Cambridge University Press
978-0-521-76803-0 — Freshwater Biodiversity
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Excerpt
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1 · *The Freshwater Commons*

> That which is common to the greatest number has the least care bestowed upon it. Every one thinks chiefly of his own, hardly at all of the common interest . . .
>
> Aristotle (350 BCE), *Politics* Book II, Part 3

> These considerations should lead us to look upon all the works of nature, animate or inanimate, as invested with a certain sanctity, to be *used* by us but not *abused*, and never to be recklessly destroyed or defaced. To pollute a spring or a river, to exterminate a bird or beast, should be treated as moral offences and as social crimes . . .
>
> Alfred Russel Wallace (1914: p. 278), *The World of Life*

> . . . this is a problem of ecology, of interrelationships, of interdependence. We poison the caddis flies in a stream and the salmon runs dwindle and die. We poison the gnats in a lake and the poison travels from link to link of the food chain and soon the birds of the lake margins become its victims. . . . They reflect the web of life — or death — that scientists know as ecology.
>
> Rachel Carson (1962: p. 189), *Silent Spring*

The Medium Is the Message

Water is essential for life in general, and for humans in particular. Food production in the form of rain-fed and irrigated agriculture, livestock production, fisheries and aquaculture depend upon the availability of fresh water. This scarce resource also sustains a significant amount of animal biodiversity, much of which is now threatened. Ichthyologist Melanie Stiassny (1999) co-opted Marshall McLuhan's 1964 catchphrase 'the medium is the message' to encapsulate the notion that freshwater biodiversity is imperilled due to dependence on a resource subject to unprecedented and ever-increasing human demands. And the trade-offs between human use of water and the water needed for nature have increasing been skewed in favour of the former. 'The medium is the message' also because fresh water is a more limiting resource than the supply of land for humans, while sea water is not limiting at all; because the land is not subject to comparable patterns of consumption, use or contamination; and because freshwater animals have far more restricted distributions than their terrestrial (or marine) counterparts. The inherent connectivity between fresh waters and their surrounding catchments, with receiving waters almost always located at the lowest point in basins (volcanic crater lakes are an exception), bestows vulnerability since threats to biodiversity can originate uphill well beyond lake or river banks. Within-river hydrological connectivity allows insults to be transmitted both down- and upstream. This is markedly different from the relatively localized effects of most human impacts in terrestrial landscapes. In short, 'the medium is the message' serves as an uncomplicated summary of the existential threat to freshwater biodiversity.

It is but a short step from Marshall McLuhan to ecologist Garrett Hardin, whose popularization of the notion of 'the tragedy of the commons' dates from a 1968 article, although the origins of this idea can be traced at least as far back as Aristotle (see chapter epigraph). The now-familiar story goes something like this. A villager puts a goat out to graze on common land around the settlement so that his family can have a regular supply of milk. Seeing their neighbour enjoying this benefit, each of the other villagers sets their own goat to graze. All goes well until one villager realizes that he can gain more milk by putting out two goats. He does so, and soon his observant neighbours do the same. As the number of goats increases, there is less grass for each to eat and their individual milk yield declines. Nonetheless, the combined yield of two goats is greater than that from a single goat, so the villagers are better off if each grazes two goats. One of the villagers is then tempted to put a third goat on the commons; his neighbours follow suit. A fourth goat is added . . . and so on. The additional increment of milk from each additional goat declines as their number increases, but so long as the villagers obtain some benefit from adding another animal, the goat population of the commons will continue to rise. A critical point is reached where the grass can no longer withstand the intensity of grazing: it dies back, the goats starve and the supply of milk dries up. The lesson here is that protection of the environmental commons requires individuals to forego some gain. Instead of maximizing the amount of milk obtained over the short term, it is wiser to limit the number of goats and optimize the long-term gain of milk by ensuring the commons is not overgrazed (Hardin, 1968).

Why is the tragedy of the commons relevant to fresh water? Water is an irreplaceable resource for both humans and biodiversity, and consumption or contamination of water by one group of human users renders it unavailable or unfit for other users – including ecosystems that sustain biodiversity. For instance, the extraction of river water for irrigation is incompatible with its role in preserving fish stocks, and therefore agriculture has impacts on those who make a living from fishing. Other uses of the same water, if it had remained in the river channel, might include generating hydropower, flushing wastes downstream, allowing navigation or sustaining biodiversity. Our warming atmosphere is another manifestation of this underlying tragedy, but the scope for conflict over freshwater use makes it the common resource *ne plus ultra*. Equitable sharing of water requires human users to forego gains: the farmer must limit the water he extracts for irrigation so that users downstream can enjoy some benefit; likewise, the industrialist must treat effluent – thereby limiting profits – rather than simply discharging untreated waste water. It is in the interest of individual water users to overextract or to contaminate because they profit more from doing so than from refraining; polluters also benefit from the convenient fact that river water flows downhill, so their impacts are felt elsewhere. Overextraction affects the commons whether water is taken from rivers and lakes or from underground aquifers, since depletion of the latter (see Dalin *et al.*, 2017) affects the former. Overexploitation of fishes and other economically valuable animals represents yet another expression of the tragedy of the freshwater commons since it is the short-term interests of the individual to capture yet one more fish now rather than leaving it in the river where it could contribute to maintaining the population. The tragedy of the freshwater commons is that individual users rarely forego gains voluntarily, while the majority of the community of users, and the ecosystems upon which they depend, share the negative consequences of those gains.

The view of fresh waters as a commons is, of course, something of a caricature. Fresh water is a complicated natural resource (Lodge, 2010): some sources are renewable (rivers and streams, for example) while others are not (fossil ground water); some uses are substitutable (flushing toilets) while others are not (drinking); and some benefits accrue as public goods (aesthetics, recreation, fisheries) while others reflect private goods (a drinking-water supply). Nevertheless, consideration of trade-offs among these different aspects of water reveals the potential for conflicts among users, as manifest in, for example, construction of a hydropower dam.

People dwelling downstream of the dam, or in cities some distance away, receive the benefits of flood control and electricity. But farmland and forest may be inundated by the impoundment formed behind the dam, and the livelihoods of fishers are compromised by changes in river ecology. Importantly, the impacts of the dam are felt locally, typically by the rural poor, whereas the benefits accrue some distance from the dam site. Decisions about dam building tend to be made by city-dwellers who have more political and economic influence than people who are directly impacted by the dam and, typically, receive no benefit from it. Thus, the interests of parties who stand to gain economically from generating electricity override concerns of others who derive livelihoods from the intact river. In any case, scant consideration is given to the need to conserve aquatic biodiversity or preserve ecosystems when conflicting human interests are at stake. Only the water which remains after human needs have been satisfied will be available to sustain ecosystems, and this may be a vanishingly small amount with compromised quality. Unless some external control is imposed, water is monopolized by the most powerful human users, leaving little or nothing for weaker parties, or for nature. Arguably, this is the real tragedy of the freshwater commons.

How much fresh water is available on Earth? And, importantly, what proportion of that is already appropriated by humans? In addition, how does human use of water compromise its quality? The answers to these questions will determine the amounts and likely condition of water available to ecosystems after humans have extracted and consumed their share. The matter of water quality will be addressed later in this chapter. Its quantity, however, sets the context in which biodiversity conservation must take place and focuses attention on the most salient characteristic of fresh water: that of absolute scarcity.

The Scarcity Issue

Almost all (97%) of the Earth's water is in the oceans and, of the ~3% that is fresh (i.e. its salt content is less than 1 part per thousand), around two thirds (69%) is frozen solid at the poles (mostly in Antarctica) and the remaining third (31%) is deep underground. Estimates of the quantities in liquid form on the surface vary slightly among authorities (e.g. Shiklomanov, 1993; Gleick, 1996) and are, for instance, sensitive to scaling of lake volume–depth relationships (Cael *et al.*, 2017). Irrespective, this volume is but a tiny fraction of global water: around 0.01% – or 0.3% of all fresh water – covering 0.8% of the Earth's surface. It amounts to

~105 000 km^3, much of it in lakes and fully 22% in Lake Baikal, Siberia. This volumetric estimate excludes water in the endorheic Caspian Sea, the world's largest inland-water body in terms of area (371 000 km^2), where many centuries of evaporation has rendered its contents saline – around one-third that of sea water – and only in the shallow northern basin, where it receives inflow from the Volga, could the Caspian be considered 'fresh'.

In terms of areal extent, lakes cover approximately 3.7% of the Earth's continental land surface (Verpoorter *et al*., 2014), whereas rivers encompass a very minor (almost negligible) proportion. They contain a mere 2% of surface fresh water (i.e. 0.006% of total fresh water, or 0.0002% of global water) equivalent, at any moment in time, to a standing volume of around 2120 km^3. A further 11% is in swamps of various types, including floodplain water bodies. The minute fraction in rivers is the source of most water used by humans and serves as habitat for many organisms found nowhere else. The total volume of water for sustaining humans and ecosystems, which consists of surface fresh water plus an estimate of the accessible ground water, amounts to a standing volume of around 200 000 km^3 – less than 1% of all freshwater resources.

Key Point

Freshwater ecosystems constitute no more than 0.01% of total global water volume and occupy less than 1% of the Earth's surface, equivalent to ~3% of the land area. The tiny amount of fresh water that is actually available as habitat, in combination with the number (and proportion) of species living in this water, makes them hotspots of global biodiversity. This association also goes some way towards explaining why fresh waters are hotspots of threatened species.

The Hydrological Cycle

Surface fresh water is not static, but a component of the global hydrological cycle which describes the movement of water above, on and below the Earth's surface driven by heat from the sun. However, the amount of water participating in the global hydrological cycle at a temporal scale relevant to nature and humans is a small proportion of the Earth's total – a mere 0.1%. In absolute terms, it represents a huge volume of around 520 000 km^3 annually. One of the major constituents of the hydrological cycle is atmospheric water vapour representing, in large part (87%), evaporation from the ocean plus evapotranspiration from land (13%). Most of it (79%) returns as precipitation to the oceans, but a slightly larger share (21%) than originated from terrestrial evapotranspiration falls as precipitation over land (~110 000 km^3 each year). This represents an annual net transport of ~40 700 km^3 of water from the oceans to the land. The hydrological cycle is closed when the water that does not return to the atmosphere as evapotranspiration flows to the oceans as river runoff or as renewable ground water; the former is the larger fraction (70% of the total). In contrast to those short-term dynamics, most water in the oceans, icecaps or under ground cycles at timescales in the order of thousands of years. The underground reserves mostly constitute non-renewable 'fossil' water (perhaps 15 000 000 km^3) accumulated in aquifers during the past when conditions were wetter: for example, after the melting of Pleistocene ice sheets.

Two components of the global hydrological cycle are particularly relevant to humans and nature (Falkenmark & Rockström, 2006). The water that flows downhill to the sea, whether by surface or underground routes, is known as 'blue water'. It is this that sustains freshwater biodiversity, and it amounts to approximately 28 000 km^3 annually. Soil water that passes from the land to the atmosphere by evapotranspiration is more than twice that volume (around 70 000 km^3 annually). Termed 'green water', it plays an essential role in supporting terrestrial biodiversity, the transpiration component contributing to the production of plant biomass. The extent to which precipitation is transformed into either green or blue water – or, more typically, a mixture of both – depends on local circumstances of climate and vegetation type, and the extent to which land has been converted to agriculture. In arid areas such as savannahs or places with highly seasonal rainfall like the Australian outback, blue-water flow may cease entirely for part of the year. In humid tropical areas, by contrast, the volumes of blue water are very substantial, as evinced by mighty rivers such as the Amazon and Congo. Human modification of vegetation cover and land use profoundly affect the trade-off between percolation into the soil and runoff, and the proportion of soil water that is transpired by plants, and hence the relative proportions of blue and green water. Blue water appropriated by humans for irrigation is the major component (over 60%) of global water withdrawals, and this diversion into the green-water pathway reduces the quantities available to sustain freshwater ecosystems. The relative proportions of blue and green water are particularly affected by the amount of land used to grow food, which now covers some 25% of continental land areas, although by no means all of that is irrigated. Much of the withdrawn irrigation water is converted by crops to water vapour, but some proportion is returned via percolation or runoff from agricultural land. The quality of this so-called grey water is often compromised by pesticides or fertilizers, and can degrade the receiving blue-water ecosystems. Blue water always flows downhill, but green-water movements lack this directionality, and repeated withdrawal of blue water along its passage to the sea results in progressive contamination and deterioration in quality.

In the Anthropocene world, we face a 'pandemic array' of human transformations of fresh waters globally (Vörösmarty *et al.*, 2004; Alcamo *et al.*, 2008), including changes in their physical characteristics, and their biogeochemical and biological processes. The future health and sustainability of freshwater ecosystems and the biodiversity they support will depend upon how humans use water and manage drainage basins, and any changes in the global water supply as a whole (see Box 1.1).

Quantifying Human Water Use

How much of the accessible blue-water supply or available runoff is appropriated by humans? Estimates of the proportion withdrawn – 54% is widely quoted (Jackson *et al.*, 2001; see Table 1.1) – are sensitive to assumptions about how much of a river or its flow can be regarded as accessible or, conversely, too remote from major population centres. Rivers in far northern latitudes are mostly untapped, representing slightly more than 20% of the inaccessible supply, as are large rivers such as the Congo and Amazon that drain landscapes where relatively few people live. Floodwaters are also typically unavailable for capture, and they represent about half of the estimated total global annual runoff of ~40 700 km^3 (see above). A consensus figure is that the 'available' remainder constitutes approximately 12 500–15 000 km^3 each year (Jackson *et al.*, 2001). Around two-thirds of the total runoff appropriated by humans is withdrawn for irrigation, which is by far the largest user, as well as for industries and municipalities, with another 6% evaporating from the surface of reservoirs (but see Table 1.1). The remaining 35% or thereabouts supports in-stream uses of rivers by humans, mainly through dilution of pollutants but also navigation, recreation, fisheries and so on.

Box 1.1 *The Global Water System*

The concept of a global water system (GWS) as a suite of water-related human, biological, biogeochemical and physical components – together with their interactions – provides a useful organizing framework that places emphasis on the primary objective of meeting the need for development within the bounds of planetary sustainability of water (Vörösmarty *et al.*, 2004; Alcamo *et al.*, 2008). The GWS connects several socio-ecological, economic and geophysical components at multiple scales: firstly, water in all its forms (liquid, vapour and ice) as part of the global hydrological cycle, including transport, precipitation, flow and storage; secondly, biological systems as integral transformers of water and the constituent fluxes that determine biogeochemical cycling and water quality; and thirdly, human beings and their water-related institutions, which are agents of environmental change through engineering works, as well as entities that experience and respond to shifts in pathways and thresholds within the GWS. A corollary of the GWS concept is that it is no longer sufficient (if it ever was) for water scientists and managers to focus solely on local processes, as there is a serious risk of overlooking important global dynamics with large and possibly irreversible impacts on society and nature (Alcamo *et al.*, 2008). Water security for humans and nature in the twenty-first century will require better linkage of science and policy, as well as innovative and cross-sectoral management initiatives and polycentric governance models (for elaboration, see Bogardi *et al.*, 2012).

The amount of water that is available for human use in the form of annual precipitation on a global scale is currently far in excess of demand, but the spatial and temporal patterns of accessibility of water derived from that precipitation are not well-matched to the distribution of people. Blue water is overextracted in some areas, often accompanied by pumping and consequent depletion of non-renewable underground water but is relatively underused in places where conditions do not favour settlement or agriculture. The demand for water has increased four-fold during the last half century, and the global population, which is now 7.5 billion, is projected to reach 9 billion by 2050 or thereabouts at which time up to 70% of the available supply may be appropriated. Human populations are growing faster than potential increases in

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Table 1.1 *Blue-water runoff, withdrawals and appropriation by humans. Data from Jackson* et al. *(2001) and sources therein. Note that these figures are broadly indicative, as estimates the volume of runoff, appropriation, consumption, etc. vary among sources, and have been subject to updating (see text and, for example, Cael* et al.*, 2017).*

	Volume (km³/y)
Total runoff (rivers + renewable ground water)	40 700
Remote (geographically inaccessible) flow	7800
Flood water	20 400
Accessible runoff	12 500
Human appropriation	6780 (54% of accessible runoff)
Withdrawals	4430
Irrigation (agriculture)	2880
Industry	975
Urban (domestic)	300
Losses from reservoirs	275
In-stream uses (e.g. dilution of pollution, navigation, etc.)	2350
Consumption (after withdrawal, converted to green water)	2285 (18% of accessible runoff; 33% of appropriation)

blue-water supply, which can only be brought about by building dams and reservoirs to trap and store flood flows, and rapid shifts in anthropogenic water use are causing dramatic changes in patterns of water stress (Alcamo *et al.*, 2008).

One-fifth of cultivated land is irrigated, and it is highly productive yielding around 40% of the world's food. An increase in its extent will likely be needed to feed the 1.5 billion additional people expected by 2050 and improve the nutritional status of many others currently undernourished. This will increase withdrawal and consumption of blue water. Water-saving and irrigation technologies could slow the rate at which demand for water grows, and more efficient application of fertilizers might reduce waste and the consequent pollution of fresh water (Foley *et al.*, 2011). Because many rivers and lakes are situated in the far north where the inhospitable climate limits agricultural potential, the demands

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for blue water in latitudes suitable for agriculture will undoubtedly increase. Shifts towards diets incorporating greater amounts of animal protein will exacerbate this situation. As a rough indication, the annual water requirements of a meat-rich diet are 12 000 m^3 per person, whereas an adequate mixed diet can be produced using only 1300 m^3; a 3000 kcal-per-day purely vegetarian diet needs only 500 m^3. Supplying the food needed to eradicate hunger, feed the Earth's growing population and provide for dietary shifts could increase both green-water use and blue-water consumption by 50% during the next two decades This scenario could result in overstepping of the 'planetary boundary' for sustainable water use by humans estimated at 4000 km^3/y globally, with an upper uncertainty bound of 6000 km^3/y (Rockström *et al.*, 2009).

The planetary boundary for blue water is of profound relevance here because (and, again, the medium is the message) as more water is consumed by humans, there is less available to sustain freshwater biodiversity. A conservative estimate of this planetary boundary should take account of both human needs and of environmental-flow requirements; i.e. it would include some allocation of water for nature to protect freshwater ecosystems. Depending on the method used to assess ecosystem needs (see Gerten *et al.*, 2013), that global boundary is ~2800 km^3/y (the average of an uncertainty range between 1100 and 4500 km^3/y), considerably less than the earlier threshold of 4000 km^3/y estimated by Rockström *et al.* (2009). Global blue-water consumption is more than 1700 km^3/y at present, and exceeds the lower end of the estimated planetary boundary, amounting to 61% of the 2800 km^3/y threshold (Gerten *et al.*, 2013; this proportion is higher than the estimate of 54% in Table 1.1).

Another estimate of planetary boundaries for blue water confirms the 4000 km^3/year global value and gives a value of ~2600 km^3/y for current consumptive use (Steffen *et al.*, 2015); this is 65% of the 4000 km^3/y threshold, close to the estimate of 61% by Gerten *et al.* (2013). This planetary boundary for water indicates there is still some scope for expansion of water use, but that impression may be misleading since water is extracted from rivers or lakes at a local rather than a global scale. At the river-basin scale, and especially in arid regions, there are likely to be many places where blue-water consumption is in excess of what would be envisaged as ecologically sustainable. The effects of decisions about how much water can be extracted locally depend on assumptions – assuming these are made at all – about the environmental water requirements of individual rivers, which will differ between those with stable