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The value of valuing nature

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molecular, circuit, and behavioral levels to guide novel interventions. Together, these efforts will enhance our capacity to develop and target treatments by age, sex, and genetic makeup of the individual.

Despite the moral imperative and long-term economic benefit of improved diagnosis and treatment of mental disorders in adolescence, there has not been commensurate investment in research to bring them about. The NIH budget has not kept pace with inflation and is threatened by cutbacks. Increased commitment and resources are needed to help address our social obligation to reduce the unacceptably high burden of mental illness on youth today and to ensure a healthier tomorrow. ■

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Phulchoki Mountain Forest, Nepal. In this and many other ecosystems, different ecosystem services are rarely optimized simultaneously by management, requiring choices to be made.

CONSERVATION

The value of valuing nature

Valuing nature in economic terms is not always beneficial for biodiversity conservation

By **W. M. Adams**

The complex ways in which humans depend on their natural environment are increasingly expressed in terms of ecosystem services, which are often assigned economic values to assist decision-making. The key attraction of the ecosystem services concept to conservationists lies in the potential for win-win outcomes (*1*), where the value of an ecosystem service depends on high biological diversity and cannot be increased by modifying it. Such outcomes are possible. For example, in Costa Rican coffee plantations, retention of forest patches doubled pest control of coffee berry borer beetle by birds, with substantial economic benefits to coffee farmers (*2*). However, attention to ecosystem services does not automatically lead to the conservation of biodiversity (*3*). A series of factors challenge the creation of synergies between ecosystem services and biodiversity conservation (see the figure).

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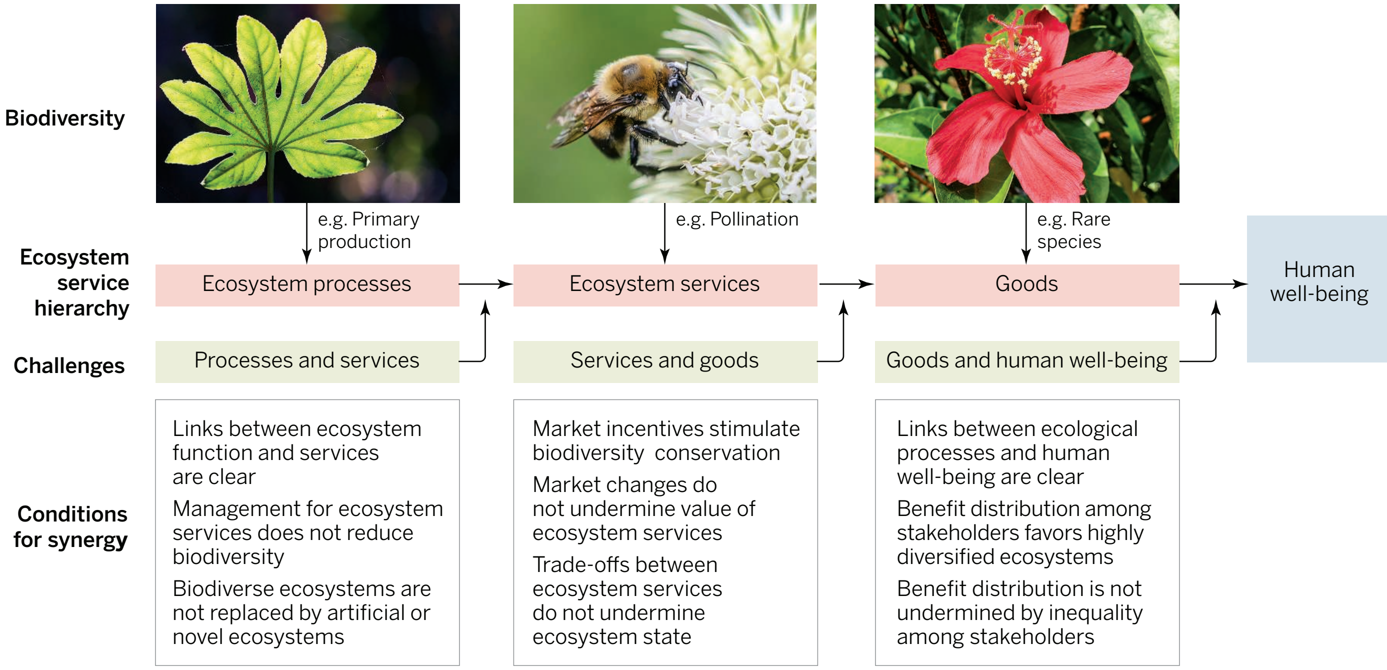
PROCESSES AND SERVICES. First, challenges arise in the relationship between ecological processes and the delivery of ecosystem services. The question of how many species (and how much genetic diversity) can be lost from an ecosystem before it ceases to provide services is critical to understanding the relationship between biodiversity and benefits from ecosystem services, but it is not easy to answer (*4*). Both biotic and abiotic processes are involved in the delivery of many ecosystem services—for example, wave attenuation in coastal defense (*5*). Relationships among biodiversity, biophysical processes, and the provision of ecosystem services are intricate and poorly understood (*6*).

Even if it is possible to identify which biophysical processes and ecosystem components underpin specific ecosystem services, a focus on those that deliver particular services is likely to affect other components of the ecosystem (such as rare species). For example, in Maryland, USA, stream channels were reengineered to provide particular services from streams (storm water management for flood control and sediment and nutrient storage). This approach causes the aquatic fauna and flora characteristic of stream ecosystems to be replaced by terrestrial and wetland species, and loss of healthy riparian trees (*7*).

Similarly, a focus on ecosystem services may lead to management aimed at controlling processes with substantial negative social impacts (e.g., disease, flood, or fire). These biophysical processes may be essential in supporting ecosystem components of



Finding synergies. Biodiversity can regulate fundamental ecosystem processes and ecosystem services, as well as constitute goods that contribute to human welfare (*4*). Challenges to the creation of synergies between ecosystem services and conservation arise in relationships among ecosystem processes, services, goods, and human well-being. These challenges define the conditions under which synergies arise or can be created.

PHOTO CREDITS: (LEAF) DAVID GOEHRING/FLICKR; (BEE) ANDREW C/FLICKR; (FLOWER) DAVID EICKHOFF/FLICKR

interest to conservation, such as threatened habitats or species (*3*). Management aimed at providing valuable services may lead to support for artificial or novel ecosystems, non-native species, and organisms shaped by synthetic biology. Thus, services such as carbon sequestration may in future be provided by ecosystems that retain little of their original diversity (*8*). Such ecosystems are likely to deliver little value in terms of biodiversity conservation.

SERVICES AND GOODS. The second category of challenges relates to the links between ecosystem services and goods. First, there is the problem of missing markets. Some ecosystem services are produced and consumed in ways that make them amenable to economic valuation (for example, products such as food or timber), but others (such as soil formation and nutrient cycling) are not, although their value can be expressed through the directly valued services that they support (*9*). There are rarely effective markets to stimulate the conservation or restoration of biodiversity that provides regulating services (such as pollination by wild species), or for noncharismatic species as a cultural ecosystem service.

In principle, economic incentives can be created to support conservation of many ecosystem elements, including charismatic rare species—for example, in payments for ecosystem services (PES) schemes, where the users of services pay those who supply them (*1*). A PES scheme across the Brazilian Atlantic Forest biome could, for instance, provide cost-effective incentives for landowners to set aside land for forest, with benefits for biodiversity and ecosystem services (*10*). However, many PES-like payment schemes do not fulfill the criteria of markets (commoditization, conditionality, and voluntary exchange) and require support from taxes or charitable giving (*1*).

A related concern is that as market prices change over time, so too will the value ascribed to ecosystem services. Although the value of rare species may rise as populations fall, that of other ecosystem services may be more variable. For example, Mexican free-tailed bats (*Tadarida brasiliensis mexicana*) control pests in U.S. cotton production by predating on moths. The value of this ecosystem service to U.S. cotton production fell by 79% between 1990 and 2008 (*11*) as many farmers began to plant a cotton genetically modified with the bacterium *Bacillus thuringiensis* (*Bt*) that is toxic to insect pests. In future, pest resistance to *Bt* cotton may cause the value of bat moth predation to rise again. In the face of such relatively rapid shifts in market conditions and agricultural technology, it would be hard to make a watertight case for bat conservation on the basis of the ecosystem service they provide.

It also matters whether ecosystem services are considered and measured together ("bundled") or separately. The act of categorization and analysis of ecosystem services implies that different components can be separated (*7*). Yet, different services are coproduced. They may interact synergistically (so that more of one service means more of another) or may compete (such that there is a trade-off between one service and another). A study of ecosystem services in the watershed of the Panama Canal found that timber production and carbon sequestration increased synergistically. However, contrary to managers' expectations, both competed with water supply, such that no form of reforestation would increase water flow in the dry season, although this relationship varied with site-specific variables such as slope, soil properties, and forest species (*12*).

GOODS AND HUMAN WELL-BEING. The third category of challenges relates to the links between the provision of goods from ecosystem services and human well-being. Birch *et al.* used a site-based ecosystem assessment toolkit in the Phulchoki Mountain Forest in Nepal (see the photo) to compare the values of different services under community forest management with those from state-managed forest and land cleared for agriculture (*13*). Community forestry proved favorable for biodiversity but for most services, for most stakeholders, and at most scales, but ecosystem services were not all maximized simultaneously, leading to choices and trade-offs among services.

It is not enough to identify the net benefits of ecosystem services: It also mat-

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ters who gets them. Ecosystems tend to be owned by somebody, either privately or by the state (exceptions being deep oceans, the atmosphere, and Antarctica). Management decisions tend to reflect the interests of the owners, and where services demand other forms of capital (such as agricultural infrastructure), the supply of services depends on the availability of financial capital from owner, state, bank, donor, or investor. For example, in the Panama basin example discussed above (*12*), timber production and carbon sequestration increase or decrease together, but the two services have different beneficiaries in different locations. Landowners have a direct interest in the private

> ***"...a monetary valuation of nature should be accepted only where it improves environmental [and] socioeconomic conditions..."***

benefits from either timber harvesting or livestock grazing, whereas carbon sequestration is a global public good. Choices about ecosystem management often involve such trade-offs between one service and another and between beneficiaries.

LOSERS AND WINNERS. Trade-offs among stakeholders in their access to ecosystem service benefits is a particular problem where there are differences in wealth and power. In the example of the Phulchoki Forest (Nepal) discussed above, community control of forest gave the local community the benefits of clean water, tourism, and harvested wild goods but restricted poor people's access to forest products, particularly those from certain "untouchable" castes. This created hardship, illegal use, and impacts on other areas (*13*).

Patterns of winners and losers from ecosystem services (and associated payment schemes) reflect prevailing patterns of wealth and power. Unequal access to ecosystem service benefits, including those experienced locally and at a distance, can lead to conflict, institutional failure, and ecosystem degradation. Institutional transparency, access to information, and secure resource tenure are fundamental to equitable outcomes.

CONSERVATION/ECOSYSTEM SERVICES. The identification and valuation of ecosystem services are valuable for sustainable environmental planning. Win-win outcomes are possible in cases where valuable ecosystem services increase support for biodiversity conservation. Although areas of high biodiversity and those providing ecosystem services do not always overlap, improved conservation planning could help identify opportunities for win-win outcomes (*14*). However, the ecosystem service approach is not itself a conservation measure. There is a risk that traditional conservation strategies oriented toward biodiversity may not be effective at protecting ecosystem services, and vice-versa. Analysis using political ecology and ecological economics suggests that a monetary valuation of nature should be accepted only where it improves environmental conditions and the socioeconomic conditions that support that improvement (*15*).

The challenges described here suggest that considering conservation in economic terms will be beneficial for conservation when management for ecosystem services does not reduce biotic diversity or lead to substitution of artificial or novel ecosystems, when effective market-based incentives stimulate and sustain the conservation or restoration of biodiversity, and when the distribution of services among stakeholders favors high-diversity ecosystem states and is not undermined by inequality.

In a world run according to an economic calculus of value, the survival of biotic diversity depends on its price. Sometimes calculation of ecosystem service values will favor conservation; sometimes it will not. Conservationists must plan for both outcomes, rather than hoping that recourse to economic valuation will automatically win the argument for biodiversity. Ultimately conservation is a political choice (*16*), and ecosystem service values are just one argument for the conservation of nature. ■

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NEUROSCIENCE

The atoms of neural computation

Does the brain depend on a set of elementary, reusable computations?

By **Gary Marcus**,[1] **Adam Marblestone**,[2] **Thomas Dean**[3]

The human cerebral cortex is central to a wide array of cognitive functions, from vision to language, reasoning, decision-making, and motor control. Yet, nearly a century after the neuroanatomical organization of the cortex was first defined, its basic logic remains unknown. One hypothesis is that cortical neurons form a single, massively repeated "canonical" circuit, characterized as a kind of a "nonlinear spatiotemporal filter with adaptive properties" (*1*). In this classic view, it was "assumed that these...properties are identical for all neocortical areas." Nearly four decades later, there is still no consensus about whether such a canonical circuit exists, either in terms of its anatomical basis or its function. Likewise, there is little evidence that such uniform architectures can capture the diversity of cortical function in simple mammals, let alone characteristically human processes such as language and abstract thinking (*2*). Analogous software implementations in artificial intelligence (e.g., deep learning networks) have proven effective in certain pattern classification tasks, such as speech and image recognition, but likewise have made little inroads in areas such as reasoning and natural language understanding. Is the search for a single canonical cortical circuit misguided?

Although the cortex may appear, at a coarse level of anatomical analysis, to be largely uniform across its extent, it has been known since the seminal work of neurologist Korbinian Brodmann a century ago that there are substantial differences between cortical areas. At a finer grain, the brain has hundreds of different neuron types, and individual synapses contain hundreds of different proteins (*3*). Duplication and divergence shape brain evolution (*4*), just as they do in biology more generally.

What would it mean for the cortex to be diverse rather than uniform? One pos-