WATER RESOURCES

Beyond infrastructure

Projects such as building dams and diverting watercourses enhance water security for humans. But they do little to protect the biodiversity of associated ecosystems, and that's a long-term necessity. SEE ARTICLE P.555

MARGARET A. PALMER

In the developed world, responses to natural disasters such as floods and droughts often involve taming or vexing nature instead of moving people out of harm's way or rethinking water-use policies. Dams are built, levees erected, and various infrastructure projects redirect flows to nourish water-stressed regions. Ironically, such actions affect the very ecological processes and natural systems that purify, store and ensure long-term delivery of the abundant fresh water that supports ecosystems and people. Many once-perennial streams and wetlands are now dry much of the year because they have been buried or re-engineered for human purposes.

In their paper on page 555 of this issue, Vörösmarty *et al.*[1] describe how they have used a detailed, comprehensive and spatially explicit global-accounting approach to quantify threats to human water security and to freshwater biodiversity. Carefully identifying the underlying causes, they document a pandemic deterioration of fresh waters, showing that there are threats to biodiversity and water security in both rich and poor countries.

Because of the interplay between the many stressors that can act on river systems, patterns of river degradation vary markedly within continents and even countries. For example, some rivers, such as the Nile, suffer major effects upstream, which are then exacerbated by impacts from densely populated regions farther downstream. The Nile supports more than 180 million people, many of whom live in poverty, yet water security and biodiversity are clearly at great risk. The spatial patterns and downstream outcomes are quite different for the Amazon. Anthropogenic effects are greatest at the river's source in Peru, and diminish downstream as the river makes its way through dense rainforests. This trend could reverse if Amazonian deforestation intensifies.

After a detailed documentation of the spatial distribution of threats to biodiversity and water security, Vörösmarty *et al.* calculated the economic investments that have been made in water infrastructure; not surprisingly, these investments are largely limited to rich nations. What may surprise many readers, however, is the authors' demonstration that, on a global scale, water security increases with affluence (higher gross domestic product) — but so do threats to biodiversity. In fact, the very actions taken to increase water security, such as the building of dams and flow diversions, typically result in habitat loss and changes to river flow that act to reduce both fish diversity and water quality. Most areas of the United States and western Europe, for example, have low threats to human water security relative to other regions around the world, yet have high threat levels for biodiversity.

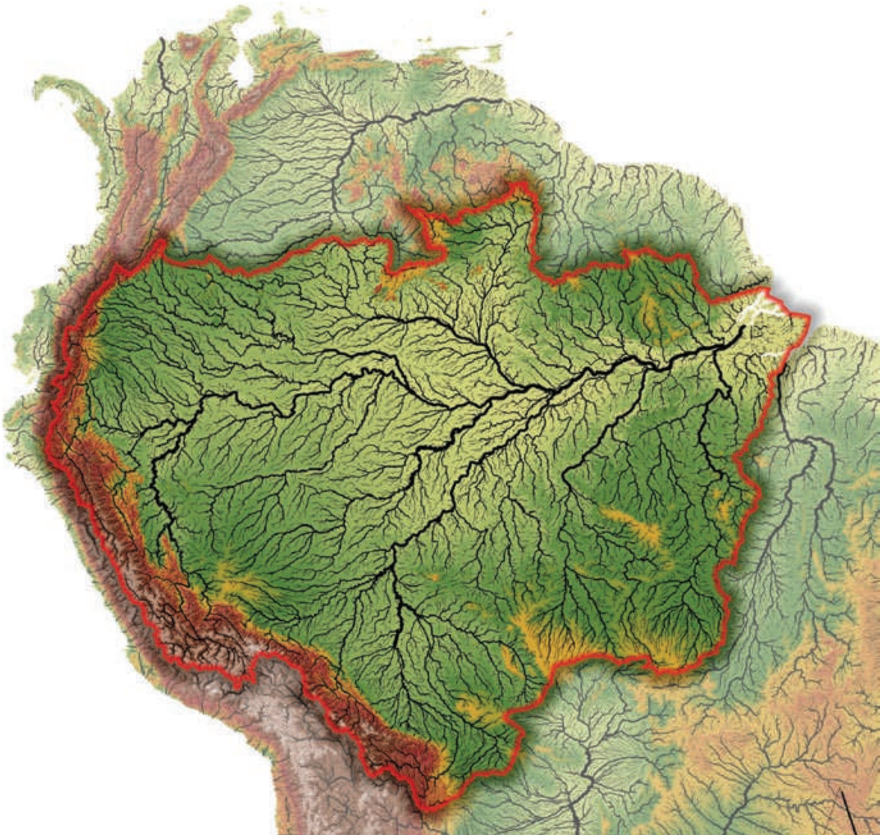
USGS

Figure 1 | Flow chart. A high-resolution map of the Amazon watershed showing the network of small streams and rivers that permeate the landscape. (Image derived from ref. 7.)

There are at least two serious implications of this research, the first of which relates to why we should worry about biodiversity. We have long known that biodiversity loss is not homogeneous across the globe, but only recently have scientists begun to examine the link between biodiversity and human well-being.

Some human benefits of biodiversity are obvious — for example, the relatively new science of ecosystem-based management has shown that diversity within the broader food web is essential to fishery sustainability. The significance of biodiversity for the provision of other ecological goods and services, such as abundant clean water, is less obvious because it involves complex relationships between biodiversity and ecological processes. For example, the cycling of nutrients such as nitrogen is a biologically mediated ecological process that influences water quality. Nitrogen is crucial to the health of ecological systems, but in excess it becomes a pollutant that can lead to eutrophication of rivers and their coastal waters. Because some aquatic plants and microbes take up excess nitrogen from the water at higher rates than others, loss of key species or groups of microbes could lead to a reduction in water quality. Identifying and quantifying relationships between biodiversity and ecological processes that regulate the provision of ecosystem goods and services — in this instance, clean water — is a challenge and an area of intense research activity.

Only recently, however, have natural and social scientists begun working together to ramp up research to the next level: namely, to link findings on the relationship between biodiversity and ecological processes to social factors that influence the delivery of ecosystem goods and services to humans[2]. For example, management decisions that lead to more intensive aquaculture operations could eliminate native fish that normally keep nuisance algae in check. The result may be poor water quality and potentially even the eventual collapse of the aquaculture operation, both of which would have economic and social consequences. These consequences, in turn, may lead to new management decisions, and thus the cycle continues. An understanding of the complex interactions between social and ecological systems is essential for securing the long-term sustainability of water and other natural resources, and will require new forms of scientific interaction that discipline-bound traditions make difficult[3].

Understanding these interactions also requires a great deal of ecological data not currently available, including information on the distribution of organisms, their functional traits (that is, their role in an ecosystem and their performance under different conditions), and how they interact with other species, social systems and the physical environment. We need global biodiversity assessments and ecosystem-service frameworks for advancing our understanding of the link between biodiversity and ecosystem services. Promising initiatives include the Group on Earth Observations Biodiversity Observation Network (GEO BON)[4] and the proposed Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[5]. The spatial modelling framework that Vörösmarty *et al.*[1] have developed is the type of scientific product needed for international efforts such as IPBES.

A second implication of Vörösmarty and colleagues' paper[1] lies in the demonstration of the controlling role that hydrology has in determining the spatial distribution of environmental impacts. Spatial 'legacy effects' mean that impacts on aquatic ecosystems and the people they support can be transmitted far from their point of origin. Whether flowing year round or only intermittently, streams are organized in complex networks that blanket the landscape and merge progressively downstream to form larger and larger rivers. Collectively, the network of linked terrestrial–aquatic ecosystems defines a watershed (Fig. 1). There can also be significant temporal lags between ecological effects on watersheds (as, for instance, in the excessive extraction of groundwater) and declines in freshwater ecosystem services that ultimately influence long-term water security for humans[6].

All life — terrestrial and aquatic, ranging from microbes to vertebrates — depends on and is shaped by water and watershed dynamics. Yet only a small subset of conservation and natural-resource management plans, and few national or international research initiatives, use the watershed as an organizing framework. It will never be possible to eliminate all impacts on biodiversity and ecological processes if the growing human demands for water are to be met, and I am not suggesting that this should be the goal of watershed-based management, planning or research.

However, societies can try to balance ecological and human needs, for example by considering where in a river network a new dam is planned, or where increased water extraction will be allowed. Similarly, I am not suggesting that terrestrial ecologists or social theorists should abandon their systems to study watershed dynamics or vice versa. Instead, the research community needs to consider co-use of a 'watershed lens' to organize investigations that address pressing socio-ecological questions that relate to enhancing human water security in both developed and developing countries. ■

Margaret A. Palmer *is at the University of Maryland Center for Environmental Science, Solomons, Maryland 20688, USA.*
e-mail: mpalmer@umd.edu

1. Vörösmarty, C. J. *et al. Nature* **467,** 555–561 (2010).
2. Wainger, L. A. & Boyd, J. W. in *Ecosystem-Based Management for the Oceans* (eds McLeod, K. & Leslie, H.) 92–114 (Island, 2009).
3. Carpenter, S. R. *et al. Proc. Natl Acad. Sci. USA* **106,** 1305–1312 (2009).
4. www.earthobservations.org/geobon.shtml
5. ipbes.net
6. Raudsepp-Hearne, C. *et al. BioScience* **60,** 576–589 (2010).
7. http://hydrosheds.cr.usgs.gov

LOW-TEMPERATURE PHYSICS

Paired in one dimension

The trend towards using ultracold atomic gases to explore emergent phenomena in many-body systems continues to gain momentum. This time around, they have been used to explore novel pairing mechanisms in one dimension. **See Letter p.567**

IMMANUEL BLOCH

Atomic gases cooled down to nanokelvin temperatures and confined in optical or magnetic traps have helped to realize and investigate fundamental many-body quantum phases of matter[1,2]. An investigation by Liao *et al.*[3] on page 567 of this issue now shows how such ultracold systems are also moving to centre stage in the quest for an exotic form of superconductivity — the elusive FFLO superconducting state of matter that was proposed more than 40 years ago by Fulde and Ferrell[4] and Larkin and Ovchinnikov[5].

In condensed-matter physics, an arbitrarily small attraction between fermions (particles with half-integer spin, such as electrons) of identical but opposing spin and momentum can lead to the formation of bound pairs that have bosonic character (bosons being particles with whole-integer spin). Under specific conditions, such pairs can undergo the phenomenon of Bose–Einstein condensation (BEC), transforming the many-body system into a 'giant matter wave' with spectacular frictionless-flow properties — a superconductor or superfluid is born. This remarkable outcome of pairing, first proposed by Bardeen, Cooper and Schrieffer (BCS), is considered to be the conventional way in which superconductivity emerges in a wide range of materials. In the world of atomic physics, the same pairing mechanism has been studied thoroughly in three dimensions with equal two-component gas mixtures of fermionic neutral atoms[1,2], each component comprising atoms with one of two spin states (up or down). But what happens to such a BCS superfluid state if the two fermionic spin states are not present in equal numbers in the system?

In a solid-state material, such a spin-imbalance condition can be created by applying a magnetic field to the system. In ultracold atomic gases, a simple initial difference in the number of spin-up and spin-down atoms will do the job. Intuitively, one might think that an increasing mismatch in the number of spin-up and spin-down particles would make it harder for the opposing spins to meet each other and pair up, thus hindering superconductivity. And this is indeed what happens in experiments. Put in more technical terms, the Fermi surfaces of the two system components will have different sizes, and this difference will hamper the formation of the pairs and the ensuing BCS superfluid state (the Fermi surface is the boundary in momentum space that separates unoccupied states from occupied ones).

Fulde and Ferrell[4], as well as Larkin and Ovchinnikov[5], proposed a clever solution that would still allow a superfluid state to exist under spin-imbalanced conditions. They