the extent of disease emergence. Both the number of divisions of habitat into smaller patches and the irregularity of patch shapes tend to increase habitat perimeter, which in turn increases contact between disease agents and humans.

The hazard is greatest in places with greater pre-existing biodiversity, where there is a greater diversity of microbial pathogens and associated hosts. There is a double risk of developing wilderness areas in these places because there are more pathogens to begin with, and the resulting biodiversity loss tends to amplify disease transmission.

> Human encroachment into species-rich habitats may simultaneously decrease biodiversity and increase exposure of people to novel microbes [Wilkinson 2018: 1].

Integration of wildlife and environmental health into a One Health approach, Sleeman et al. 2019

This article introduces the concept of One Health, a public health framework adopted by the Centers for Disease Control in 2009, which recognizes the interdependence of humans, animals and our shared environment. The concept has gained traction as a way to address health problems arising from global environmental change.

> Climate change, loss of biodiversity, habitat fragmentation and pollution, and subsequent degradation of natural environments threaten the range of ecosystem services that support all life on this planet [Sleeman 2019: 91].
>
> …
>
> It was the challenge of responding to these complex [environmental] problems that led to the emergence of the concept of One Health, which is defined by the Centers for Disease Control and Prevention (CDC) as the collaborative effort of multiple disciplines and sectors - working locally, nationally, regionally and globally - with the goal of achieving optimal health outcomes, recognizing the interconnection among people, animals, plants and our shared environment. This definition acknowledges that human, domestic animal and wildlife health are interconnected within the context of

> ecosystem/environmental health and provides a useful conceptual framework for the development of solutions to global health and environmental challenges. Given this interconnection, it follows that actions aimed primarily at improving the health of one part of the human-animal-environmental triad may have unanticipated consequences for the system as a whole if the harms they may cause to the other components are not considered. However, previous authors have noted that, despite the acknowledged interdependencies, few public or livestock health interventions include a consideration of biodiversity conservation or ecosystem/environmental health. Instead, health-promoting interventions focus largely on single-sector outcomes and, thus, may miss the opportunity to concurrently optimize outcomes in the other two sectors [Sleeman 2019: 92].

The authors suggest that despite its potential, the One Health approach does not as yet fully integrate wildlife and environmental health, instead favoring human health. Yet failure to optimize the health of all three realms can lead to unexpected and outcomes, ironically increasing risk to humans in some cases. Therefore, the authors propose the clarification of One Health values and goals, and integration of a systems approach and a harm reduction perspective into the One Health framework.

> Systems biology provides methods to understand how interactions among [interrelated and interdependent] parts [livestock, humans and wildlife, for example] give rise to the function and behavior of that system [Sleeman 2019: 96].

> A harm reduction perspective recognizes that solutions to complex problems require a broad societal response and that elimination of risk is not feasible for most issues. Consequently, this perspective promotes collaborative, multisectoral approaches whereby reducing harm, despite uncertainty regarding the outcome, is valued over inaction spurred by a desire for a perfect solution [Sleeman 2019: 94].

Emerging human infectious diseases and the links to global food production, Rohr et al. 2019

Increasing agricultural production to feed >11 billion people by 2100 raises several challenges for effectively managing infectious disease. Of many factors examined in this article linking agricultural expansion to infectious disease, one is conversion of natural habitat to cropland or rangeland. Land conversion increases contact between wild animals, livestock and humans.

> As natural ecosystems are converted to crop land or range land, interactions among humans, and domesticated and wild animals, could increase. … These interactions are

> crucial because 77% of livestock pathogens are capable of infecting multiple host species, including wildlife and humans, and based on published estimates from the 2000s, over half of all recognized human pathogens are currently or originally zoonotic, as are 60–76% of recent emerging infectious disease events [Rohr 2019: 451].

> "As natural ecosystems are converted to crop land or range land, interactions among humans, and domesticated and wild animals, could increase" [Rohr 2019: 451].

Land conversion pushes humans and livestock up against wilderness areas, increasing contact between species with previously little to no contact. The jumping of a pathogen to a new host species is called "spillover."

> Spillover appears to be a function of the frequency, duration and intimacy of interactions between a reservoir and novel host population. For example, influenza is believed to have jumped from horses to humans soon after domesticating horses and then made additional jumps to humans from other domesticated animals, such as poultry and swine [Rohr 2019: 451].

Furthermore, agricultural intensification tends to involve greater concentrations of a single variety of a single species, increasing the risk that any new disease will spread quickly in the population.

> A central tenet of epidemiology is that the incidence of many infectious diseases should increase proportionally with host density because of increased contact rates and thus transmission among hosts. Hence, increasing human and livestock densities could cause increases in infectious diseases unless investments in disease prevention are sufficient to prevent these increases [Rohr 2019: 451].

Industrial-scale confined livestock production is

> vulnerable to devastating losses of animals to disease. For instance, in just the last 25 years, an influenza A virus (H5N1) and a foot-and-mouth outbreak led to the destruction of more than 1.2 million chickens and 6 million livestock in China and Great Britain, respectively, and a 'mad cow disease' epizootic led to the slaughter of 11 million cattle worldwide [Rohr 2019: 449].

Increased agricultural production tends to be accompanied by new irrigation infrastructure and increased pesticide, fertilizer and antibiotic use, all of which increase infectious disease risk. Dams (often created for irrigation schemes) increase risk of mosquito-borne disease. Antibiotic overuse for livestock fosters resistance among pathogens that can also infect humans. Greater pesticide use leads to resistance among disease vectors such as mosquitoes to insecticides, while also weakening immune systems among exposed humans and wildlife hosts, increasing infection rates/severity. Nutrient enrichment caused by fertilizer can also contribute to the spread of infectious disease, for example, through mosquitos or snail vectors.

Finally, the urbanization and globalization associated with agricultural intensification/expansion elongates food supply chains, which increases movement of people and goods over borders, spreading food-born illness, flu and other infections.

In short,

> These analyses revealed that agricultural drivers were associated with 25% of all diseases and nearly 50% of zoonotic diseases that emerged in humans since 1940. These values are even higher if we include the use of antimicrobial agents as an agricultural driver of human disease emergence, given that agricultural uses of antibiotics outpace medical uses in the developed world nearly nine to one [Rohr 2019: 451].

The authors recommend numerous measures for improving agricultural production while limiting infectious disease, including reducing antibiotic use for livestock, conserving biodiversity, improving and diversifying livestock and crop genetic material, investing in urban agriculture, social investments, and inter-disciplinary research and collaboration.

Approaches to ecosystem restoration

The UN’s Decade of Ecosystem Restoration declaration aims to “prevent, halt and reverse the degradation of ecosystems worldwide,” stating that “there has never been a more urgent need to restore damaged ecosystems than now” [UNEP/FAO Factsheet 2020].

Estimates of global land degradation range from 25% to 75% of Earth’s land surface. The uncertainty is due to different ideas about what counts as degraded land and different methodologies for quantifying it (expert opinion, satellite data, or modeling, for example).

Generally, degradation is defined as “a reduction in productivity of the land or soil due to human activity” [Gibbs & Salmon 2015: 13].

Another global assessment [IPBES 2019] states that 75% of the land surface “is significantly altered, 66 percent of the ocean area is experiencing increasing cumulative impacts, and over 85 percent of wetlands (area) has been lost” [IPBES 2019: 11]. Meanwhile, wilderness remains on just 23% of Earth’s land surface [Watson 2016]. Wilderness areas are defined as

> biologically and ecologically largely intact landscapes that are mostly free of human disturbance. These areas do not exclude people, as many are in fact critical to certain communities, including indigenous peoples. Rather, they have lower levels of impacts from the kinds of human uses that result in significant biophysical disturbance to natural habitats, such as large-scale land conversion, industrial activity, or infrastructure development [Watson 2016: 1].

Degraded lands have reduced ecosystem function, upon which humans and other beings depend for clean water and air, shelter, food, and habitable local and global climate systems. In fact, half of Earth’s surface (including ocean and land) should be maintained or restored to intact ecosystems, in addition to cutting fossil fuel emissions, for any chance of keeping global warming from surpassing 1.5C above pre-industrial levels and averting catastrophic climate change [Dinerstein 2019].

This means existing wilderness needs to be protected and degraded lands regenerated. Currently less than 15% of land surface is formally protected and 2% of oceans [Dinerstein 2019]. Furthermore, intact ecosystems need to be connected by wildlife corridors to allow for migration and dispersal of diverse species. Quantifying a few of the direct human benefits from large-scale restoration, the UN estimates that:

> Restoration of 350 million hectares of degraded land between now and 2030 could generate USD 9 trillion in ecosystem services and take an additional 13-26 gigatons of greenhouse gases out of the atmosphere [UNEP 2019].

So how does ecosystem restoration happen? There are critical social, political and cultural responses to this question that are beyond the scope of this review – except to stress that all hands are needed on deck. As the UN says:

> This incredible challenge can only be met if everyone - including member states, local governments, partners from the private sector, academia and civil society - come together to find viable, lasting solutions [UNEP/FAO Factsheet 2020: 1].

Here we present a handful of the solutions as discussed in a growing body of ecological restoration literature, such as the articles summarized in the following section. There are two overarching approaches – active versus passive restoration. The latter aims simply to remove the anthropogenic disturbance causing the degradation and allow abandoned or no-longer-disturbed land to regenerate on its own. Sometimes simple removal of the disturbance (such as a dam) involves plenty of human energy, and may not seem passive at all. By contrast, though, active restoration actively facilitates land regeneration. Activities may include installing hollow logs, wood piles or other habitat features; planting; dredging; prescribed burning; reintroducing key species; or controlling invasive species, for example.

A somewhat intermediate approach of planting “tree islands” to restore tropical forests is another option [Holl 2020]. Instead of planting rows of trees throughout a given plot, clusters of trees are planted on just a fraction of the area, costing just a fraction of the price of a plantation-style restoration effort. Tree islands simulate the patchiness of natural forest recovery, while speeding up the process, and rely on animals to disperse tree seeds. In a study in Costa Rica of the tree island restoration method, cover of trees and shrubs had increased from 20% to over 90% over 15 years [Holl 2020].

Deciding which approach is best may depend on the situation – the degree of degradation needing to be reversed or the proximity of adjacent ecosystems as a seed source to kickstart colonization. Funding may also be a factor as active restoration projects typically cost more than do passive ones. Interestingly, in spite of being less expensive and often less work, passive regeneration projects are comparable to or more effective than active restoration in terms of achieving outcomes, according to two meta-studies [Jones 2018, Crouzeilles 2017]. Desired outcomes for restoration projects relate to measures of biodiversity, density and height of vegetation, amount of biomass produced, and speed of recovery, for example.

> Letting ecosystems repair themselves in many cases may be the most effective restoration strategy - a counterintuitive yet critical finding that could help society allocate restoration funds more efficiently in the future [Jones 2018: 6].

The most effective strategy for a given situation is not always taken, and projects sometimes fail or only partially succeed. One reason for underperformance is simply that ecosystems are complex and restoring them requires “significant time, resources, and knowledge,” which may not always be available [Gann 2019: 14]. Necessary follow up after activities are completed may never happen, such as when trees are planted and then abandoned in the first few critical years of establishment. Another potential roadblock to ecological recovery is competing goals for a project, which may be skewed toward economic concerns.

For instance, the Bonn Challenge to restore 330 million hectares of deforested and degraded land by 2030 has been criticized for counting monoculture timber plantations in progress toward reforestation goals [Lewis & Wheeler 2019]. Such woodlots offer little in the way of wildlife habitat and store an estimated 40 times less carbon than do natural forests [Lewis &

Wheeler 2019]. Part of the problem of allowing such practices to count as restoration lies in the definition of “forest” used in setting goals and making policy; definitions may lack consideration of biodiversity or other essential elements of natural forests. The UN Food and Agriculture Organization’s definition in use today was originally created to facilitate timber inventories [Chazdon 2016].

Early afforestation efforts in arid and semi-arid northern China reveals how restoration can go wrong when natural ecosystem characteristics are ignored [Cao 2008]. Much of the area, whose natural state is grasslands, had become desertified by the middle of the 20th Century due to agriculture, overgrazing and monoculture timber plantations. Large-scale afforestation began in 1978, when modern restoration science was not yet well established. Plantings involved fast-growing water-use inefficient tree species not well adapted to arid environments, which only exacerbated dry conditions, rather than native grassland shrubs.

> The natural vegetation of much of the region was desert steppe vegetation or dryland shrub communities, which have a much higher water-use efficiency than most tree communities and which have evolved to use soil water sustainably under these environmental conditions [Cao 2008: 1828].

In his analysis of the project, Shixiong Cao [2008] recommends a change of practice.

> In terms of revegetation strategies, planners must understand that different environments will support different vegetation communities and that forests are not a suitable choice in all areas. To successfully revegetate an area, planners must determine which vegetation types a given environment can naturally sustain and target restoration activities at creating such communities. For example, stable communities of natural desert steppe and grassland vegetation, and possibly even lichen species in more severely degraded environments, can develop in arid and semiarid areas as a result of natural processes, thereby increasing vegetation cover beyond the levels that could be sustained for trees, and can thereby provide better protection for the soil [Cao 2008: 1830].

The concept of rewilding, which entered ecological restoration discourse a couple of decades ago, has sparked confusion and controversy due to its multiple definitions [Hayward 2019]. However, the concept has also perhaps served to reinforce ecological principles within the larger restoration movement. Rewilding is an approach to restoring ecosystems that “aims to restore self-sustaining and complex ecosystems with interlinked ecological processes that promote and support one another while minimizing or gradually reducing human interventions” [Perino 2019: 1].

For example, rewilding has often focused on the roles of top predators in ecosystem processes, and proposed their reintroduction as a key tactic. The addition of large animals to a system enhances trophic complexity and dispersal. Along with natural disturbances (like natural fires), these are key ecosystem processes rewilding aims to activate.

> Rewilding aims to restore these three ecological processes [trophic complexity, dispersal and natural disturbances] to foster complex and self-organizing ecosystems that require minimum human management in the long term [Perino 2019: 2].

Establishing ecological corridors that connect larger intact ecosystems can facilitate migration and dispersal of plants and animals to colonize new areas. The value of ecological corridors highlights the role of small-scale, local restoration and conservation projects in rebuilding landscape-level ecological integrity. Protecting and expanding hedges, river systems and roadsides contributes to the success of the larger wilderness areas they connect. Similarly, even small woodlots in agricultural landscapes can have unexpectedly high ecosystem functionality [Valdes 2019]. The relevance of small projects to overall ecological wellbeing means that almost anybody anywhere has a role to play.

Lastly, the importance of conserving existing ecosystems cannot be overstated, and restoration projects should never serve to justify destruction elsewhere - mature intact ecosystems are irreplaceable. Rather, ecosystem restoration should be viewed as a strategy that “seeks to advance conservation by rebuilding nature” [Young & Schwartz 2019: 1]. Many restoration projects achieve only partial recovery during relevant time periods, meaning they may not ever become as fully functional as mature intact ecosystems during our lifetimes [Jones 2018]. Existing mature forests and other ecosystems are major carbon sinks in terms of the large amount of carbon they contain and in terms of the superior sequestration rates of older larger trees [Moomaw 2019]. Intact forests are also home to about two thirds of all species on Earth [Dinerstein 2019].

Both conservation and restoration are essential – they are an inseparable two-part solution to a dire global ecological crisis.

Lastly, the importance of conserving existing ecosystems cannot be overstated, and restoration projects should never serve to justify destruction elsewhere - mature intact ecosystems are irreplaceable. Rather, ecosystem restoration should

be viewed as a strategy that “seeks to advance conservation by rebuilding nature” [Young & Schwartz 2019: 1].

Approaches to ecosystem restoration article summaries

Ecological restoration success is higher for natural regeneration than for active restoration in tropical forests, Crouzeilles et al. 2017

This meta-analysis comparing active restoration to natural ecosystem regeneration found the latter to be more effective. The authors conclude that “lower-cost natural regeneration surpasses active restoration in achieving tropical forest restoration success for biodiversity and vegetation structure[7]” [Crouzeilles 2017: 4]. This conclusion runs counter to conventional wisdom that active restoration is preferable despite being more expensive.

> Natural forest regeneration is the spontaneous recovery of native tree species that colonize and establish in abandoned fields or natural disturbances; this process can also be assisted through human interventions such as fencing to control livestock grazing, weed control, and fire protection. In contrast, active restoration requires planting of nursery-grown seedlings, direct seeding, and/or the manipulation of disturbance regimes (for example, thinning and burning) to speed up the recovery process, often at a high cost to establish structural features of the vegetation (hereafter termed vegetation structure), reassemble local species composition, and/or catalyze ecological succession [Crouzeilles 2017: 1].

However, “restoration success for biodiversity and vegetation structure was significantly lower in both natural regeneration and active restoration than in reference systems” [Crouzeilles 2017: 2], underscoring the importance of conserving existing intact ecosystems.

[7] Vegetation structure was determined by measuring the number of individuals per unit area, the amount of leaf litter, the area covered by vegetation (measured in three forest strata - floor, understory, and canopy), the amount of below- and above-ground biomass produced, and the aboveground height of vegetation [Crouzeilles 2017: 4].

“Restoration success for biodiversity and vegetation structure was significantly lower in both natural regeneration and active restoration than in reference systems” [Crouzeilles 2017: 2], underscoring the importance of conserving existing intact ecosystems.

Part of the explanation for the lower success of active restoration compared to natural regeneration is that the composition and/or diversity of species chosen for planting in active restoration may be inappropriate, while the species that colonize abandoned land are likely to be diverse and locally adapted.

> Natural regeneration is initiated through the colonization of opportunistic and locally adapted species, resulting in a stochastic dynamic process of forest restoration that ultimately leads to higher diversity of native, locally adapted plant species than in tree planting schemes (that is, active restoration). Active restoration also can create a highly diverse habitat through human introduction of up to 6000 seedlings/ha, but tree species used in plantings often lack the full range of functional traits found in natural regrowth forests. In addition, most tropical forest plantings for restoration or forest plantations use relatively few species, that is, these plantations may not be planted primarily for biodiversity outcomes. Thus, the higher plant biodiversity in naturally regenerated systems creates more habitats and resources, which provide additional sources of food, shelter, nesting, and breeding sites, to support higher animal biodiversity [Crouzeilles 2017: 2].

Restoration and repair of Earth’s damaged ecosystems, Jones et al. 2018

This meta-analysis of 400 studies compared passive and active ecosystem repair outcomes in terms of the speed and completeness of recovery, and found little difference between the two approaches.

> Active restoration did not result in faster or more complete recovery than simply ending the disturbances ecosystems face [Jones 2018: 1].

Passive recovery simply means ending the anthropogenic disturbance that was causing the degradation, while active restoration here includes anything from fertilizer application to recontouring/dredging to planting a desired species mix.

The authors speculate that the lack of different outcomes between the two approaches could be due to restoration managers correctly choosing to actively restore the ecosystems that “are not recovering on their own and require active restoration to improve recovery outcomes relative to passively recovering systems” [Jones 2018: 6]. Also, the actively managed sites in the study had, on average, less time to recover than the passively managed sites. Finally, the authors suggest there may be right and wrong ways to actively restore ecosystems, and “recommend that restoration strategies be tailored more closely to overcome the specific barriers to recovery in individual sites” [Jones 2018: 6].

Assuming active and passive restoration achieve comparable outcomes in many cases, then passive restoration deserves serious consideration, given limited resources available for the vast amount of ecosystem repair required in the world today.

Letting ecosystems repair themselves in many cases may be the most effective restoration strategy - a counterintuitive yet critical finding that could help society allocate restoration funds more efficiently in the future [Jones 2018: 6].

The study also consistently found that across systems, ecosystems didn’t fully recover, at least not within the timeframe of the studies.

> Our results expand those findings to a broader range of ecosystems and geographies, and, together with previous work, suggest the majority of ecosystems have not yet recovered fully following disturbance and may not in the future. Thus, restoration should not be considered a substitute for conservation, which is a key strategy to ensure sustained support of biodiversity and delivery of ecosystem services in the future [Jones 2018: 4].

Rewilding complex ecosystems, Perino et al. 2019

> A growing body of literature emphasizes the need for novel, process-oriented approaches to restoring ecosystems in our rapidly changing world. Dynamic and process-oriented approaches focus on the adaptive capacity of ecosystems and the restoration of ecosystem processes promoting biodiversity, rather than aiming to

> maintain or restore particular ecosystem states characterized by predefined species compositions or particular bundles of ecosystem services [Perino 2019: 1].

In contrast to other types of restoration efforts aiming to recreate the composition and appearance of an historical ecological community, rewilding focuses on ecosystem function and recognizes the dynamic and unpredictable nature of ecosystems. This article highlights three key ecological processes that rewilding aims to activate: trophic complexity, natural disturbances and dispersal.

> Rewilding aims to restore these three ecological processes to foster complex and self-organizing ecosystems that require minimum human management in the long term [Perino 2019: 2].

Trophic complexity implies the presence of large vertebrates, including herbivores that modify the landscape through grazing or dam building and predators that control the herbivore populations. These keystone species can promote biodiversity in the landscapes they inhabit.

Stochastic (random) natural disturbance (such as fire or flooding) can increase ecosystem heterogeneity and complexity, allowing less competitive species to survive. Rewilding involves discontinuing both controlled anthropogenic disturbances and suppression of natural disturbances.

> Rewilding actions aim to release ecosystems from continued and controlled anthropogenic disturbances to allow for natural variability and sources of stochasticity. Mowing of grassland can be reduced or replaced by natural grazing. Dams can be removed or their management modified to restore natural flood regimes. Logging can be replaced by allowing natural fire and pest regimes [Perino 2019: 4].

Dispersal **–** rewilding aims to remove anthropogenic barriers that limit the movement of plants and animals and thus the dispersal of their genetic material and potential for recolonization after a disturbance event. The creation of ecological corridors is an example of a rewilding activity that enhances dispersal.

The interaction of these ecological processes boosts the functioning of each. For example, the presence of larger animals facilitates seed dispersal throughout the system. High levels of dispersal, in turn, can facilitate ecosystem recovery following a disturbance.

Rewilding projects can be passive (allowing abandoned agricultural fields to recover on their own) or active (species reintroductions, for example), and are most effective when conducted in a manner that engages the local community in the process.

Rewilding: a call for boosting ecological complexity in conservation, Fernández et al. 2017

Rewilding is gaining traction as an approach to conservation. However, many different perspectives about which species and ecological processes to focus rewilding efforts on and how deeply to intervene in systems has created some confusion and contention within the field. Furthermore, the most ambitious and extreme rewilding proposals (for example, recreating communities that went extinct millennia ago) have often attracted more attention, while the more pragmatic and immediate solutions in the field are overlooked.

This article attempts to clarify the concept. The authors emphasize that rewilding is a process-oriented approach to biodiversity conservation "focused on preserving and restoring the structural and functional complexity of degraded ecosystems" [Fernandez 2017: 276].

> Rewilding pursues the goal of restoring wild species interactions and their regulation of key ecosystem processes including nutrient and energy flows, vegetation succession and disturbances, drawing specific attention to the key roles of large-bodied species that are especially sensitive to the human appropriation of landscapes [Fernandez 2017: 277].

The authors suggest further research is needed. They note that while the negative effects on ecosystems of the loss of biodiversity and keystone species is well documented, ecosystem responses to species reintroduction and other rewilding efforts are not as well studied. To guide future research, the authors

> propose an unequivocally process-oriented formulation of the "rewilding hypothesis" as a general guidance: that the large-scale restoration of apex consumers and large herbivores promotes self-regulation in community assemblages, and increases the complexity of ecological processes in ecosystems [Fernandez 2016: 277].

Also needed is policy and management practice support, particularly in terms of protecting the areas and species in question. Proactive policies could ensure that gains made toward ecological restoration are not undermined by damaging human activity.

> Policies and practices should be developed in order to enforce the idea that rewilding is about reducing the human control on ecosystem processes. It must begin to include varied objectives to alleviate pressures on wildlife populations such as a full legal protection of large predators based on their unique ecological roles and not just depending on their conservation status; the eradication of predator control programs; or the elimination of game management practices such as wildlife fencing, introduction of alien game populations, supplementary feeding and others that profoundly alter the

> natural regulation and the genetic structure of large herbivore populations [Fernandez 2016: 278].

The differences between rewilding and restoring an ecologically degraded landscape, du Toit & Pettorelli 2019

This commentary distinguishes between restoration and rewilding of ecosystems, explaining that the latter aims at ecological adaptation to novel local environmental conditions wrought by global climate change. By contrast, restoration, as defined here, aims to recreate and maintain an historical state or condition of an ecosystem, regardless of current environmental conditions.

Although the two words are often conflated,

> Rewilding is thus conceptually different from restoring. It is an adaptive approach to conserving ecological functionality under changing environmental conditions, to which historical benchmarks are less relevant than to restoring. It inherently acknowledges and promotes unpredictability, while placing the emphasis on function over species composition [du Toit & Pettorelli 2019: 2].

The authors assert that rewilding is better suited to preserving biodiversity and ecosystem function under present and future conditions.

> It is difficult to imagine how conserving biodiversity and ecosystem services could be possible in predicted future scenarios without rewilding. Simply stated, anthropogenic environmental forcing makes ecosystem restoration a diminishing option [du Toit & Pettorelli 2019: 4].

Reintroducing rewilding to restoration – rejecting the search for novelty, Hayward et al. 2019

This perspective piece argues against scientific or public adoption of the term “rewilding,” which the authors view as being generally synonymous with the classical and better-understood concept of ecological restoration. Definitions of restoration are sufficient to encompass practices espoused in rewilding.

> Early definitions of restoration describe the practice as “the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems” (Jackson et al., 1995). Although at the time of this definition, restoration science was still developing, it was clear that it had established itself under the broad banner of repairing damaged ecosystems. … More recently, restoration has been defined as “any activity whose aim it is to ultimately achieve ecosystem recovery, insofar as possible and relative to an appropriate local native model (termed here a reference ecosystem), regardless of the period of time required to achieve the recovery outcome” (McDonald et al., 2016) [Hayward 2019: 257].

The term rewilding, which has evolved over time, “was arguably conceived to promote the original authors' view of conservation via cores [habitats], corridors, and carnivores” [Hayward 2019: 256]. In this early context,

> ‘rewilding’ referred to conservation and management interventions that focused on reintroducing keystone predators and ensuring that they had sufficient interconnected space to live. The authors emphasized within their original work that rewilding was “one essential element in most efforts to restore fully functioning ecosystems” (Soulé and Noss, 1998). As such, it is clear that rewilding was originally aimed to be a term that referred to one component of ecological restoration [Hayward 2019: 256].

Since then, rewilding has come to refer to practices involving “translocating substitute species to fill vacant ecological niches left by extinct species” [Hayward 2019: 257] or reintroducing locally extinct species, or simply allowing natural succession to occur on abandoned land. Given multiple definitions, all of which relate to the idea of restoration, the term rewilding is seen here as superfluous and confusing.

> Given the lack of clear differences between rewilding and restoration in both definition and practice, we see little need for these competing terms within scientific discourse [Hayward 2019: 257].

However, the authors suggest two positive contributions from the rewilding discourse. Because of its overall focus on large fauna, rewilding has captured public imagination and interest in conservation, while also helping to shift a potential vegetation bias among restoration practitioners/scientists toward equal emphasis on the ecosystem role of animals.

> Therefore, rather than adopting a new term with copious definitions that lack clarity, this debate can be used as an opportunity to adaptively improve current restoration practice by incorporating a more equal focus between flora and fauna [Hayward 2019: 258].

Because of its overall focus on large fauna, rewilding has captured public imagination and interest in conservation, while also helping to shift a potential vegetation bias among restoration practitioners/scientists toward equal emphasis on the ecosystem role of animals.

Intact forests in the United States: proforestation mitigates climate change and serves the greatest good, Moomaw 2019

The concept of “proforestation” presented here means letting existing forests continue to grow and reach their full ecological potential. Due to intensive management practices, most existing forests sequester carbon at only half (or less) of their potential rate. In addition to storing (embodying) more carbon than their smaller counterparts, large trees also sequester carbon at a faster rate. For example, “Each year a single tree that is 100 cm in diameter adds the equivalent biomass of an entire 10-20 cm diameter tree, further underscoring the role of large trees” [Moomaw 2019: 4]. Imagine, reader, that every year you planted a whole new medium-sized tree - that’s essentially what large trees are doing.

“Each year a single tree that is 100 cm in diameter adds the equivalent biomass of an entire 10-20 cm diameter tree, further underscoring the role of large trees” [Moomaw 2019: 4].

> Much of Maine’s forests have been harvested continuously for 200 years and have a carbon density less than one-third of the forests of Southern Vermont and New Hampshire, Northwestern Connecticut and Western Massachusetts - a region that has not been significantly harvested over the past 75-150 years. …
>
> Ecosystem services accrue as forests age for centuries. Far from plateauing in terms of carbon sequestration (or added wood) at a relatively young age as was long believed, older forests (e.g., >200 years of age without intervention) contain a variety of habitats, typically continue to sequester additional carbon for many decades or even

> centuries, and sequester significantly more carbon than younger and managed stands [Moomaw 2019: 5].

Because existing forests are already sequestering carbon, and will continue at an increasing rate as tree size grows, the author argues that proforestation is a more effective immediate solution than either reforestation (planting new trees where they had been cleared for agriculture, etc.) or afforestation (planting trees in new places), though these other two approaches are important for longer term ecosystem function. Moomaw et al. argue that the urgency of removing CO_2 makes it imperative to keep existing forests growing.

> Globally, existing forests only store approximately half of their potential due to past and present management, and many existing forests are capable of immediate and even more extensive growth for many decades. During the timeframe while seedlings planted for afforestation and reforestation are growing (yet will never achieve the carbon density of an intact forest), proforestation is a safe, highly effective, immediate natural solution that does not rely on uncertain discounted future benefits inherent in other options [Moomaw 2019: 7].

Furthermore, existing, older forests are critical habitats for threatened wildlife, even small intact woods.

> Forest bird guilds also benefit from small intact forests in urban landscapes relative to unprotected matrix forests. Several bird species in the U.S. that are globally threatened - including the wood thrush, cerulean warbler, marbled murrelet, and spotted owl are, in part, dependent on intact, older forests with large trees [Moomaw 2019: 5].
>
> In sum, proforestation provides the most effective solution to dual global crises - climate change and biodiversity loss. It is the only practical, rapid, economical, and effective means for atmospheric CDR [carbon dioxide removal] among the multiple options that have been proposed because it removes more atmospheric carbon dioxide in the immediate future and continues to sequester it long-term. Proforestation will increase the diversity of many groups of organisms and provide numerous additional and important ecosystem services. While multiple strategies will be needed to address global environmental crises, proforestation is a very low-cost option for increasing carbon sequestration that does not require additional land beyond what is already forested and provides new forest related jobs and opportunities along with a wide array of quantifiable ecosystem services, including human health [Moomaw 2019: 8].

Plant diversity enhances the reclamation of degraded lands by stimulating plant-soil feedbacks, Jia et al. 2020

This study tested biodiversity effects on ecosystem function in the process of reviving severely degraded and contaminated land, and found that "increasing plant diversity greatly enhanced the reclamation of these lands" [Jia 2020: 1].

> Prior to implementing the reclamation experiment, the degraded mine wasteland investigated in this study was heavily impacted by past mining activities and was devoid of vegetation for more than a decade and the soil lacked structure, contained high levels of toxic metals and low levels of nutrients. … our results showed that higher plant species richness enhanced land reclamation across all standard measures of reclamation success and specifically resulted in higher vegetation coverage, biomass yield and stability for all 3 years [of the experiment] [Jia 2020: 6].

Furthermore, higher biodiversity plots had higher levels of organic carbon in the soil, higher soil microorganism abundance, lower fungal pathogens, and lower heavy metal concentrations in plant tissue.

> The most striking impact of plant diversity on soil was on the microbial communities. Both soil fungal and bacterial OTUs [operational taxonomic units[8]] increased significantly with plant species richness. More importantly, we found that higher plant species richness significantly increased the relative abundance of soil cellulolytic bacteria that degrade cellulose and are thus essential components of nutrient cycling [Jia 2020: 7].

High ecosystem service delivery potential of small woodlands in agricultural landscapes, Valdes 2020

This article assesses the ecological value of small woodlands relative to larger ones. The authors conclude that:

> …smaller woodlands potentially deliver multiple services at higher performance levels on a per area basis than larger woodlands of a similar age, even if the larger woodlands harbor a higher biodiversity [Valdes 2020: 12].

[8] OTUs are a measurement of diversity.

Because of their high edge-to-core ratio, smaller woodlots get more sunlight and more nutrient input from surrounding farmland, resulting in denser vegetation cover and higher biomass production at edges.

> This altered functioning in turn increases the delivery potential of some services, such as game production potential, due to an increased quantity of food available for game, and topsoil carbon storage, due to the faster incorporation of organic matter in the soil. Tick-borne disease risk is, however, lower, likely due to decreased larval densities in the unfavorable (e.g. hotter and drier) microclimatic conditions at the edge [Valdes 2020: 12].

While smaller woodlands were more apt to deliver "multiple services at higher levels of performance per area than larger woodlands of a similar age," the greater biodiversity of larger woodlands increased certain individual ecosystem services.

> The supply potential of several individual ecosystem services indirectly increased in larger and more ancient woodlands because it was dependent on higher levels of biodiversity. For example, abundance of usable plants and game production potential might have increased due to a positive correlation with vascular plant diversity, while pest control potential probably increased due to bottom-up effects through the trophic chain. On the contrary, tick-borne disease risk, topsoil carbon storage and stemwood volume were unrelated to multidiversity, probably because they depended on particular environmental conditions or on the presence and abundance of specific species rather than on species richness per se.
>
> Finally, it should be noted that we focused on the service delivery potential on a per area basis and that the total amount of services provided by large patches might still be larger than that of small patches. Our findings should therefore not be interpreted as a trade-off between large, biodiverse patches versus small patches that have a higher potential to deliver services, but rather as an observation that small woodlands in agricultural landscapes have the potential to deliver a high flow of services relative to their size [Valdes 2020: 12].

Effectiveness of the Miyawaki method in Mediterranean forest restoration programs, Shirone, Salis & Vessela 2011

This study tested the Miyawaki method of rapid natural forest regeneration (which has been shown to work in Japan and elsewhere) in the arid Mediterranean. In this area, millennia of human civilization have resulted in degraded soils and reduced and changed forest cover, traditional reforestation efforts have often failed, and desertification is a looming threat. The Miyawaki method speeds up the process of ecological succession by densely planting a multilayer forest made up of a wide diversity of indigenous species.

> In a natural forest cycle, as Clements (1916) described, annual plants on barren land are succeeded by perennial grass, sun-tolerant shrubs, light-demanding, fast-growing trees, and finally natural forests; each step may require decades, and the climax vegetation could be formed after two centuries or more. Currently, most forest reforestation programs adopt a scheme of planting one or more early successional species; after successful establishment, they are gradually replaced by intermediate species (either naturally or by planting), until late successional species arise. This pattern tries to simulate natural processes of ecological succession, from pioneer species to climax vegetation. However, it requires several silvicultural practices and normally takes a long time [Shirone 2011: 82].

In the Miyawaki method, by contrast, one plants all at once the many plant species normally present in a native forest community, thus bypassing the earliest stages of ecological succession. Other tree-planting methods favor fast-growing non-native tree species, while omitting understory species – in other words, creating a simple plantation rather than a forest community that functions ecologically and can evolve and sustain itself.

> Multilayer forests, and natural biocoenosis [ecological community] is possible, and well-developed ecosystems can be quickly established because of the simultaneous use of intermediate and late successional species in plantations. The Miyawaki method involves surveying the potential natural vegetation of the area to be reforested and recovering topsoil to a depth of 20– 30 cm by mixing the soil and a compost from organic materials, such as fallen leaves, mowed grass, etc. In this way, the time of the natural process of soil evolution, established by the vegetational succession itself, is reduced [Shirone 2011: 82].

The authors of this study found that compared to traditional reforestation, there was “a more rapid development of trees on the Miyawaki plots, in particular, early-successional species [especially maritime pine]. The benefits over previous methods are remarkable and comparable with those obtained by Miyawaki in Asia and South America.” The Miyawaki method favoring denser plantings works even in arid climates, in spite of traditional views favoring sparse plantings in arid places, although the optimal density for the Mediterranean still needs testing, according to the authors.

> In fact, low plant density has been traditionally retained as appropriate in arid and semiarid environments in order to avoid competition for water resources between plants, but it is now evident that cooperative processes, e.g., mutual shading, prevail

> over competitive processes. High plant density also reduces the impact of acorn predators, thus encouraging oak regeneration, i.e., the main late-successional forest species in Mediterranean environments. In addition, excellent plant stock remains fundamental for planting success in harsh environments [Shirone 2011: 91].

When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration, Chazdon et al. 2016

This article analyzes the policy context for forest ecosystem restoration, arguing that it is heavily shaped by the way we define a forest. The use of a forest definition lacking ecological considerations severely undermines conservation and restoration initiatives.

> We live in an era of unprecedented environmental change, motivating equally unprecedented global actions to protect and restore forest ecosystems. These efforts could fail to achieve their ambitious goals if they are not informed by clear and appropriate concepts and definitions of forests [Chazdon 2016: 1].

There are multiple definitions of a forest. Early European and internationally adopted definitions tended to define forests according to their usage for timber. FAO's 1948 definition created for assessing wood harvesting potential of the world's forests is still in use today. Yet new definitions have since been created that emphasize conservation, carbon sequestration and biodiversity values of forests.

However, national and global forest assessments tend to use narrow technical definitions that ignore ecological values of forested land.

> In many cases, forest assessments do not distinguish between land covered by natural and planted forests. Thus, if natural forests are cleared and replaced with plantations, no net loss of forest cover is reported [Chazdon 2016: 6].

In other words, areas that should not be considered forest in ecological terms are counted as forest - an obfuscation with disastrous environmental outcomes. Similarly, ecologically important yet small patches of trees that are not counted in forest inventories and lack legal protection are at risk of being lost.

> Areas classified as ''non-forests'' are as important to forest definitions as are forests. More than 43 % of agricultural land globally is in agroforestry systems with 10 % tree cover. In Rwanda and Brazil, forest inventories using a 0.5-ha threshold ignore substantial areas of small forest fragments, agroforests, and woodlots, leading to

> underestimates of actual tree cover. Small patches of trees and even isolated remnant trees can hold high ecological and conservation value, and can play an important role in enhancing landscape connectivity, local biodiversity, and local livelihoods [Chazdon 2016: 7].

Information from participatory local monitoring and remote sensing technology that distinguishes "among successional stages of forests, selectively logged forests, and single-species plantations" [Chazdon 2016: 10] is needed.

> Access to this information will allow countries and international agencies to track changes in natural forest cover, and to monitor processes of restoration, rehabilitation, and afforestation within a landscape context and, consequently, make informed policy decisions. We are on the frontier of developing new ways of monitoring and assessing land cover that will provide robust indicators of the quality and origins of tree cover and enable new ways of viewing and defining forests and reforests. To see beyond the overly simplified categories of forest loss, forest degradation, and forest gain, we need to develop and apply more adapted and nuanced definitions that will deepen our understanding of the drivers and outcomes of land-use change and forest dynamics within landscapes [Chazdon 2016: 10].

Worthy miscellany article summary

Biodiversity increases multitrophic energy use efficiency, flow and storage in grasslands, Buzhdygan 2020

While several studies have shown that biodiversity within a trophic level (among plants, for example) increases ecosystem function (such as productivity), this study examines the effects of increased plant diversity on multi-trophic networks (encompassing plants, soil microorganisms, and above- and belowground invertebrates). The authors compared monoculture plots (with one plant species) to plots containing 60 plant species, and found that:

> higher plant diversity leads to more energy stored, greater energy flow and higher community-energy-use efficiency across the entire trophic network. These effects of biodiversity on energy dynamics were not restricted to only plants but were also expressed by other trophic groups and, to a similar degree, in aboveground and

> belowground parts of the ecosystem, even though plants are by far the dominating group in the system [Buzhdygan 2020: 1].

“More energy stored” means there is more standing biomass in the system, including plants, plant litter, microorganisms, insects and other invertebrates – in short, more life.

Compared to monoculture plots, high-diversity plots also had 50% greater energy flow, which implies “that the overall amount of resources consumed and recycled by the community increased with greater plant diversity” [Buzhdygan 2020: 2].

A community with “higher energy-use efficiency” has lower “maintenance costs,” referring to the amount of energy expended (through respiration) “to support the energetic demands of the living biomass stored in the system” [Buzhdygan 2020: 2]. In other words, organisms in an ecological community with high energy-use efficiency collectively work less hard to sustain themselves compared to, collectively, the organisms in a community with low energy-use efficiency. Biodiversity increases energy-use efficiency by increasing the quantity and variety of resources available to consumers.

> Plant communities with a high plant diversity are typically more productive than low-diversity communities and, therefore, provide a larger quantity and variety of resources to consumers. This increase in resource availability can reduce competition and increase energy flow to consumers. A larger variety of resources can also attract a higher number of specialized species, supporting trophic complementarity across the network and resulting in a reduction of community maintenance costs [Buzhdygan 2020: 4].

In this way, higher energy-use efficiency boosts ecosystem function.

> Higher energy use efficiency at high plant species richness may be an additional mechanism that contributes to the resilience of ecosystems because communities with low maintenance costs have a higher potential to compensate for energy loss during disturbance. … Moreover, lower community maintenance costs may imply a reduced ‘leakiness’ of ecosystems at high biodiversity. Indeed, evidence is mounting that high-biodiversity ecosystems lose less soil nitrogen, store more carbon in the soil and have more efficient soil microbial communities [Buzhdygan 2020: 7].

Inversely,

> the reduced community-energy-use efficiency and standing stock biomass in species-poor ecosystems indicates that more carbon is released into the atmosphere;

this implies potential feedback effects of the ongoing global biodiversity loss on carbon sequestration and climate change [Buzhdygan 2020: 8].

Blessed Unrest

In continuation of the "blessed unrest" section of previous issues of the Compendium, the following sketches illustrate how people everywhere are seeing that humanity depends on nature for both our physical and spiritual wellbeing and our survival. As this awareness takes hold, people act to protect and restore not only the land, but also our relationship to it. As the stories below show, growing food in an eco-friendly way does that. Adopting Paul Hawken's terminology and characterization of "blessed unrest" as a spontaneous, decentralized global social movement, we here present a diverse series of vignettes of everyday heroes. May such stories light the fire for new heroes to perpetually emerge in defense of all life on Earth.

The hopeful work of turning Appalachia's mountaintop coal mines into farms

https://www.yesmagazine.org/issue/just-transition/2017/10/12/the-hopeful-work-of-turning-appalachias-mountaintop-coal-mines-into-farms/

In Mingo County, West Virginia, the soil on a flat expanse of what had been a mountaintop is compacted, composed mainly of blasted rocks, and lacks organic matter, due to several years of coal mining. The ground is harder than anticipated; even the soil scientists say they are not sure how long it will take to bring the soil back to life. Besides, the ground does not retain water very well as it was engineered to drain water into the valley. Furthermore, there is the problem of aggressive invaders (autumn olive, multiflora rose, and tall fescue), making it difficult to penetrate the terrain.

As Ben Gilmer, president of Refresh Appalachia, which helps convert post-mine lands into agriculture and forestry enterprises, says, "it's a long-term science project." Refresh Appalachia provides job training and encourages farming systems that form a loop between the animals and plants, where one nourishes the other, cutting down on feed and fertilizer, providing food and land management, and helping ensure food sovereignty in an economically depressed region. Refresh farms raise poultry, goats, pigs, and honey bees, along with fruits, nuts, vegetables, and herbs.

Appalachia is a temperate region with heavy rainfall, not a barren moonscape. Each site being restored “just needs some care and management appropriate to their characteristics,” says Carl Zipper, Virginia Tech crop and soil science professor specializing in mine-land restoration.
The workers previously responsible for blowing up are now trying to put back together that which was blown up. Many are working on associate degrees in conjunction with job training in sustainable agriculture and related fields. “I’m living the dream,” Refresh member Wilburn Jude exclaimed. Former miner Chris Farley is excited to be part of the first group to attempt to farm these lands. Everyone was eager for the arrival of a mulcher to remove and chew the invasive shrubs into the wood chip. The clearing would then be planted with over 2,000 berry, pawpaw, and hazelnut seedlings.

In South Korea, centuries of farming point to the future for sustainable agriculture

https://news.mongabay.com/2020/05/in-south-korea-centuries-of-farming-point-to-the-future-for-sustainable-agriculture/?utm_source=Mongabay+Newsletter&utm_campaign=624a4d7680-Newsletter_2020_04_30_COPY_01&utm_medium=email&utm_term=0_940652e1f4-624a4d7680-77145713

In South Korea, knowledge of ancient farming techniques adapted to various harsh conditions, along with a sense of urgency about the need to adapt to even harsher conditions as the global climate system deteriorates, is bringing about the blossoming of an environmentally friendly agriculture movement.

Farmers draw on traditional knowledge of “nitrogen-fixing plants, soil bacteria, micro-organisms, and the relations between all of them to optimize yields by increasing soil fertility, boost crop health and biomass for livestock grazing, and reduce weed and pest infestations.” These practices are combined with intercropping (planting multiple crops together in a field) and crop rotation (constantly changing crops over time in a field) in a developing agricultural ethic that favors biodiversity and soil health.

Interestingly, the role of soil microorganisms is understood and valued in a way that intersects a fermentation-based food culture.

> Traditional Korean knowledge of soil nutrients and food fermentation techniques is also used by some farmers to create natural fertilizer and pesticide. This is done by

> culturing and proliferating indigenous microorganisms - fungi, bacteria and yeast - to enhance the soil's fertility without the need for livestock waste.

Such practices are supported both by national policy aiming to facilitate transition to organic and environmentally friendly methods, and by community-led organic farming movements. From participating in national climate strikes to demanding protections of native seeds to facilitating organic food commerce, consumer coops are doing their part to help make South Korea a global model for sustainable farming.

Similarly, both government and grassroots groups have established initiatives to recruit youth into agricultural careers.

> The South Korean Ministry of Agriculture, Food and Rural Affairs has set up a Back-to-Earth Promotion Project, Youth Farmer Fostering Policy, and the Farmland Banking Project, aiming to promote and fund startups and businesses in the agricultural sector and in farming villages. …
>
> Grassroots initiatives that are part of a similar movement can be seen in the Milmeori Farm School in Yeoju county and the Geumsan Gandhi School in Geumsan county. These are boarding school programs that bring youth from cities to experience the countryside, learn Korean organic farming, and cook plant-rich dishes from their harvests.

Gardening advice from indigenous food growers

https://www.yesmagazine.org/environment/2020/05/20/garden-advice-indigenous-food-growers/

Covid19 has been an additional stressor on many Native American communities already burdened by deprivations from centuries of ongoing injustice. According to Julie Garreau, project coordinator of Cheyenne River Youth Project, which operates a 2.5-acre youth garden in South Dakota, gardens are a source of both food and healing. "Gardens represent so much more," she said. "Food, yes, but a belief in our future. Gardens represent resiliency, strength, wellness, culture." During the pandemic, the Youth Project delivered garden produce and other foods to the homes of Cheyenne River Sioux Reservation children.

Another youth-focused gardening organization is Dream of Wild Health. Based in Minneapolis/St. Paul, MN, this Native-led organization operates a 30-acre biodiverse suburban farm that supplies food, learning experiences, and the chance to reconnect with nature. Kids learn cooking and seed saving, and student interns called Garden Warriors help grow food. Due to Covid19, workshops moved online, with the organization delivering ingredients to kids' homes and then leading them in an online cooking class.

"Working in a garden develops your relationship to the land," says Aubrey Skye, a Hunkpapa Lakota gardener who for many years ran a gardening program on Standing Rock Reservation on the border of North and South Dakota. "Our ancestors understood that. Look at the old pictures. It's etched on their faces. When you understand it as well, a sense of scarcity and insecurity transforms into a feeling of abundance and control—something we all need these days."

Some tips from the gardeners mentioned in this article:

1. Start small if you're a beginner (in a few pots or a raised bed).
2. Favor companion planting. ("Look at nature, and figure out combinations that mimic it," recommends Traditional Native American Farmers Association Director Clayton Brascoupé.)
3. Embellish your garden with colorful native flowers to attract and nourish pollinators.
4. Use rocks to keep crops cozy and supported; rocks act as heat sink and can protect seedlings from early frost.
5. Reuse discarded materials - you'll get for free while building a network in the collection process: mulch with used cardboard and paper; create drip irrigation from soda pop bottles pierced with a needle at the neck, fill with water then bury the neck in the soil close to the plant.
6. Make compacted soil soft and plant friendly using dandelions, a supposed weed with nutritional value, whose taproot breaks up hardened soil enabling earthworm activity.
7. Include healing herbs, especially native varieties.
8. Save the seeds of the plants that thrive best and are favorites, which not only enables future food supply, but also, as Aubrey Skye says, preserves history like little time capsules.

References

Buzhdygan, Oksana, Y., et al., 2020, Biodiversity increases multitrophic energy use efficiency, flow and storage in grasslands, Nature Ecology & Evolution 4, https://www.nature.com/articles/s41559-020-1123-8.

Cao, Shixiong, 2008, Why large-scale afforestation efforts in China have failed to solve the desertification problem, Environmental Science and Technology, https://pubs.acs.org/doi/pdf/10.1021/es0870597.

Chazdon, Robin L., et al., 2016, When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration, Ambio 45, https://link.springer.com/article/10.1007/s13280-016-0772-y.

Civitello, D., et al., 2015, Biodiversity inhibits parasites: broad evidence for the dilution effect, PNAS 112(28), https://www.pnas.org/content/112/28/8667.short.

Crouzeilles, Renato, et al., 2017, Ecological restoration success is higher for natural regeneration than for active restoration in tropical forests, Science Advances 3, https://advances.sciencemag.org/content/3/11/e1701345?intcmp=trendmd-adv.

Diaz, S., et al., 2019, Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, IPBES secretariat, Bonn, Germany, https://ipbes.net/news/global-assessment-summary-policymakers-final-version-now-available.

Dasgupta, Partha & Ingar Anderson, 2020, Coronavirus shows we must change our economy to recognise that human wealth depends on nature's health, Independent, Friday 5 June 2020, https://www.independent.co.uk/news/business/analysis-and-features/biodiversity-economy-coronavirus-covid-19-dasgupta-review-a9550156.html#gsc.tab=0.

Daszak, P., A.A. Cunningham & A.D. Hyatt, 2001, Anthropogenic environmental change and the emergence of infectious diseases in wildlife, Acta Tropica 78, https://www.sciencedirect.com/science/article/pii/S0001706X00001790.

Du Toit, Johan T. & Nathalie Pettoreli, 2019, The differences between rewilding and restoring an ecologically degraded landscape, Journal of Applied Ecology, https://besjournals.onlinelibrary.wiley.com/doi/abs/10.1111/1365-2664.13487.

Fernandez, Nestor, Laetitia M. Navarro & Henrique M. Pereira, 2017, Rewilding: a call for boosting ecological complexity in conservation, Conservation Letters 10(3), https://conbio.onlinelibrary.wiley.com/doi/full/10.1111/conl.12374.

Gibbs, H.K. & J.M. Salmon, 2015, Mapping the world's degraded lands, Applied Geography 57, https://www.sciencedirect.com/science/article/pii/S0143622814002793.

Granter, Scott R., Richard S. Ostfeld & Danny A. Milner, 2016, Where the wild things aren't: loss of biodiversity, emerging infectious diseases, and implications for diagnosticians, American Society for Clinical Pathology 146, https://academic.oup.com/ajcp/article/146/6/644/2632330.

Hayward, Matt W., et al., 2019, Reintroducing rewilding to restoration – rejecting the search for novelty, Biological Conservation 233, https://www.sciencedirect.com/science/article/abs/pii/S0006320719301351.

Holl, Karen D., et al., 2020, Applied nucleation facilitates tropical forest recovery: lessons learned from a 15-year study, Journal of Applied Ecology, https://besjournals.onlinelibrary.wiley.com/doi/epdf/10.1111/1365-2664.13684

Jabr, Ferris, 2020, How humanity unleashed a flood of new diseases, New York Times Magazine June 17, 2020, https://www.nytimes.com/2020/06/17/magazine/animal-disease-covid.html.

Jia, Pu, et al., 2020, Plant diversity enhances the reclamation of degraded lands by stimulating plant-soil feedbacks, Journal of Applied Ecology, https://besjournals.onlinelibrary.wiley.com/doi/abs/10.1111/1365-2664.13625.

Jones, Holly P., et al., 2018, Restoration and repair of Earth's damaged ecosystems, Proceedings Royal Society B 285, https://royalsocietypublishing.org/doi/suppl/10.1098/rspb.2017.2577.

Keesing, F., R.D. Holt & R.S. Ostfeld, 2006, Effects of species diversity on disease risk, Ecology Letters 9, https://onlinelibrary.wiley.com/doi/full/10.1111/j.1461-0248.2006.00885.x.

Keesing, F., et al., 2010, Impacts of biodiversity on the emergence and transmission of infectious diseases, Nature 468, https://www.nature.com/articles/nature09575/boxes/bx1.

Kilpatrick, A. Marm, et al., 2017, Conservation of biodiversity as a strategy for improving human health and well-being, Philosophical Transactions Royal Society B 372, https://royalsocietypublishing.org/doi/full/10.1098/rstb.2016.0131.

Moomaw, William R., Susan A. Masino & Edward K. Faison, 2019, Intact forests in the United States: proforestation mitigates climate change and serves the greatest good, Frontiers in Forests and Global Change 2(27), https://www.frontiersin.org/articles/10.3389/ffgc.2019.00027/full?te=1&nl=climate-fwd:&emc=edit_clim_20200328.

Ostfeld, R.S., 2009, Biodiversity loss and the rise of zoonotic pathogens, European Society of Clinical Microbiology and Infectious Diseases 15 (Suppl. 1), https://onlinelibrary.wiley.com/doi/full/10.1111/j.1469-0691.2008.02691.x.

Perino, Andrea, et al., 2019, Rewilding complex ecosystems, Science 364, https://science.sciencemag.org/content/364/6438/eaav5570.abstract.

Rohr, Jason R., et al., 2019, Emerging human infectious diseases and the links to global food production, Nature Sustainability 2, https://www.nature.com/articles/s41893-019-0293-3.

Rulli, Maria Cristina, et al., 2017, The nexus between forest fragmentation in Africa and Ebola virus disease outbreaks, Scientific Reports 7, https://www.nature.com/articles/srep41613.

Settele, Joseph, et al., 2020, COVID-19 stimulus measures must save lives, protect livelihoods, and safeguard nature to reduce the risk of future pandemics, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) guest article April 2020, https://ipbes.net/covid19stimulus.

Schirone, Bartolomeo, Antonello Salis & Federico Vessella, 2011, Effectiveness of the Miyawaki method in Mediterranean forest restoration programs, Landscape and Ecological Engineering 7, https://link.springer.com/article/10.1007/s11355-010-0117-0.

Gann, George D., et al., 2019, International principles and standards for the practice of ecological restoration, Second Edition: November 2019, Society for Ecological Restoration (SER), https://www.ser.org/page/SERStandards/International-Standards-for-the-Practice-of-Ecological-Restoration.htm.

Sleeman, J.M., et al., 2019, Integration of wildlife and environmental health into a One Health approach, Rev. Sci. Tech. Off. Int. Epiz. 38(1), https://pubmed.ncbi.nlm.nih.gov/31564738/.

UNEP 2019, New UN Decade on Ecosystem Restoration offers unparalleled opportunity for job creation, food security and addressing climate change, United Nations Environment Program, retrieved July 2020 at https://www.unenvironment.org/news-and-stories/press-release/new-un-decade-ecosystem-restoration-offers-unparalleled-opportunity.

UNEP/FAO Factsheet 2020, The UN Decade on Ecosystem Restoration 2021-2030, retrieved July 2020 at https://www.decadeonrestoration.org/.

Valdes, Alicia, et al., 2019, High ecosystem service delivery potential of small woodlands in agricultural landscapes, Journal of Applied Ecology 57, https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/1365-2664.13537.

Watson, James E.M., et al., 2016, Catastrophic declines in wilderness areas undermine global environmental targets, Current Biology 26, https://www.sciencedirect.com/science/article/pii/S0960982216309939.

Wilkinson, David A., et al., 2018, Habitat fragmentation, biodiversity loss and the risk of novel infectious disease emergence, J. Royal Society Interface 15, https://royalsocietypublishing.org/doi/full/10.1098/rsif.2018.0403.

Young, Truman P. & Mark W. Schwartz, 2019, The Decade on Ecosystem Restoration is an impetus to get it right, Conservation Science and Practice 1 (145), https://conbio.onlinelibrary.wiley.com/doi/full/10.1111/csp2.145.