

# *Three challenges for the science of river conservation*

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## INTRODUCTION

Millennial perspectives, like the one prompted by this Special Issue of *Aquatic Conservation*, are challenging. If we look back, we realize the degree of change in culture, technology, science and environmental quality that can occur over such time scales. Consider, for example, that by the turn of the last millennium, our global population was somewhere between 200 and 500 million (Ehrlich *et al.*, 1977; Goode, 1993). *Homo sapiens* had only just colonized Madagascar (*ca* 500 AD) and New Zealand (*ca* 700–800 AD). Forest clearance was already under way in some areas, including Britain (Birks, 1988), but large areas of the rest of the world were still largely under semi-natural vegetation (Goode, 1993). Emerging from the dark ages, major new technologies were the compass (*ca* 1100 AD)—among the first of all hand-held instruments—but also features that from here on would hasten the worldwide modification of wetlands and their catchments: the horse collar, the stirrup, the heavy plough, the windmill, and the water wheel. Now, 1000 years later, technology pervades most of our activities. We approach our 6th billion (population), and large areas of the world are dominated by human activity or management: 65% of Europe, 29% of Asia, 25% of North America, and 36% of the exploitable global surface in total (Hannah *et al.*, 1994). Global extinctions have accelerated from a background rate of just 2–3 species per year to 100–1000 times this value, with the prospect of increase in the coming decades by a further order of magnitude (Lawton, 1996). All this has occurred in the equivalent of about 13 human lifetimes.

Looking forward, therefore, there are bound to be difficulties in making straightforward predictions about the shape of things to come. Yet, there is one certainty of both our past and future: we are fundamentally dependent on the need to exploit water resources, and to protect their quality for the services, resources and intrinsic ecosystem value they contain. It was no coincidence that human civilizations grew along the fertile and richly irrigated floodplains of the Nile, the Indus, the Euphrates and the Tigris. Already by 2500 BC human settlements were characterized by wells, reservoirs, aqueducts, canals, piped distribution systems and sanitary drainage. Intimately bound with water as we have been, archaeological artefacts provide evidence that exploitation of aquatic resources is ancient: pots, boats, fish-traps, the use of *Papyrus* or *Salix* spp.

Now, however, there are indications that this fundamental bond with water is under strain. Current global trends in population mean that demands on surface water and groundwater resources must

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rise—in some regions substantially (Falkenmark, 1997). Only long-term, large-scale perspectives in environmental management will sustain freshwater environments, but some will face major risks. In this brief polemical essay, I will discuss our ability to sustain the informed management of river ecosystems and their catchments in the wake of three major challenges:

- (i) To understand river ecosystems in regions of the world where the threats to water resources will be greatest.
- (ii) To develop approaches to river management that are scientifically robust and validated at the geographical and temporal scales required.
- (iii) To maintain an holistic and ecological understanding of rivers at a time when biological research is increasingly reductionist.

### A GLOBAL VIEW

Many—probably most—readers of this article will work in offices or laboratories in the economically ‘developed’ regions of Europe, North America, Australasia or South Africa. All of us will know cases where aquatic management continues to be problematic due to pollution, exotic introductions, habitat change, disturbance, abstraction or impoundment. In addition, because of our economic history, the developed regions have the dubious privilege of being able to offer unique examples of the difficulties in *restoring* river ecosystems from past damage. The effects of diffuse pollutants—eutrophication, xenobiotic chemicals and acidification—indicate by their persistence over decades to centuries that it is probably wiser to protect ecosystems from damage in the first instance than to allow degradation from which recovery will be uncertain (e.g. Buckton *et al.*, 1998).

There are now good reasons to believe, however, that more substantial problems for river management will arise over the coming decades in the less developed regions of the global south and east. They will add to problems in these same regions that are already locally substantial (e.g. Jüttner *et al.*, 1996). Greenland *et al.* (1997) edited a series of review articles that arose from a special meeting at the Royal Society of London to consider the current balance between global population trends and resource availability. Working from United Nations population projections, Fischer and Heilig (1997) illustrated the key predictions that have serious consequences for all other resources. First, despite falling fertility (currently *ca* 2.7 births per woman), global population will probably continue to rise by around 80 million per year until 2015. Medium UN projections then suggest that *growth* will slow to around 50 million per year to produce a global total of 8.9 billion people by 2050 (7.3 or 10.7 billion at the low and high projections; UN data for 1988: <http://www.popin.org/pop1998/>). Second, however, growth and population will not be equally distributed across the world. Most of the additional 3.7 billion people between now and 2050 will occupy the less developed world; 2 billion will be in Asia, and 734 million in Africa, so that its current population will more than double. This latter increase is adjusted already to account for likely increased mortality through AIDS, which in any case affects many people only beyond their reproductive age. India, China, Pakistan, Nigeria, Ethiopia, Indonesia, Bangladesh, Zaire and Iran—and paradoxically the United States—will contribute most to world growth. At finer scales, growth through birth and migration will continue to augment urban populations, which already comprise 50–60% of the world’s people. All these projections are, of course, underscored by uncertainty—at least beyond a horizon of 10–15 years. Nevertheless, even demographers critical of longer-term projections illustrate that human populations are now approaching numbers close to most estimates of global carrying capacity (Cohen, 1995). Planning and development with the expectation of population increase is prudent and inevitable.

The potential consequences of these demographic trends for water resources are alarming. Current estimates are that around 35% of the earth's accessible run-off of 12500 km<sup>3</sup> per year—excluding that in remote regions or some large rivers—is now co-opted directly into human use (Postel *et al.*, 1996). Of this, the major use by far is in agriculture (> 65%) and industry (22%). An additional 2350 km<sup>3</sup> of unabstracted run-off is sometimes considered within the 'used' fraction since it provides for essential instream needs, such as navigation, recreation and the dilution of pollutants. With this further contribution, our use of the world's available water is already at 55%.

As with population distribution, however, exploitation rates are not evenly distributed across the globe. Areas such as western, southern and central Asia are already using more than 55%, and north Africa exploits near to 100% of all available sources (Falkenmark, 1997). Falkenmark (1997) and Wallace and Batchelor (1997) have calculated the additional demands that might arise from population growth at the UN estimated rates. In outline, the projections by 2025 are that 55% of the world's population will have insufficient water for food production due to two combined effects: population growth and the difficulty of tapping new water resources rapidly enough to meet the new demand. Those 4.6 billion people affected will be mostly in southern and western Asia, northern China and the whole of Africa. Equally alarming for those concerned with river conservation and management, population growth in some regions—for example, in south-east Asia—is considered manageable by exploiting a further 20–40% of the run-off available. This indeed is suggested as a major strategy for coping—along with improved efficiency of use, water-saving technology and integrated catchment management (Wallace and Batchelor, 1997).

Even with all the uncertainties, the difficulties posed for river conservation and management from these future trends will be substantial. First, the exploitation rates proposed will clearly require the development of impoundments, increased surface abstraction, groundwater use and inter-basin transfer. All will reduce river flows in some locations and at some times. Second, increased water demands will be accompanied by other consequences of population growth and urbanization, such as diffuse and point-source pollution from sewage, industry and agricultural production. Third, there will be a need to maintain the quality of raw water relative to human uses—particularly potable supply. Fourth, increased pollutant release implies a need to maintain in-river volumes to allow appropriate dilution. These consequences, of course, embody a series of conflicts (Figure 1). The ultimate consequences for rivers and wetlands will be reduced availability, effects on quality, and increased management. Knock-on effects will also be likely in terrestrial systems as evapo-transpiration is co-opted and flow-paths rerouted (e.g. Postel *et al.*, 1996). Moreover, all these interactions will take place within a context of increasing climatic uncertainty.

The fact that many of these changes will take place in Asia and Africa adds to concerns for aquatic conservation and further compounds uncertainty. Increasingly, macroecological perspectives reveal that biodiversity is not evenly distributed across the globe, with areas such as the tropics recognized for their richness. So far, assessments of the global distribution of freshwater organisms have been scarce. Recently, however, Buckton (1998) showed for specialist river birds that subtropical regions with high relief, high drainage density, high rainfall and large primary productivity contribute disproportionately to global species diversity. South America, Africa and, in particular, Asia have large richness (Figure 2). These patterns appear to match those for fish (Oberdorff *et al.*, 1995) and amphibians (Dudgeon, 1999). These same subtropical areas of high relief are characterized sometimes by marked endemism (Jüttner *et al.*, unpublished data) and rich benthic communities with well developed altitudinal patterns in beta diversity (Ormerod *et al.*, 1994). However, despite some pioneering limnological research over decades, ecological knowledge of aquatic ecology in the less-developed world is still scant. The review of Buckton (1998) on global knowledge of specialist river birds, perhaps predictably, reveals that published ecological work has overwhelmingly avoided exactly those areas of the world where biological richness is greatest (Figure 2).

Together, these foregoing discussions take us to the view that the future ecological impacts of population change and water resource development will be in exactly those areas of the world where biological richness is greatest and ecological knowledge thinnest.

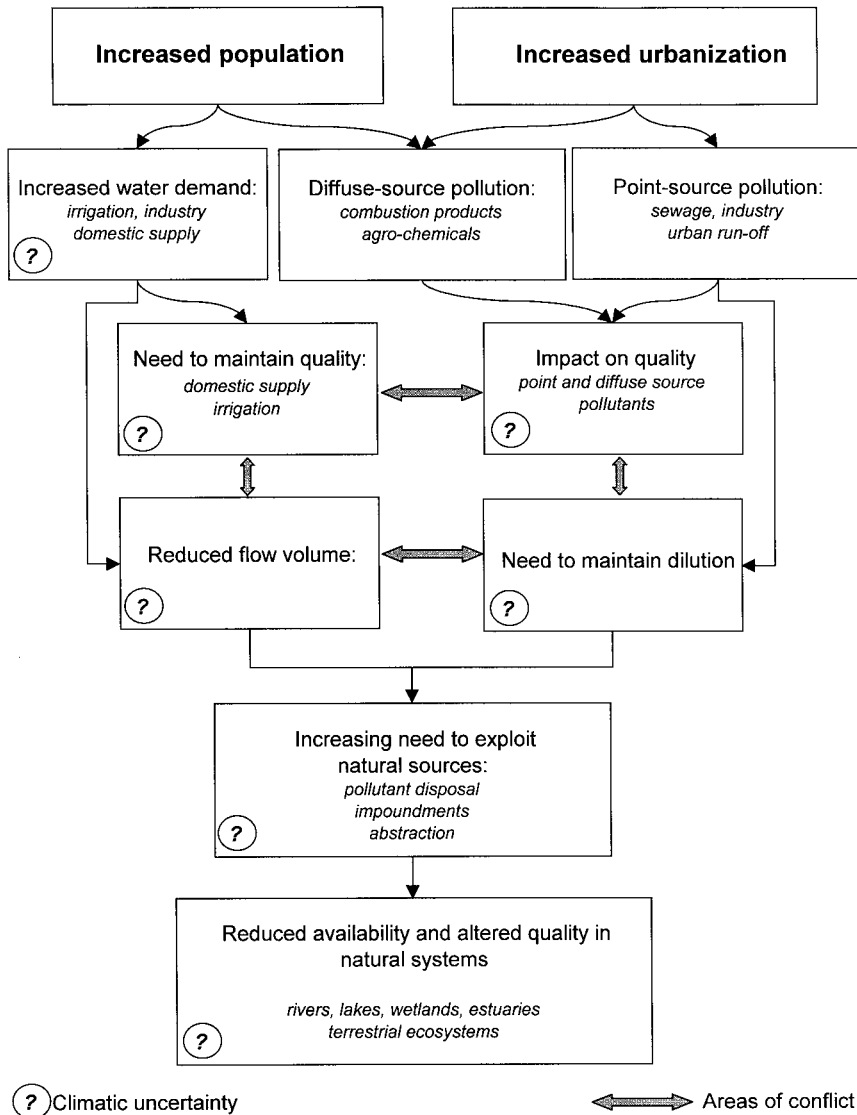


Figure 1. Possible ecological consequences for waters likely to arise from UN predicted population growth and increased urbanization in the less-developed world.

### A QUESTION OF SCALE

The difficulties of river management in both the developed world and the less-developed world require us to take long-term and large-scale perspectives. Many of the problems are large and diffuse in their own right (acidification, eutrophication, climate change, xenobiotic pollutants). In addition, only a macroscopic view can reveal the cumulative regional effects on ecosystem quality and biodiversity of piecemeal change due, for example, to habitat alterations, abstraction, impoundments, introduced species, sewage and other point-source outfalls. The arguments for taking this larger view of river systems are well rehearsed (e.g. Allan and Johnson, 1997; Johnson and Gage, 1997):

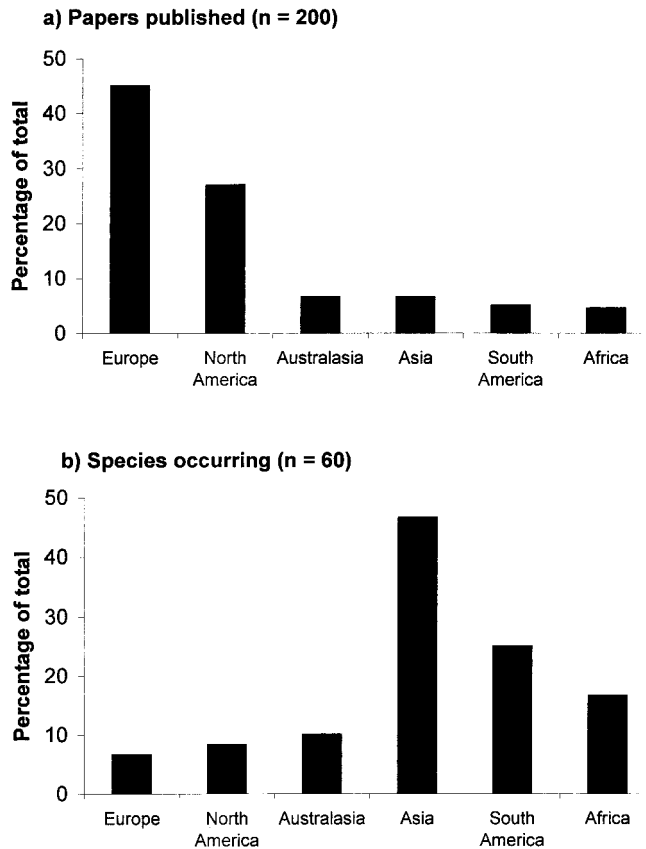


Figure 2. (a) The percentage of all scientific papers published by region on specialist river birds and listed by the Bath Information Data System (BIDS), 1981–1999. (b) The percentage of specialist river birds occurring in each of the same regions (after Buckton, 1998).

- River basins function as integrated hydrochemical units in which catchment character and river ecology are inextricably bound.
- River catchments are natural nested hierarchies or graded patchworks with microhabitats, reaches, segments, streams and subcatchments.
- Rivers and their processes express longitudinal patterns, such as energy continua or nutrient spirals, in which are embedded zonal biological patterns.
- River catchments embrace wetland–floodplain interactions and ecotonal links with riparian zones or groundwater.
- Catchment units figure increasingly in management perspectives, regulation and conservation designation.
- River catchments cross political boundaries, providing some of the major barriers to effective care.
- The tools to allow scientific analysis at catchment scales are increasingly available.

Rather less often, however, are there expressions of how difficult it is to deliver scientifically robust approaches to managing rivers and their catchments at the scales required. Experimentation is now a central paradigm in ecology (Hairston, 1989), through which hypotheses are falsifiable or model predictions testable to destruction. Indeed, some authors believe that *only* manipulative experiments permit us to test ecological hypotheses, and hence to provide a rational and scientific basis for

understanding environmental cause and effect (e.g. McArdle, 1996). Others point to the problems of assuming that correlative data—so common in riverine studies—can deliver the same degree of confidence (Havens, 1999). Part of my own work, involving a large-scale experiment to test predictions from empirical observation about the effects of acidification, revealed why such assumptions can fail to deliver the whole truth (Rundle *et al.*, 1995). One corollary is that river management based on observational data alone risks taking actions that might have effects different from those desired.

It is clear, however, that some ecological phenomena occur over spatial scales and time scales too large to be reproduced by replicated manipulation (Levin, 1992). Moreover, workers carrying out typically scaled ecological studies (Kareiva and Anderson, 1989) recognize often that their work is characterized by limited realism and limited relevance to larger patterns. The first of these problems impinges at the catchment scale: experimentation—although important and classical when performed—is scarce and difficult. The problems of expense and logistics are particularly acute in remote areas of the less-developed world, where many of our needs for ecological understanding are becoming greatest.

So where might this leave the ecologist or manager seeking a scientifically robust catchment perspective? On the one hand, there are the difficulties of realism and limited scale in experimentation. On the other, there are the risks of confounds, lack of control and limited cause–effect perspective, which surveys or observational data can provide.

Most of the required leads are currently coming from different quarters. For example, fundamental macroecologists have responded to criticisms about the correlational nature of their own field by condoning the use of ‘natural’ experiments, models and observational data in hypothesis testing (Gaston and Blackburn, 1999). They argue the importance of understanding global-scale ecological patterns that are inevitably beyond experimental validation. They point to parallels with astronomy, in which a whole universe is interpreted through observational studies without experimental manipulation. Parallels with catchment science and conservation are also apparent. Second, river and catchment ecologists show a growing confidence in their own approaches. Johnson and Gage (1997), for example, highlight the array of computational techniques now available for gradient analysis and for relating river ecology to catchment attributes. Although correlational, these approaches can be validated in a modelling context where ecological pattern is predicted at sites geographically isolated from those involved in calibration (e.g. Manel *et al.*, 1999).

Observational studies also offer important opportunities when groups of independent sites are contrasted by essentially experimental techniques, such as analysis of variance. For example, Ormerod *et al.* (1993) and Jüttner *et al.* (1996) used this approach to compare, respectively, across replicate groups of catchments with contrasting riparian management and pollution status. These same effects could have been recreated by experiments only over time scales of decades. Particularly when supported by studies of catchment processes at smaller numbers of locations, these catchment-focused approaches offer important information about catchment management and conservation. Examples are still few, however, and their application in the less-developed world is in its infancy. Moreover, observational approaches call for a degree of scientific pragmatism since the investigator must accept some of the drawbacks of non-interventionist studies in the same way that experimental ecologists have to accept the effects of design artefacts.

## A QUESTION OF DISCIPLINE

All of the foregoing discussion about the work that river and catchment ecologists might deliver for river conservation is based on two assumptions. First, that we will continue to train personnel with appropriate skills. Second, that appropriate ecological science will be funded and developed. Many ecologists are now concerned, however, that their discipline is in decline. Quantitative evidence is not always easy to find, but

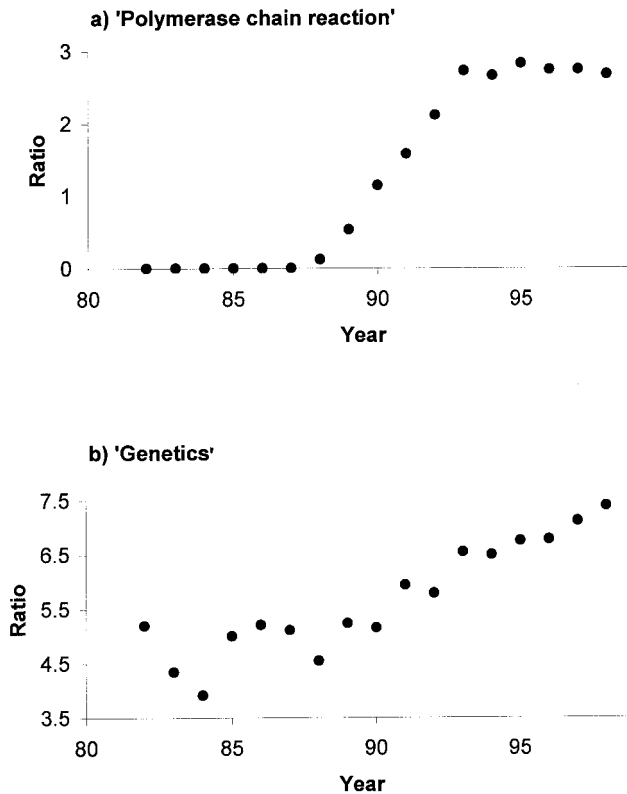


Figure 3. The changing face of biology. The ratio for each year between the number of published papers carrying the words 'polymerase chain reaction' (a) or 'genetics' (b) in the summary or title and those carrying the word 'ecology' as reported in the Bath Information Data System between 1981 and 1999.

consider Figure 3. According to the Bath Information Data System (BIDS), which abstracts a large but not exhaustive listing of the world's journals, around 22474 papers carrying the word 'ecology' in the title or summary were published between 1981 and August 1999. This compares with 141850 carrying the word 'genetics' and 46381 the phrase 'polymerase chain reaction' (PCR). Note, however, the temporal trend in the ratio between papers in which these words figured: roughly seven papers are now published in genetics to every one in ecology by comparison with roughly 3.5–4:1 in the early 1980s. PCR, since appearing as a major genetics technique in the late 1980s, is now used in nearly three papers for every one in 'ecology'. It is so far unclear whether these trends from very crude indicators represent a real redirection of research funds away from whole-organism and ecosystem biology. Equally, some of the new explosion in molecular biology is being directed at ecological knowledge and conservation biology. Nevertheless, patterns like this are consistent with the view that the scope of biology is changing towards reductionism at exactly the time when the needs for holistic approaches to environmental problems have never been greater.

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