REVIEW SUMMARY

CONSERVATION

Landscapes that work for biodiversity and people

C. Kremen* and A. M. Merenlender

BACKGROUND: Biodiversity is under siege, with greatly enhanced rates of local and global extinction and the decline of once-abundant species. Current rates of human-induced climate change and land use forecast the Anthropocene as one of the most devastating epochs for life on earth. How do we handle the Anthropocene's triple challenge of preventing biodiversity loss, mitigating and adapting to climate change, and sustainably providing resources for a growing human population? The answer is in how we manage Earth's "working lands"; that is, farms, forests, and rangelands. These lands must be managed both to complement the biodiversity conservation goals of protected areas and to maintain the diverse communities of organisms, from microbes to mammals, that contribute to producing food, materials, clean water, and healthy soils; sequestering greenhouse gases; and buffering extreme weather events, functions that are essential for all life on Earth.

ADVANCES: Protected areas are the cornerstone of biodiversity conservation. Although the total area of protected regions needs to be increased, parks will nonetheless continue to lose species if these areas are isolated from one another by inhospitable land uses and are faced with a rapidly changing climate. Further, many species, such as those that migrate, remain unprotected as they occupy lands outside of parks for all or portions of their life cycles. Lastly, protected-area effectiveness is greatly influenced by surrounding land management. "Working lands conservation" aims to support biodiversity while providing goods and services for humanity over the long term, assuring sustainability and resilience. By managing lands surrounding parks favorably, working lands can buffer protected areas from threats and connect them to one another. This approach complements protected areas by providing accessory habitats and resources for some species while facilitating dispersal and climate change adaptation for others. Further, by maintaining the biodiversity that supplies critical ecosystem services within working lands, these approaches ensure that the production of food, fiber, fuel, and timber can be sustained over the long run and be more resilient to extreme events, such as floods, droughts, hurricanes, and pest and disease outbreaks, which are becoming more frequent with climate change. A variety of biodiversity-based land management techniques can be used in working lands, including agroforestry, silvopasture, diversified farming, and ecosystem-based forest management, to ensure sustainable production of food and fiber.

OUTLOOK: The underlying principle of biodiversity-based management of working lands has been practiced since ancient times. Today, these systems have largely been replaced by unsustainable resource extraction, rather than serving as models that could be adapted to modern conditions. Although various regulatory, voluntary, and financial tools exist to promote sustainable land management, many barriers prevent individuals, communities, and corporations from adopting biodiversity-based practices, including deeply entrenched policy and market conditions that favor industrialized or extractive models of land use. Thus, uptake of these approaches has been patchy and slow and is not yet sufficient to create change at the temporal and spatial scales needed to face the triple Anthropocene threat.

Biodiversity-based land management practices are knowledge- rather than technology-intensive. They are well adapted to empower local communities to manage their natural resources. One of the most exciting emerging trends is community-driven initiatives to manage working landscapes for conservation and sustainability. By linking up through grassroots organizations, social movements, and public-private partnerships, these initiatives can scale up to create collective impact and can demand changes in government policies to facilitate the conservation of working lands. Scientists and conservation practitioners can support these initiatives by engaging with the public, listening to alternative ways of knowing, and cocreating landscapes that work for biodiversity and people. ■

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Strawberry production in Central Coast, California. On the left, a homogeneous landscape of strawberry monoculture, including organic fields, supports fewer wild species then a diversified, organic farm (right) in the same region, which includes a small field of strawberry, surrounded by orchards, hedgerows, diverse vegetable crops, and natural habitats. The monoculture landscape creates barriers to wildlife dispersal, whereas the diversified landscape is more permeable.

PHOTO: C. KREMEN

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How can we manage farmlands, forests, and rangelands to respond to the triple challenge of the Anthropocene—biodiversity loss, climate change, and unsustainable land use? When managed by using biodiversity-based techniques such as agroforestry, silvopasture, diversified farming, and ecosystem-based forest management, these socioeconomic systems can help maintain biodiversity and provide habitat connectivity, thereby complementing protected areas and providing greater resilience to climate change. Simultaneously, the use of these management techniques can improve yields and profitability more sustainably, enhancing livelihoods and food security. This approach to "working lands conservation" can create landscapes that work for nature and people. However, many socioeconomic challenges impede the uptake of biodiversity-based land management practices. Although improving voluntary incentives, market instruments, environmental regulations, and governance is essential to support working lands conservation, it is community action, social movements, and broad coalitions among citizens, businesses, nonprofits, and government agencies that have the power to transform how we manage land and protect the environment.

Biodiversity, the product of 3.8 billion years of evolution, is under siege. Not only are both marine and terrestrial species experiencing accelerated rates of local and global extinction (1–3), but even common species are declining (2, 4, 5). This alarming situation has prompted a strong call for increasing the number (6, 7) and effectiveness (8) of protected areas, the principal method for combatting species loss. Though such protections are essential, we cannot rely on protected areas alone to preserve species. As protected areas become increasingly isolated because of habitat loss and degradation, much research has revealed that they will lose species over time (9). Further, many critical threats to species do not respect protected-area boundaries (10), including climate change, which both exacerbates species losses (11) and threatens to alter the biomes of many currently protected regions entirely (12).

More hopefully, recent studies show that some human-dominated landscapes can support much more biodiversity than previously recognized (13–17), suggesting a complementary path forward. Specifically, when these areas, generally referred to as the "matrix," represent a high-quality mosaic of land uses, they can play a critical role in sustaining biodiversity, both in situ and by promoting species dispersal among protected areas and remnant habitats and along migratory routes (Fig. 1) (15, 18, 19). Of course, human survival also depends on the long-term capacity of this matrix of "working lands," including rangelands, forests, and farms, to produce food, water, fiber, fuel, and forest products. All too often, however, these goods are produced at severe environmental cost, including habitat degradation, toxic contamination, and depletion of water quantity and quality, leading to ecological collapse, local extinctions, and the creation of unproductive wastelands (20, 21). We argue that, instead, working lands can be used to support high levels of biodiversity while satisfying human needs in a sustainable way. Because rangelands, forests, and cultivated lands collectively occupy ~80% of terrestrial area (21), the potential for conservation in such lands is enormous.

Critical ecosystem functions and services are provided by a suite of diverse organisms, from microbes to mammals, and thus maintenance of these organisms is necessary for long-term and sustainable productivity of working lands (22, 23). Hence, managing the matrix to maintain biodiversity is not only necessary for species conservation but also essential for sustainable production. Biodiversity-based production systems, including agroecological farming or ecosystem-based forest management, are often perceived as unproductive, an incorrect viewpoint that impedes the public investment needed to develop and promote these methods. Here, we describe managing the matrix jointly and sustainably for biodiversity and people through "working lands conservation" and ask what strategies can be used to strengthen and scale up this approach as rapidly as possible to help combat the triple Anthropocene threats of biodiversity loss, climate change, and unsustainable land use.

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Working lands conservation defined

Although the term "working lands conservation" is already used in policy statements and in guidance for conservation programs [e.g., (24)], the concept has yet to be formally defined and risks being misapplied. We define it at the landscape scale (Box 1).

To avoid mass extinction and ecosystem collapse, we must integrate biodiversity conservation into the landscapes we use and not simply relegate nature to a limited number of protected areas that are doomed if left as isolated habitat islands within biological deserts. Working lands can provide food, breeding sites, and shelter for a myriad of species while maintaining abiotic conditions, including temperature, light, wind, water, fire, and other disturbance processes, within required ranges. They can facilitate functional connectivity—that is, the movement of organisms across the landscape and among habitat patches that promotes population persistence by allowing for gene flow, recolonization, and adaptation to climate and other global changes (25, 26).

To support humanity sustainably, a working landscape must be productive and maintain the ecosystem services, such as pollination, pest control, and nutrient cycling, that underlie that production. Maintaining these services requires supporting the underlying populations of service-providing organisms. Within each service, a greater diversity of service providers often enhances the level and/or quality of services and reduces uncertainty in service delivery (22), because different species respond differentially to environmental change (27, 28). Maintaining connectivity is also important, both to support flows of ecosystem service providers and/or materials (e.g., pollination requires animal vectors to move pollen between flowers; water purification requires water to flow through vegetation) (29) and to enhance metacommunity persistence of service-providing organisms to sustain ecosystem functions and services over space and time (22, 30).

Box 1. Definition of working lands conservation.

Definition: Conservation in working landscapes maintains biodiversity, provides goods and services for humanity, and supports the abiotic conditions necessary for sustainability and resilience.

These socioecological systems both support biodiversity by providing critical resources and rely on biodiversity (specifically, ecosystem service providers) for sustainable production of food, water, fiber, fuel, and forest products. These landscapes also enhance connectivity to promote the movement of organisms, natural processes, and ecosystem services.

Working lands conservation emphasizes the critical role of managing the matrix for species conservation to complement protected areas.

Fig. 1. Rebuilding connectivity in the matrix by using silvopasture. Photo of Finca La Luisa showing several types of silvopastoral systems, including regenerating secondary tropical dry forest trees with grass understory (yellow) and rows of planted *Eucalyptus* trees interspersed with nitrogen-fixing *Leucaena leucocephala* fodder shrubs and forage grasses (blue). These systems were established on former monoculture agricultural lands to restore compacted, degraded soils; the red area shows early stages of tropical dry forest regeneration prior to grass seeding for silvopasture. Silvopastures produce more cattle sustainably on less land, buffer ranchers from economic losses due to climate extremes, and create landscape connectivity to other forest fragments (orange) in the Cesar river valley, Colombia.

PHOTO: J. J. LOPERA/CIPAV; ADAPTED BY NIRJA DESAI/*SCIENCE*

Ensuring the sustainability of production requires balancing across provisioning, regulating, and supporting services; in other words, seeking multifunctionality and stability rather than maximal production. For example, conventional (chemically intensive) monoculture agriculture produces high yields but often at the expense of water quality, climate regulation, and soil health (Fig. 2A) (*20*) and can suffer production collapse in response to periodic extreme weather, pests, and diseases (*31*–*33*). Although transforming to a more sustainable system may reduce average yields somewhat [e.g., (*34*)], by relying on ecosystem services produced on the farm and in the surrounding landscape, a sustainable system is both multifunctional and more resilient to change (*20, 31*) (Fig. 2C).

Working landscapes often comprise heterogeneous patch types, including novel communities made up of mixtures of native and nonnative species, as well as remnants of natural or seminatural habitats whose composition is more similar to that of a historical ecological community (*35*). Although management goals likely will differ among patch types, both individual patches and the whole landscape should be managed for sustainability. For example, patches whose communities are far from historical could be managed principally for crops (a provisioning service) by using sustainable agricultural practices to minimize negative effects on biodiversity and ecosystem services on and off site. Remnant patches could be retained as stepping-stone habitats to support species dispersal and provide regulating services such as pollination (*29*, *31*). Maintaining mosaic landscapes composed of different patch types provides opportunities to maximize diversity, resilience, and multifunctionality. Radar diagrams reveal likely trade-offs and sustainability within and across patches (Fig. 2B), as well as multifunctionality at the landscape scale (Fig. 2C).

Conservation in working landscapes draws upon several related concepts. Integrated landscape management initiatives seek to simultaneously improve food production, biodiversity or ecosystem conservation, and rural livelihoods and are being implemented by governments and nongovernmental organizations in Latin America and Africa (*36*). The ecosystem stewardship concept focuses on the need to sustain Earth's capacity to provide ecosystem services and support socioecological resilience under conditions of uncertainty and change (*27*). The socioecological production landscape of the Japan Satoyama Satoumi Assessment refers to dynamic landscape mosaics that have been shaped over time by the interactions between people and nature in ways that jointly support biodiversity and human well-being (*37*). These concepts also emphasize critical social components, such as involving multiple stakeholders at the landscape scale, community participation, intersectoral coordination, flexible and adaptive governance systems, social learning, and adaptive management, which are necessary for successful conservation of working landscapes.

The underlying principle of maintaining ecological diversity inherent to these approaches has been practiced since ancient times. Some of these management systems, such as indigenous use of fire, weeding, pruning, and the seed dispersal that shaped Californian ecosystems (*38*), no longer exist in their original form, whereas others, such as regional pastoral and high-mountain farming systems in Europe (*39*), persist in some areas. By creating highly simplified and intensified production systems (*21*, *40*), from corn and soy in U.S. midwestern states to palm oil plantations in southeast Asia and vineyards in Chile, we have abandoned this critical sustainability principle across much of Earth's cultivated landscapes. However, it is a fallacy that such systems will ultimately spare more land for nature conservation or feed the world indefinitely; rather, we need to find ways to allow biodiversity-based production methods to figure much more prominently in local, regional, and global markets (*16*).

Working lands conservation as a complement to protected areas

Given the dire situation facing many species and the expectation of further species losses and shifts in ecosystem composition due to climate change (*2*, *4*, *11*), ceasing further habitat conversion completely and protecting large regions of Earth effectively are critical necessities for conservation (*6*–*8*), although just how much should be protected is highly debated (*41*). [By "protected area," we refer to parks whose primary function is to conserve biodiversity and wilderness (International Union for Conservation of Nature and Natural Resources categories I to IV, constituting 6.75% of terrestrial area) (*42*), in contrast to areas blending conservation and livelihood objectives (categories V to VI, constituting 8.65%).] However, the protected-area strategy alone will not be successful without complementary working lands conservation in the surrounding landscapes. First, even the largest protected areas will lose species over the long term (*9*) unless surrounding landscapes can be managed to provide connectivity among parks. Further, less than 10% of protected areas are expected to represent current climatic conditions within 100 years, increasing the criticality of matrix connectivity to permit species to follow their suitable climates (*12*). Lastly, effectiveness in controlling threats, such as invasive species, encroachment, poaching, and other impacts on protected lands, also critically depends on the surrounding matrix (*10*). Thus, to stem the tide of biodiversity loss, we must expand beyond protected areas, using working lands conservation both to buffer and to reduce the threats that cross park boundaries and to create accessory habitats for both movement and persistence.

Working lands conservation is a key linchpin for combatting the triple Anthropocene challenge of biodiversity loss, climate change, and unsustainable land use. A large-scale example is the Mesoamerican Biological Corridor project, which has fostered a multistakeholder participatory process to enhance connectivity on cultivated, range, and forest working lands to link more than 650 protected areas in the region (43). A concurrent goal is to use sustainable agriculture and forestry techniques to promote livelihoods and enhance resilience to climate change (36). Protected areas are vital in this region because many species are restricted to forest; however, most reserves are small and isolated. In combination with steep elevational and latitudinal gradients in the region, this isolation makes species inhabiting reserves particularly vulnerable to climate change. The Mesoamerican Biological Corridor project recognizes the role that working lands can play to restore critical connectivity by increasing tree diversity and cover through live fences, agroforestry, silvopasture, forest fallows, home gardens, and protection or restoration of riparian forests and forest fragments (43). These forest elements, which include both ribbonlike and patch structures, support a large number of neotropical birds, insects, mammals, and plants (17, 44); enhance the movement of birds and bats across the landscape (45–47); and thus contribute to conservation, even of vulnerable wildlife (17, 47, 48). Forest elements also promote sustainable land use and contribute to local livelihoods by supporting ecosystem services. For example, evidence suggests that an economically devastating invasive pest, the coffee berry borer, is reduced by the integration of forest elements within coffee landscapes, which both limits the borer's ability to colonize new coffee fields (49) and promotes bird species that prey on the borer (50). Reduced economic losses due to pest control from birds are similar in magnitude to average per capita income in the region and are strongly related to forest cover (50). Adopting sustainable agricultural techniques and enhancing tree cover simultaneously creates more flexible and resilient production systems that allow farmers and ranchers to adapt to extreme conditions prompted by climate change (33, 51). Although some critics decry the effectiveness of the Mesoamerican Biological Corridor project, it may be too early to judge. Quite a few integrated landscape initiatives are concentrated in the region, in association with biological corridors (36). However, many began relatively recently, and we know from the few scientific studies that exist that developing an effective multistakeholder participatory process takes substantial time (36, 43, 52). In one case that is more advanced (the San Juan–La Selva Biological Corridor in Costa Rica), some success has been achieved in arresting deforestation and encouraging tree planting, forest regeneration, and connectivity through a government-run payments for ecosystem services program, as well as other grassroots initiatives (43, 53).

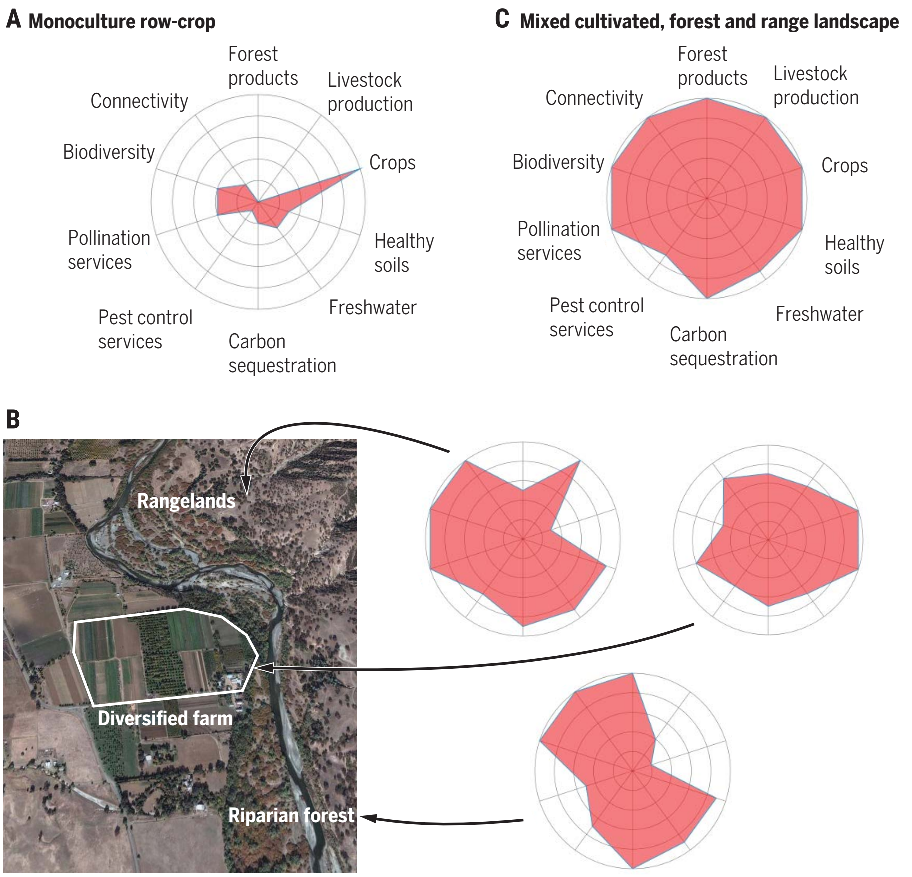

Fig. 2. Ecosystem service trade-offs with land management. Radar diagrams display how different land uses affect various ecosystem services and biodiversity. (**A**) Monoculture row cropping contributes to food production at the expense of other ecosystem services and biodiversity. (**B**) In a working landscape managed for conservation, patch types differ in the services they provide, but each patch type should display a relatively even array of services, minimizing trade-offs. (**C**) Across patches, the services provided for the working landscape in (B) are multifunctional.

ILLUSTRATION: NIRJA DESAI/*SCIENCE* BASED ON C. KREMEN AND A.M. MERENLENDER; PHOTO: NATIONAL AERIAL IMAGERY PROGRAM. ADAPTED BY NIRJA DESAI/*SCIENCE*

Mechanisms for promoting working lands conservation

The challenge of shifting from managing working lands solely for profit to conservation of working lands is not insignificant, but there are clear paths toward larger-scale integration of this approach. These strategies include various regulatory, voluntary, incentive, market-based, or governance instruments (table S1), which vary in their applicability to private, communal, or state-owned lands and the extent to which they support biodiversity conservation versus livelihoods or economies (Fig. 3A). Each approach has challenges, especially around reconciling conservation and socioeconomic objectives (table S1) (42, 54). Collectively, problems associated with regulatory and incentive programs can include inter alia lack of permanence or compliance, complex implementation, unintended economic consequences, low adoption rates, high monitoring costs, and little evaluation of effectiveness against goals (table S1).

Further, there is often the risk that the biodiversity conserved through these actions is not equivalent to that which was lost because of economically driven land conversion. Instruments for private lands may result in piecemeal land management actions that have little positive effect on biodiversity at the landscape scale; promising public-private initiatives to overcome this defect include corridor planning (43, 55) (Box 2 and Fig. 4) and landscape-level mitigation (table S1). For example, landowners required to set aside forest on their properties under Brazil's forest code may develop these lands in exchange for mitigating lands elsewhere within the same biome that provide greater conservation value (56). Managing the matrix to promote biodiversity could also exacerbate human-wildlife conflict; however, the recovery of carnivore populations within human-dominated areas in Europe provides a hopeful and inspiring example for how landscapes can be shared between wildlife and people (14) (Box 3). These instruments can exacerbate the unequal distribution of benefits and costs within and across communities (table S1). For example, trading development rights on forestlands in exchange for permitting high-density urban development elsewhere can provide open spaces for working lands conservation. However, such trades could exacerbate the lack of access to open space already experienced by low-income urban households. Thus, the effects of conservation measures on social equity and environmental justice should also be considered (57). A final concern is that there is often a trade-off between the rigor of environmental standards or restrictions enforced and the likelihood of adoption (table S1); incentive schemes that are flexible, provide obvious benefits, target likely adopters, fit the sociocultural context, foster enabling market and regulatory environments, and provide technical assistance may boost adoption (58). For example, payments for conserving or restoring forests in Costa Rica are based on area, whereas transaction costs are the same regardless of size, disincentivizing smaller landowners from participating in the payments for ecosystem services scheme. Encouraging smallholders to participate would require adjusting the costs of participation so that these landowners could also realize net gains (53). Although numerous changes are required, careful attention to the construction of these programs could increase their success.

Further, several current trends favor working lands conservation approaches. First, new policy instruments [such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation)] operating across a range of scales, from individual private landholdings to large-scale community-based or government-funded initiatives, are being developed to incentivize conservation on working lands. Second, the number and variety of institutions involved in working lands conservation are increasing, and such institutions include both public-private partnerships and nongovernmental conservation organizations that formerly focused primarily on protected areas (36, 59, 60). Third, these institutions can take advantage of recent increases in both public and private "investments for conservation" (investments designed to cogenerate financial returns and conservation benefits) (60). Such investments include projects in sustainable food and fiber production, water quality and quantity projects, and outright habitat conservation (in the latter, financial returns are based on changing land values or carbon stocks). Fourth, outside of these investments, an increasing number of companies have committed to greening their supply chains by reducing the environmental impacts at the source, processing, delivery, and end-of-life management of the product (61). Although supply chain greening requires much better monitoring, accountability, and inclusion of biodiversity conservation as an explicit goal (61, 62), it could ultimately contribute to conservation in working landscapes, particularly given the vast economic power represented within corporations (61). A final trend is the creation of voluntary, community-driven programs (Box 2) in which local communities participate in the conservation of working landscapes to gain increased access to information and expertise, build interpersonal connections, and obtain both personal benefits and public recognition for practicing sustainable methods (63).

We argue that this latter trend of community-based actions and the innovations, networks, and social movements that sometimes emerge from them present the most exciting opportunity to turn the tide against the triple Anthropocene threat [see also (64)]. Communities seeking solutions for socioecological resilience frequently rely on working lands conservation approaches. For example, Sustainable Solutions restores mangrove forests in Sri Lanka and India through youth-based community engagement to build shoreline resilience to cyclones while enhancing livelihoods from fisheries dependent on mangrove ecosystems.

Further, local initiatives can link together to form larger networks with the help of boundary organizations to form social movements that can advance environmental policies, improve sustainable behaviors, and demand supply chain

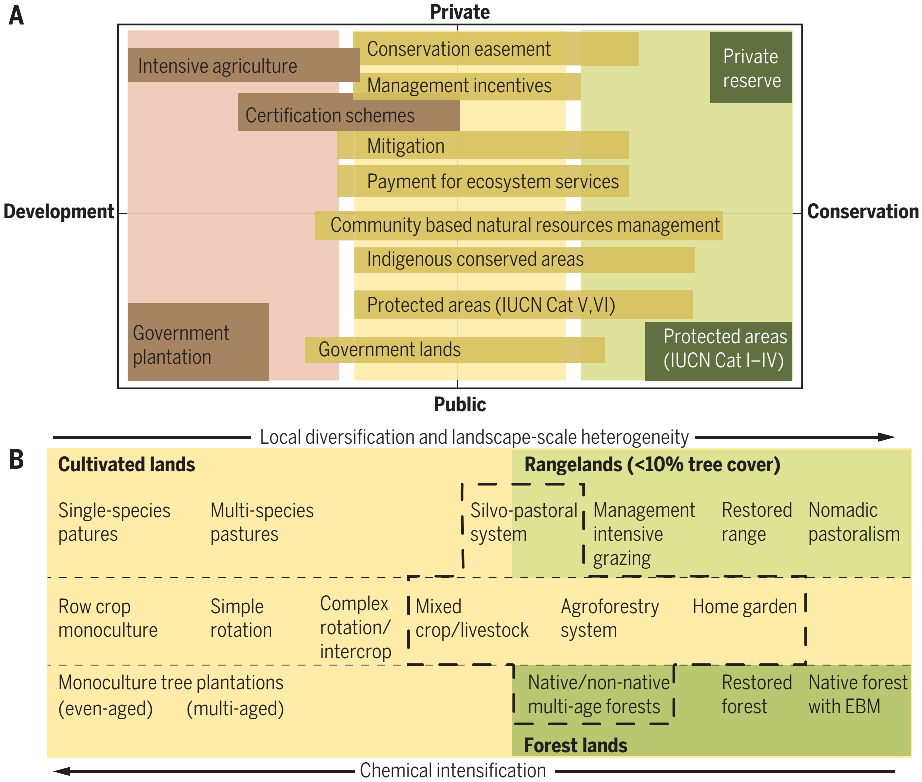

Fig. 3. Approaches for conservation of working lands occupy the space (yellow) between highly developed (brown) and highly conserved (green) land uses. (**A**) An array of tools are available for working lands conservation, for private, communal, or public lands (see table S2 for more detail and examples). IUCN Cat. International Union for Conservation of Nature and Natural Resources categories. (**B**) Forms of management for forage, crops, and tree products from cultivated lands (yellow), rangelands (light green), and forests (dark green), arrayed roughly along a management gradient of diversification (left to right) or chemical intensification (right to left). Cultivated lands include all planted systems. Dashed lines indicate overlapping concepts. EBM, ecosystem-based management.

Box 2. Community stewardship: The case of Landcare Australia.

The Landcare movement is a well-documented community stewardship effort begun in the mid-1980s to conserve biodiversity and sustain agriculture in Australia, resulting in more than 5000 Landcare and Coastcare groups. More than 20 countries have since adopted the model. In Australia, this model combines substantial government investment with landowner and community engagement. For example, Landcare groups across eastern Australia contribute to the delivery of the Great Eastern Ranges (GER) Initiative (105), alongside public land management authorities, conservation organizations, research institutions, and traditional owners groups. The GER is one of Australia's largest public-private partnerships to conserve biodiversity in the face of climate change (Fig. 4) as part of Australia's National Wildlife Corridors Plan. Landcare groups along the corridor undertake restoration and management activities, along with community building and engagement. In the Queanbeyan Landcare group, 25 landholders signed up to increase the foraging habitat for the glossy black cockatoo (*Calyptorhynchus lathami*) through the restoration of 10,000 she-oaks (*Allocasuarina* sp.) in production lands along three river catchments. The social networks and learning spaces created are promising ways of encouraging conservation commitment among land managers. However, far more landowners must become engaged to restore connectivity at the scale desired.

ILLUSTRATION: NIRJA DESAI/*SCIENCE* BASED ON C. KREMEN AND A.M MERENLENDER

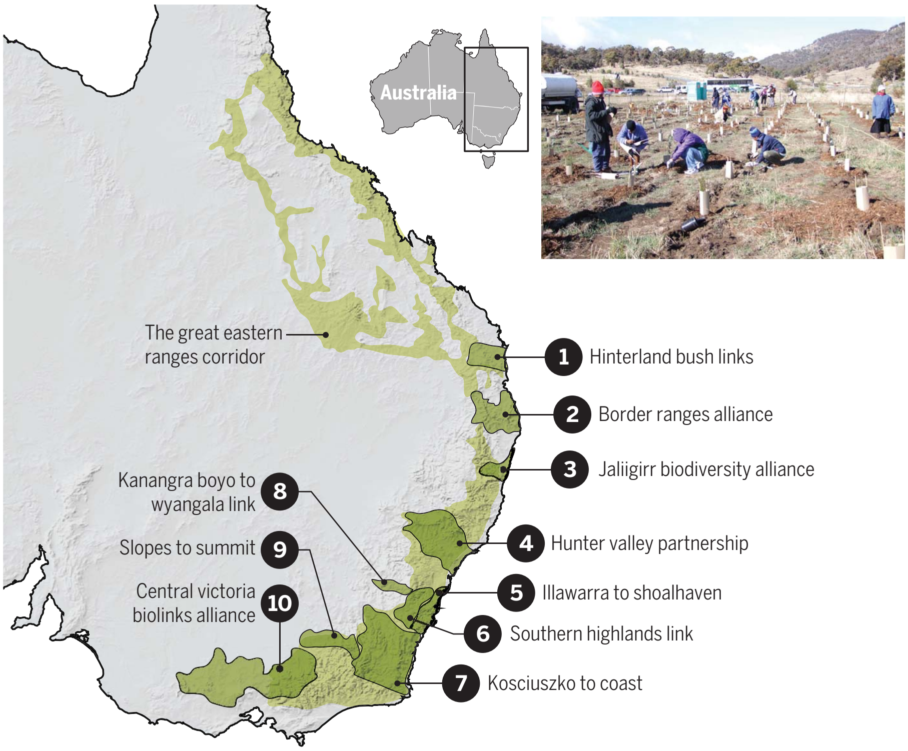

Fig. 4. The GER Corridor Initiative, Australia. The light green outline represents the plan to protect and restore more than 3,600 km^2 as a climate corridor. The numbered, dark green shapes denote regional alliances of conservation and natural resource management organizations, including Landcare communities (Box 2). In the photo, members of the Molonglo Catchment Group Landcare community conduct restoration.

MAPS: GREAT EASTERN RANGES; PHOTO: ANDREW CAMPBELL; ADAPTED BY NIRJA DESAI/*SCIENCE*

Box 3. Carnivore conservation in shared landscapes.

Maintaining populations of large carnivores ranks among the greatest of conservation challenges. These area-demanding species require larger territories than most protected areas possess, potentially necessitating costly translocations to ensure gene flow and maintain populations. Further, these species conflict with people in surrounding matrices through predation on livestock or, occasionally, maiming or killing of humans. Nonetheless, in Europe, most large carnivore populations are stable or expanding. One-third of the area of mainland Europe hosts at least one permanent population of its four large carnivore species, persisting alongside moderate human densities and largely outside of protected areas. The success of carnivore conservation in Europe is attributed to well-enforced, coordinated legislative protection, improvements in habitat and ungulate prey base, and rural depopulation. Importantly, ranchers have found ways to live with carnivores by using carnivore-proofed electric fences and re-invigorating traditional livestock-guarding practices using shepherds and dogs (*14*). Similarly, in a cultivated region in India, large carnivore species (the leopard and striped hyena) persist with few conflicts despite high human densities (300 people/km^2) and the lack of wild prey (*106*), suggesting the potential that exists for carnivore conservation in shared landscapes.

accountability (*64*). For example, the withdrawal of the United States from the Paris Agreement at the 21st Conference of Parties (COP21) and delays in regulation of emissions by other nations galvanized a series of on-the-ground climate actions from civil society, businesses, nonprofits, and subnational government. The Global Action Climate Summit of 2018 instigated by California governor Jerry Brown illustrates a new stage of this growing social movement. Its Land and Ocean Stewardship "30 × 30" challenge brings together more than 100 organizations focused on managing forests, farmlands, and oceans to provide 30% of the climate change solution by 2030, rather than waiting on agreements among nation states that continue to fall short of the necessary carbon reduction targets. The land management techniques being developed locally to mitigate and adapt to climate change are generally consistent with the conservation of working lands approach [e.g., (*65*)].

The benefits of local land conservation can also be scaled up and made more effective if they are carried out within a landscape or regional conservation program organized by a state or nonprofit agency (*58*). Innovative social and institutional arrangements for working lands conservation may emerge, such as The Nature Conservancy's BirdReturns program in California. Through a reverse auction, the program finds and pays farmers willing to alter water management to create "pop-up" wetlands to provide habitats for shorebirds during their northward migration, selecting sites that optimize the conservation benefits relative to payments (*15*).

Management techniques for conserving working lands

Cultivated lands

Cultivated lands make up 12% of the terrestrial ice-free surface (*66*) and comprise row and forage crops, seeded pastures, vineyards and orchards, mixed crop and livestock systems, and tree crops and plantations (Fig. 3B). Cultivated lands are often highly simplified ecologically; thus, they rely extensively on chemical fertilizers and pesticides to replace ecosystem services formerly generated within or around agroecosystems (*31*), often creating negative consequences for the environment and human health (Fig. 2A) (*21*), including continued large-scale forest conversion in some areas of the biodiverse tropics (*62*). Instead, diversified farming systems using agroecological management practices operate by fostering biophysical conditions and ecological interactions favorable to crop production (*31*, *67*, *68*), producing a more balanced (sustainable) distribution of ecosystem services (Fig. 2B). Evidence also suggests that they minimize many of the negative environmental consequences associated with simplified farming (*31*) (Fig. 5). Further, these techniques can maintain crop yields and profitability; create new market opportunities; enhance food security, nutrition, and livelihoods; and contribute substantially to the global food supply, particularly under a changing climate (table S2). Because they rely on relatively low-cost, low-technology, knowledge-based methods (*69*), agroecological diversification techniques can be made accessible to the majority of farmers. [Small-scale farms with <5 ha make up 94% of farms worldwide (*40*) and produce more than half of world food crops (*70*).] These farming methods use open-pollinated seed varieties that can be saved and cultivars that are locally adapted; thus, they are less dependent on purchased seeds and other inputs that can lead to poverty traps (*71*). Multiple grassroots organizations and social movements support learning, sharing, and adaptation of agroecological knowledge and seeds through farmer-to-farmer networks under participatory governance (*64*). Diversified, agroecological practices are therefore farming methods that are highly compatible with working lands conservation, although potentially more applicable to certain farming systems. Large-scale commercial farmers that have invested heavily in the machinery associated with chemically intensive agriculture may not readily switch to agroecological techniques (*68*, *72*); however, the use of some agroecological techniques can be compatible with existing infrastructure and can lead to reduced agrochemical use at similar or even enhanced profits [e.g.,(*73*)].

A concern is that the use of "wildlife-friendly" agroecological practices will require more land to be farmed to produce the same amount of food, promoting deforestation and harming biodiversity (*74*). However, a number of diversified, agroecological farming methods maintain or increase yields (table S2) (*32, 50, 73, 75*–*78*). For example, techniques such as intercropping, cover cropping, and crop rotation may promote crop yields through a variety of ecological mechanisms (*23*), including complementarity of water and nutrient use (e.g., different crops access different soil layers for water and nutrient uptake), facilitation of nutrient uptake [e.g., intercropped faba bean acidifies the soil, mobilizing phosphorus that is taken up by rice (*79*)], reduction of pests and diseases [e.g., pests and diseases spread more slowly in spatially or temporally heterogeneous crop systems, and such systems also support predator populations that keep pests in check (*80*, *81*)], and enhancement of soil biota and fertility (*82*). By improving soil structure and stability, which then enhances water infiltration and retention, these techniques also stabilize yields against annual environmental fluctuations and more catastrophic disturbances such as droughts and hurricanes (*32*, *33*).

Beyond providing resources and habitats for agrobiodiversity, specific techniques such as agroforestry and the use of silvopasture, hedgerows, flower strips, live fences, and riparian buffers may also enhance the connectivity of landscapes and promote the dispersal of various wildlife species (*16*, *47*, *83*). Although these structural features are known to increase the occurrence of a wide variety of organisms within agricultural landscapes (*43*, *84*), how they affect the dispersal potential of organisms within diversified agricultural lands is poorly understood. Nonetheless, ambitious, large-scale connectivity projects, such as the Mesoamerican Biological Corridor project (*43*), the silvopastoral and rotational grazing project in the Santa Catarina Atlantic Forest (*55*), various linkages in Australia (Box 2), and the restoration of the migratory pathway of the monarch butterfly (*Danaus plexippus*) in the U.S. midwestern states (*85*), are under way for agricultural lands. In the latter case, although a daunting amount of restoration would be required to support the butterfly, it could simultaneously enhance soybean pollination, improve water quality, protect other biodiversity, and increase agricultural profitability (Fig. 5 and table S2) (*86*, *87*).

Although entrenched policies and the extreme concentration of agrifood industries favor industrialized supply chains and make transformation to diversified, agroecological systems difficult (*68*, *72*), reasons for optimism exist. Global grassroots movements such as La Via Campesina have provided technical, social, and material support to farmers for the spread of agroecology, confronted industrial agribusiness, and fought to influence national and global policies (*64*). Alternative agrifood systems and local and regional initiatives that provide support for diversified, agroecological systems are emerging (*64*, *69*). International initiatives supporting agroecology include the United Nations Right to Food program, which embraces it as a key element for enhancing food security globally (*88*), and programs of the Food and Agriculture Organization, which has held global and regional conferences on agroecology and included it in Farmer Field Schools since 2014 (*68*).

Rangelands and forests

Forests in the boreal, temperate, and tropical regions make up ~30% of Earth's area (*89*), whereas rangelands, which are defined as having <10% tree cover and include grasslands, desert shrublands, savanna woodlands, alpine meadows, and areas of tundra grasses and shrubs, constitute ~44% (*90*). Grazed by wild and domestic animals, they vary greatly in productivity. Both natural forests and rangelands have been lost or degraded over the past several hundred years by the increased extent and intensity of human use, including timber harvest, grazing, and conversion to agriculture. Forests continue to be lost and degraded at an alarming rate (*62*), although forest regrowth due to rural depopulation is also occurring in some areas (*20*). A recent global analysis of sources of tree cover losses showed that industrial agriculture for commodity crops is responsible for the permanent conversion of 5 million ha of forest per year (27% of losses, concentrated primarily in portions of Latin America and Southeast Asia), whereas shifting agriculture (primarily in Africa) and forestry (primarily in North America and Europe) cause forest disturbance or degradation over an equivalent land

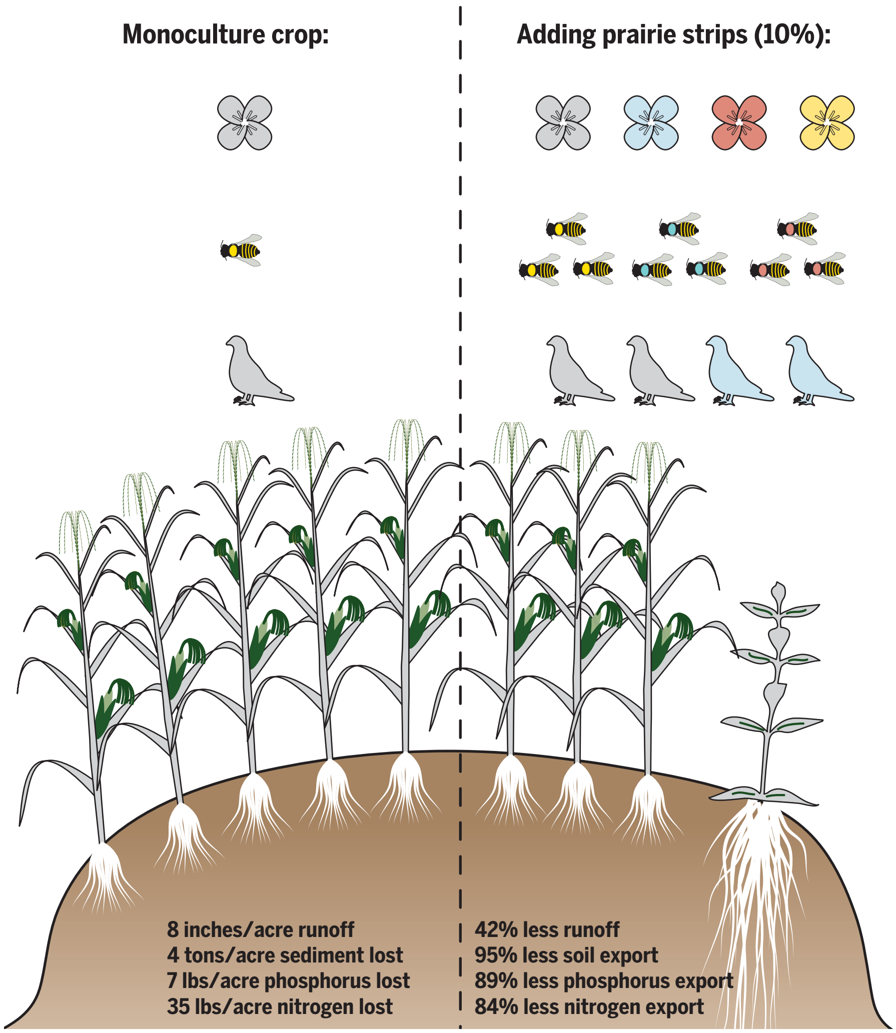

Fig. 5. Diversification practices can increase biodiversity. The integration of prairie strips into a corn-soy rotation exemplifies how diversification within working lands can substantially increase plant, pollinator, and bird species richness and abundance by two- to fourfold (as indicated by colors and numbers of icons, respectively) while minimizing externalities and enhancing other ecosystem services, such as pollination for the soy crop (table S2) (*86*).

ILLUSTRATION: NIRJA DESAI/*SCIENCE* BASED ON STRIPS RESEARCH TEAM AND LEOPOLD CENTER FOR SUSTAINABLE AGRICULTURE area, followed by regrowth (*62*). It is critical, therefore, to cease permanent conversion of forests for commodity cropping and to apply restorative management approaches in working forests and rangelands.

Since 1990, many nations have created enabling policies and legislation for sustainable forest management (*89*). Of the 54% of global forests considered "permanent" (that is, expected to retain forest cover in the long term), 99% of these 2.17 billion ha are covered by such policies, a necessary but not sufficient condition for sustainable management. Indicators of sustainable management also show positive temporal trends, but over smaller areas. For example, forest certification (table S1) covered 430 million ha by 2014 (*89*), but largely within boreal and temperate regions, where land-clearing rates are less acute than those in the tropics.

An array of restorative forest and rangeland management options exist that are compatible with the conservation of working lands (Fig. 3B and table S2). For forests, the adoption of ecosystem-based management approaches has led to the integration of a greater variety of tree species and age and size classes, including old growth and dead and downed trees, and the incorporation of natural disturbance regimes to support more diverse ecological communities (*91*). This uneven-aged management style maintains similarities between natural and managed forests, contrasting with even-aged management from clear-cutting. Evidence from silvicultural trials and natural forests suggests that greater tree diversity also enhances wood yield quantity and stability (*23*). In keeping with the ecosystem stewardship concept (*27*), ecosystem-based management also emphasizes collaborative decentralized control and adaptive management, as well as landscape planning and the designation of corridors to promote wildlife (*92*). However, stakeholders may reject harvesting practices that negatively affect financial returns in the short term. Environmental outcomes suffered when stakeholders had stronger oversight of the process than a regulatory authority with political backing (*93*), supporting the need for public-private partnerships to achieve biodiversity conservation objectives.

In rangelands, compatible management practices are exemplified by the dehesa and montado traditional pastoral systems in oak savannas of Spain and Portugal, respectively. The oak trees (*Quercus rotundifolia* and *Q. suber*) are pruned to increase the production of acorns to feed to pigs and other livestock grown for high-value meat products; other sustainably harvested products include fuelwood and cork from oaks (*94*). These ecosystems also support endangered species and high plant and animal diversity relative to other seminatural habitats in Europe. However, grazing, browsing, and trampling can limit oak regeneration; thus, pasture areas need periodic temporary protection from livestock to promote oak recruitment and sustainable use (*95*). In Colombia, many ranchers are restoring degraded agricultural lands by using various silvopastoral techniques, which also enhance connectivity in these landscapes (Fig. 1).

Freshwater ecosystems

Maintaining stream flows and hydrologic connectivity is essential for conserving freshwater biodiversity and ecosystems. Because of changes in stream flows, estimates suggest that up to 75% of freshwater fish species are headed for local extinction by 2070 (*96*). Fresh water also limits the production of many natural resources, and its quantity and quality are in turn affected by landscape management. Appropriate management techniques can promote groundwater recharge and stream flow in working landscapes (table S2) (*31*, *86*), of increasing importance under drier futures with more extreme precipitation events (*97*). Flood plains and associated riparian zones are particularly critical to conserve in working landscapes, because they disproportionately support biodiversity and ecosystem processes compared with other landscape elements (*98*). Riparian corridors also provide cooler and moister microclimates than surrounding areas and often span elevational and climatic gradients that may permit species to follow their climate envelopes (*99*).

Recommendations and concluding thoughts

Managing the working lands matrix for biodiversity needs to become a mainstream component of public and private conservation efforts, complementing the more traditional (and essential) focus on increasing the extent and effectiveness of protected areas (*16*). These restorative, working lands conservation approaches (table S2) should be applied to the large land area that is already used for farming, forestry, and ranching. At the same time, we critically need policies to prevent further conversion and degradation of wilderness and relatively intact ecosystems (*62*).

To scale up working lands conservation, increased support is needed for the voluntary, policy, and market instruments described in table S1. However, further adaptation and learning is needed to improve their efficacy, both at the project level and through evidence-based syntheses [e.g., (*100*)], and to increase adoption rates by considering an array of social factors (*58*). Further, these measures must be complemented by community-driven conservation initiatives, which, by involving young and old in stewardship, communication, citizen science, and education, can create a shared vision and innovative practices that result in collective impact. Scientists can support community-driven conservation and help advance environmental social movements by engaging the public, listening to alternative ways of knowing, and cocreating conservation, management, and policy alternatives. Especially important is to create alliances with existing community actions and social movements that share common ground, such as climate or local food movements.

Ultimately, our efforts to protect biodiversity and sustain resources must be accompanied by measures to reduce human population and consumption while increasing equitable access to resources to achieve sustainability. Opportunities to stabilize population and consumption exist. For example, through concerted government investment in voluntary family planning programs, enormous progress in reducing total fertility rates has been made even in poor countries [e.g., (*101*)], leading to smaller families living better. Globally, a large unmet need for family planning still exists (*101*); further investment could help stabilize the global population at 6 billion people by 2100, instead of the 9 to 12 billion projected without intervention (*102*, *103*). To reduce consumption, critical targets include reducing food waste and meat consumption (*104*) and seeking efficiencies in energy and water use that can accompany urbanization (*102*). Even with well-structured policies, these changes toward lower human population and consumption would take time; thus, concerns exist that humanity will destroy biodiversity and natural resources before achieving a more sustainable human population (*102*). Conservation in working landscapes can help maintain all species, including people, as we strive to achieve a planet where a smaller human population lives better and more equitably with and because of wild nature.

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SUPPLEMENTARY MATERIALS

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Science

Landscapes that work for biodiversity and people

C. KremenA. M. Merenlender

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A nature-friendly matrix
As the human population has grown, we have taken and modified more and more land, leaving less and less for nonhuman species. This is clearly unsustainable, and the amount of land we protect for nature needs to be increased and preserved. However, this still leaves vast regions of the world unprotected and modified. Such landscapes do not have to be a lost cause. Kremen and Merenlender review how biodiversity-based techniques can be used to manage most human-modified lands as "working landscapes." These can provide for human needs and maintain biodiversity not just for ecosystem services but also for maintenance and persistence of nonhuman species.

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