

## PART ONE

# Methods

Part 1 of this book explores various methodological approaches to the problem of the “Anthropocene” and, in so doing, challenges any simplified notion of what Anthropocene scholarship might look like. The concern here is first and foremost the implications of global anthropogenic environmental change, but it is also the ways that scholars, policy makers, NGOs, and communities might work together to respond to these challenges.

In different ways, the authors implicitly engage with methodological problems associated with scale. They are interested in how to take the abstract concept of the Anthropocene—the idea that it is an anthropogenic, historical, global phenomenon that has permanently altered the earth’s systems (water cycles, climate, etc.) and has left a defined geological mark across the entire planet—and adapt it to regional and local conditions. They recognize the fact that scientific agendas, frameworks of governance, and even individuals’ imaginations rarely operate at the global scale. Except for global modeling and high-level governance, such as the Paris Accords, most people’s engagement with and understanding of the environment is much more localized. Even the Paris Agreement (United Nations Framework Convention on Climate Change), which was framed according to global principles, emerged out of localized interests and will be implemented differently throughout the world.

This disconnect between the abstraction of the Anthropocene and its lived realities is a challenge to researchers. For example, those working at the interface between science and governance recognize that biophysical systems rarely align with geopolitical boundaries. This is especially the case with rivers, which often flow across numerous geopolitical divides. Take the Colorado River. Reflecting on a visit to its delta in 1922, Aldo Leopold wrote of a vibrant ecosystem:

The still waters were of a deep emerald hue, colored by algae, I suppose, but no less green for all that. A verdant wall of mesquite and willow separated the channel from the thorny desert beyond. At each bend we saw egrets standing in the pools ahead, each white statue matched by its white reflection. Fleets of cormorants drove their black prows in quest of skittering mullets; avocets, walleys, and yellow-legs dozed one-legged on the bars; mallards, widgeons, and teal strand skyward in alarm. As the birds took the air, they accumulated in a small cloud ahead, there to settle, or to break back to our rear. When a troop of egrets settled on a far green willow, they looked like a premature snowstorm. (Leopold 1968, 142)

That same year, individuals from states that intersected with the river signed the Colorado River Compact, a plan that set in process the decades-long siphoning of water from the river. The following years saw the construction of Lake Powell and Lake Mead. By the 1970s, coupled with the increased consumption of water upstream, the Colorado delta had shrunk until water no longer flowed to the sea, destroying a once healthy ecosystem and undermining the livelihoods of those who relied on its flow, including the Cucapá, who used the river for agriculture and fishing. A map of the Colorado River Basin published by the U.S. Department of the Interior, Bureau of Reclamation, in 2012 provides a metaphor for the challenges of working with transboundary river systems. In its summary map, “Colorado River Basin Water Supply and Demand,” the basin itself stops at the U.S. border with Mexico (U.S. Department of the Interior, Bureau of Reclamation 2012). In effect, there is a historical mismatch between the geographical scales of river systems and the geopolitical scales of states.

Even when they do not cross international boundaries—even at the local level—sociopolitical frameworks shape how we respond to rivers. River governance is often a hodgepodge of overlapping public agencies, nonprofits, and private interests. One small stretch of a river in the eastern United States might be governed by federal agencies, such as the Army Corps of Engineers, the Environmental Protection Agency, or the United States Geological Survey; state departments of environmental management and natural resources; municipal authorities; local utilities; and citizens’ groups. Conceptualizing the global nature of the Anthropocene in the context of regional or local affairs reveals the difficulty of scaling the concept. What does the Anthropocene mean to a local council or municipal government? How might it transform the decision-making process? In a democratic society, what are the implications for a disconnect between local conditions and global challenges in the minds of voters?

In chapter 2, Large, Gilvear, and Starkey ponder the problem of shifting baselines. Across large distances and swaths of time, capturing micro-level data to establish both site-specific and systemwide change is difficult. Their solution is to merge the framework of ecosystems services with open data and citizen science as a new method for capturing information. In chapter 3, Marx turns to issues of scale and power. In her words, humankind is “not a single global agent.”

Both the causes and the consequences of environmental change are experienced unevenly. Looking at the Koga water projects in Ethiopia, she shows that even narratives about how to respond to environmental change operate differently at different scales. Drummond continues the theme of narrative by focusing on the story of the Anthropocene itself. She argues that all narratives—especially historical ones—embed ethical constructions. Her essay emphasizes the power of exploring these stories. In chapter 4, Lubinski and Thoms explore the relationship between scholars and society. Whereas Large, Galvear, and Starkey consider how to develop a methodology that involves citizens in the research endeavor, Lubinski and Thomas ask how scholars can keep issues relevant to the public and high on the priority list of policy makers. Their answer is that a key element of scholarly methodology is public engagement.

In sum, these chapters suggest that the Anthropocene—as both an intellectual concept and a lived experience—might encourage scholars to rethink the practices and assumptions built into their research practices and institutions. The geophysical-sociocultural shifts of the Anthropocene, new baselines and accelerated change, may require new modes of scholarship better suited to these new contexts.



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# Ecosystem Service-Based Approaches for Status Assessment of Anthropocene Riverscapes

Andy Large, David Gilvear, and Eleanor Starkey

## RIVERS OF THE ANTHROPOCENE AND KEY DRIVERS OF GLOBAL CHANGE

Rivers are of immense importance, geologically, biologically, historically, and culturally, and they are central to many of the environmental issues that concern society (see, e.g., Sponseller, Heffernan, and Fisher 2013). It is clear, however, that we are entering an era in which humans are accelerating and decelerating natural processes and altering, creating, and destroying ecosystems at “an astonishing pace” (Syvitski 2012, 12). Gaffney (2009, 1) has described this as “moving out of the Holocene envelope,” also highlighting the fact that in an “astonishingly short period” of 250 years, humans have developed the capacity to alter the global earth system in ways it has not been altered for millions of years. Pastore et al. (2010) highlight four principal drivers of hydrological change in river systems: water engineering, land cover change, climate change, and human decision making—all of which have provoked worldwide adjustments in terms of catchment-scale water stores and fluxes, biogeochemistry, and river morphology. Harrigan et al. (2013) demonstrate how multiple drivers, acting simultaneously but over differing time scales, drive stream-flow alteration. It is estimated that the annual, worldwide, deliberate shift of sediment equates to 57,000 million tonnes (Mt), an amount that exceeds that of transport by rivers from the land to the oceans (22,000 Mt) by almost a factor of three (Douglas and Lawson 2000; Price et al. 2011). In terms of the planet’s river systems, we have clearly entered the “Anthropocene” (Crutzen and Stoermer 2000), when earth systems are becoming defined by human agency so profound that it is potentially affecting the stratigraphic record. Erosion and

sedimentation offer a classic case of this process in action (Waters et al. 2016; Zalasiewicz et al. 2008).

The planet is now host to over seven billion people, and as of the first decade of the twenty-first century, 50 percent of humanity was urbanized. Each and every one of us was born and lives in a river catchment; therefore, a number of key questions arise as to how we approach management of river systems, with their uneven range of pressures experienced under often intensely crowded conditions. Relatively natural or pristine segments of rivers are increasingly rare throughout much of the world. As Thorp, Thoms, and Delong (2006) attest, this makes it a formidable task to study and manage such systems in a human-dominated world. Ellis and Ramankutty (2008, cited in Schwägerl 2014, 38) make the claim that “only 22 percent of the earth’s surface is still wilderness and only 11 percent of photosynthesis takes place in these wild areas.” From this, they conclude that this new worldview of the biosphere constitutes a paradigm shift from it constituting “natural ecosystems with humans disturbing them” toward a vision of “human systems with natural ecosystems embedded within them” (Ellis and Ramankutty 2008, 445).

Yet after more than a century of research on rivers and their physical and biotic makeup, we still lack robust baselines as to how these freshwater ecosystems function. This paucity of reference points hinders widespread understanding of what ecosystem services are delivered by rivers either as natural systems with humans disturbing them or as human systems with remnants of natural aquatic ecosystems embedded in them. More and more, as we venture deeper into the new Anthropocene epoch (as defined by Waters et al. 2016), it is vital to gain this widespread understanding in forms that are accessible to scientists, planners, managers—and to the general public who live in these riverine landscapes or “riverscapes” (*sensu stricto* Wiens 2002). Scholars from a range of disciplines have traditionally framed problems of environmental change and degradation within disciplinary constructs; however, an increasingly important question is to what extent *transdisciplinary* perspectives on the relatively recently defined Anthropocene epoch can provide new ideas, new understanding, and better approaches to river management. Here, we define “transdisciplinary” as producing new frameworks of understanding and working that would not be achievable in individual disciplines alone or by using interdisciplinary approaches (where typically two disciplines come together to produce a more integrated approach).

In this chapter, we briefly explore what constitutes a “river of the Anthropocene” and introduce a methodology using free and ubiquitous software to assess river condition and status using physical (geomorphological) features as they relate to ecosystem service provision. The methodology is designed to have worldwide applicability, and we illustrate it here using the River Tyne, a medium-sized temperate river system in the United Kingdom. Enacting meaningful catchment or watershed-wide change in systems like the Tyne may appear a daunting task, but

is perhaps more easily visualised as “seven billion collective decisions”—that is, envisaging a world where each and every one of us living in a particular watershed has a choice to make and a role to play. Using a subcatchment of the River Tyne, we therefore also briefly explore here the role of people and communities in “crowd-sourced knowledge partnerships” built through communities assessing and monitoring the “pulse” of their own watersheds. Such approaches, combining the rigor of small-scale studies with broader ecosystem-scale assessments (e.g., Nelson et al. 2009), as well as proper mapping, monitoring and assessment programmes (e.g., Naidoo et al. 2008; Langhans et al. 2013), are needed for more effective management of rivers in the Anthropocene through integration of new knowledge with changing societal goals.

### THE CONCEPT OF DAMAGE

It is undeniable that today the vast majority of the planet’s rivers are anything but “pristine” or even near-“natural” (see, e.g., Wohl 2013). Despite the fact that shoreline length and tributary junctions still provide key space in modern catchments for natural processes, worldwide we are no longer dealing with “natural” rivers. Here we use Newson and Large’s (2006) definition of natural rivers as those requiring minimum management interventions to support system resilience and protect a diversity of physical habitat. While system resilience and habitat diversity are neither universal nor perpetual, their role increases with the proportion of the channel network within the fluvial system exhibiting a full interplay of unmanaged water and sediment fluxes with local boundary conditions. Catchment connectivity (and increasingly its lack) is therefore key. Over the past several decades, catchment management efforts worldwide have made major strides, but their overall effectiveness has typically been hampered by two things: lack of definition of what constitutes a useful reference point (baseline) typical of a natural or little-altered river; and inability to fully address this issue of catchment connectivity. Where freshwater systems are fragmented, truly effective ecological restoration is difficult; at the same time, inappropriate catchment management can exacerbate issues like flooding whereby water is moved speedily through catchments with devastating effects on downstream communities (worldwide, the vast majority of catchments have their urban areas downstream rather than in the uplands).

Implicit in the many studies is the idea that human involvement in catchments equates to “damage.” It is not so important when this damage began to occur (debate continues as to the timing of the onset of the Anthropocene, often seen as the point where rivers of prior reference status began to significantly degrade, with “degradation” broadly defined as ecological and physical simplification). According to Crutzen and Stoermer (2000), the start of the Industrial Revolution (ca. 1800) is the point when human activity accelerated so dramatically that humans became a dominant force on the planet and its water bodies. Kirch (2005), on the other hand,

asserts that while human-induced changes to the global environment have accelerated with industrialization over the past three hundred years, such changes have a significantly longer cultural history, highlighting deforestation, spread of savannah, and rearrangement of landscapes for agriculture as examples. The conclusion of Waters et al. (2016) that the Anthropocene is functionally and stratigraphically distinct from the Holocene can only induce a stream of works each claiming to pinpoint the date of commencement of the new geological epoch. The time scale we adopt in this chapter is that of the “Great Acceleration” (Steffen, Crutzen, and McNeill 2007). Far more important overall is how we view and determine the *future* for rivers in the Anthropocene given that most rivers globally no longer operate according to their “Holocene norms” (Large and Gilvear 2015). Steffen, Crutzen, and McNeill (2007, 618) contend that that we are already at the beginning of the “third stage of the Anthropocene” (stages 1 and 2 being the Industrial Era and the Great Acceleration, respectively), where the “recognition that human activities are indeed affecting the structure and functioning of the Earth System as a whole (as opposed to local- and regional-scale environmental issues) is filtering through to decision-making at many levels.” This growing awareness of human influence on the earth system has been aided by rapid advances in research and understanding. Pastore et al. (2010) emphasize the importance of understanding how humans have shaped the hydrology of the past in order to expand our understanding of the hydrology of today and of the future.

For rivers of the Anthropocene new organizational frameworks are needed for transdisciplinary investigation. These frameworks need to encompass the four areas referred to above, water engineering, land cover change, climate change, and human decision making, but also include the questions of motivation and impact. Researchers need to debate what constitutes “damage” and what it means to “restore” freshwater systems. What constitutes ecosystem “health” in the Anthropocene is also not at all clear, despite some notable international water legislation that has already been enacted (notably, the European Union Water Framework Directive at whose core is the definition of aquatic system health).

“Conservation-based management” and “design with nature” (Downs and Gregory 2004) have been identified as key approaches to the management of modern rivers. In both approaches there is an implicit reference to the current damaged state of river ecosystems and loss of reference status. This debate over “nature” is a vital component of both the scientific and popular agendas for sustainable development (Newson and Large 2006) but in extreme cases can become a barrier to efficient restoration projects. In some cases historical assumptions regarding “nature” can be confounding; Walter and Merritts (2008), for instance, highlight how a vision of an “ideal meandering form” exemplified by gravel-bed rivers has dominated restoration efforts in many riverscapes of the United States. In fact, the pre-European settlement of swampy landscapes and forest-dominated anabranching systems with cohesive sediments was the markedly different reality.

Effective management of Anthropocene riverscapes therefore requires more structured condition assessments. Where and what are the major riverine habitat areas under threat? Which are of greatest priority for river conservation, and why? What are their optimal sizes and spatial arrangements? What will be the effects of widely predicted global climate change? Globally, there is still an urgent need to effectively map refugia in order to boost chances of restoring key communities within catchments. Carpenter et al. (1992) have highlighted the potential impacts of global climate change on freshwater systems, and the United Nation's Millennium Ecosystem Assessment (MEA 2005) has clearly shown that in terms of drivers of change freshwaters in particular have experienced very high rates of habitat change and pollution and that these impacts are increasing at a rapid and worrying rate. While we cannot ignore these warning signs, geographically the type and scale of impacts also differ markedly. In the world's drier lands the main perceived fluvial damage is that caused by dams to flow regimes (Graf 1999; Newson, Pitlick, and Sear 2002). Elsewhere, the "damage" inflicted by flood defense works during the past century currently dominates the agenda of river restoration in northern Europe and North America. In all cases, management for the future of our Anthropocene rivers is complicated by the specter of climate change, with the current forecast being increased incidence of extreme drought and flood events in a warmer world (Kendon et al. 2014).

This takes us back to the issue of what constitutes a "natural" riverscape and to what extent this should actually constitute reference conditions in catchments that we cannot hope to return to their pre-Industrial Revolution status (fig. 2.1). Acreman et al. (2014) conclude that in heavily modified river systems lower expectations of a return to "naturalness" lead to flow regimes designed both to maximize natural capital and to incorporate broader socioeconomic benefits. Defining how far such rivers have shifted from their historical (i.e., dynamic) equilibrium requires extensive monitoring, which entails significant economic costs. Associated issues include (a) prevalence of suboptimal monitoring strategies, (b) an assumption of "active" engineering-based restoration (again costly in economic terms) rather than "assisted natural recovery" (Newson and Large 2006), and (c) a lack of evidence linking restoration/rehabilitation with tangible ecological and economic benefits. To assess rivers effectively so that our "Anthropocene management interventions" are deemed similarly effective, methods need to be developed that integrate river system hydrology/hydraulics, geomorphology, and ecology (and the complex interplay between these three different scientific disciplines). This leads to a challenge for scientists, policy makers, and managers of rivers as to how we can effectively merge quantitative models of earth systems and human systems with the more qualitative approaches prominent in the environmental humanities to establish effective baseline assessments. As Carpenter et al. (2009, 1305) conclude, "New research is needed that considers the full ensemble of processes and feedbacks, for a range of biophysical and social systems, to better

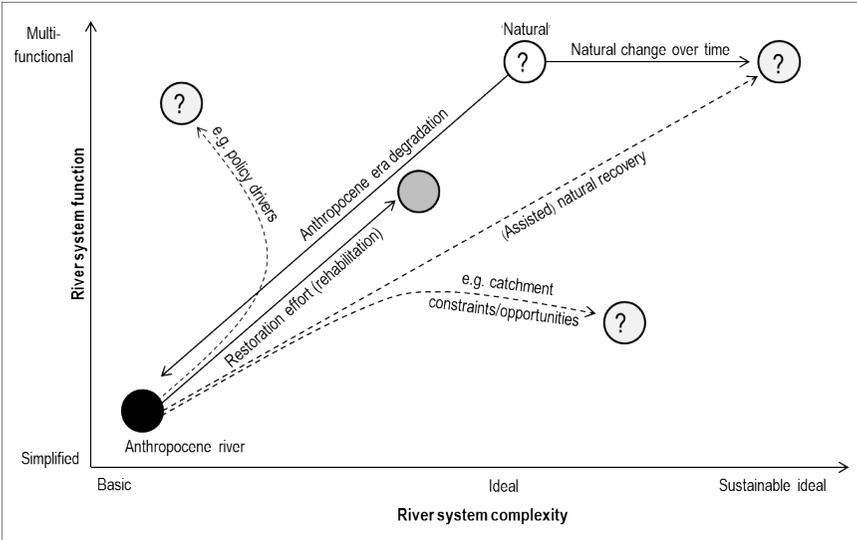


FIGURE 2.1. The response of river systems to anthropogenic drivers, illustrating shift from historical equilibrium conditions (degradation) and potentially different endpoints of restoration dependent of based on opportunities for, and constraints against improvement and wider policy drivers. The complicating factor of inherent/natural system change over time (also known as “shifting baseline syndrome”) is also depicted; this will affect the vision for improvement. Modified from Bradshaw 1988.

understand and manage the dynamics of the relationship between humans and the ecosystems on which they rely.”

According to Olsen (2002), if we know the baseline for a degraded river, we can work to restore it. But if the baseline shifts before it can be properly quantified, there is a danger we can end up accepting a degraded state as normal—or even as an improvement. The term “shifting baseline” was coined by Pauly (1995), who noted that each generation subconsciously views as “natural” the way in which their surroundings appeared in their youth. Although Pauly described shifting baselines in relation to fisheries science, the phenomenon is general and applies to all sectors of society. As one generation replaces another, people’s perspectives change such that they fail to appreciate the extent and implications of past and current environmental modifications. Olsen (2002) provides an illustration of shifting environmental baselines in the Pacific Northwest’s Columbia River, where the number of salmon in the river at the start of the twenty-first century and after an intensive effort at restoration was two times the population of the 1930s. In itself, that number is encouraging—but only if the 1930s numbers comprise the accepted reference point or baseline. In reality, salmon numbers in the Columbia River in the 1930s were only 10 percent of what they were in the 1800s, so, as Olsen (2002) points out, the 1930s numbers for the Colorado reflected a baseline that had already significantly shifted

over the historic period. Papworth et al. (2009) present evidence for two distinct forms of shifting baseline syndrome: “personal amnesia,” where knowledge extinction occurs as individuals forget their own experience, and “generational amnesia,” where loss of knowledge occurs because younger generations are simply not aware of past conditions or baselines. This is reflected in figure 2.1, in which change over time (top) is associated with a loss of knowledge as to what type of system actually should represent the reference point in terms of what restoration outcome is deemed desirable or appropriate. Waldman (2010) recognizes this in stating that to put an end to the kind of persistent ecosystem degradation such as rivers and their watersheds have experienced, we will need to “rewind” important historical connections and interdependencies. Although it is important to look back for context, it is now more important to look forward to what society wants for our rivers in the future. Indeed, while it is important that we reestablish many of the connections and interdependencies of the past, we must also recognize that the watershed-scale fluvial processes that control the nature of our river environments can never again match those of the more undisturbed past. Therefore, there is a pressing need to understand “modern” aquatic ecosystem functioning and the constraints that our watershed usage imposes on the ways we manage our rivers in order to deliver the vital services to society that they wish for in the future. Waldman (2010) concludes that no less important in achieving this will be the tools, funding and legislation, and education to build social awareness and, crucially, the will on the part of politicians, policy makers, and the public to enact meaningful change.

#### TOWARD AN ECOSYSTEM SERVICE-BASED APPROACH

In 2000, then General Secretary of the United Nations Kofi Annan made a call for the first comprehensive assessment of the state of the global environment. The outcome was the Millennium Ecosystem Assessment (MEA 2005). Unsurprisingly, one of the key conclusions of the MEA was that over the preceding fifty years, humans, in the course of achieving substantial net gains in economic development and overall well-being, have degraded river ecosystems more rapidly and extensively than at any other time in history. This leads to two interconnected issues: while it is highly probable based on past evidence that ecosystem degradation will continue to worsen as we move deeper into this century, the challenge of reversing this degradation while meeting increased demands for “ecosystem services” (due primarily to population rise) will require major changes in institutions, policies, and practices. The 2005 MEA report uses a utilitarian definition of ecosystem services as the benefits people obtain from ecosystems (divided into “supporting,” “provisioning,” “regulating,” and “cultural” services) and emphasizes the links between human well-being and these ecosystem services as being those of security, basic material for a good life, health, and good social relations. However, it should be recognized that ecosystem services, at least as defined here as qualities of

ecosystems that benefit people, is not the same thing as an “ecosystem approach” to managing rivers. That distinction becomes important in discussing human modification of rivers and what it might mean to restore such rivers.

Worldwide, politicians, legislators, and policy makers are starting to recognize that aquatic systems comprise precious resources, not only providing the essentials of life—air, water, food, and fuel—but also underpinning national health, well-being, and prosperity and providing the potential for significantly improving quality of life. At the same time, it is increasingly understood that critical thresholds, or “tipping points,” exist (Rockström et al. 2009a, 2009b; Biermann et al. 2012), beyond which sharp reductions in ecosystem service provision may result. In the United Kingdom, securing and maintaining a healthy natural environment and avoiding such thresholds is one of the government’s two high-level goals, the other being tackling climate change. New ways of thinking and working have to be adopted for watersheds whereby the focus of policy making and delivery needs to be shifted away from isolated natural environment policies for air, water, soil, and biodiversity toward more holistic or integrated approaches based on whole ecosystems. Intrinsic to this shift are innovative yet widely accessible ways of assessing river system status and making this information widely available to a range of managers and interest groups. Such assessments of ecosystem services delivered by in riverscapes are starting to grow in number. The 2005 MEA provided the impetus in the United Kingdom for the 2011 UK National Ecosystem Assessment (UKNEA), the first major analysis of the nation’s natural environment in terms of the benefits it provides to society and continuing economic prosperity. The UKNEA represented a wide-ranging, multi-stakeholder, cross-disciplinary (as opposed to transdisciplinary) undertaking. It was also aligned with other international initiatives, including The Economics of Ecosystems and Biodiversity (TEEB) study, a major international initiative whose findings were initially published in 2010, and the ongoing UNEP Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). The UKNEA aimed to provide a comprehensive picture of past, present, and possible future trends in ecosystem services and their values (see, e.g., Brown et al. 2011), with one of the key objectives being to identify and understand what has driven the changes observed in freshwater systems and associated implications for ecosystem service delivery since 1950, the period coinciding with the Great Acceleration.

Despite the increasing number of assessment methodologies, there are a variety of reasons for the relative lack of impact of the MEA and associated national-scale initiatives. Prominent among these are (a) persistent gaps in the ecosystem services knowledge base, (b) a lack of operational tools and methodologies, and (c) limited awareness and understanding among decision makers of the concept of ecosystem services (fig. 2.2). While conceptual models of links between catchment landscape management, ecosystem services, and resultant human well-being exist, the scientific assumption of a direct link between geomorphic features and processes, ecological functions, and, for example, biodiversity remains largely

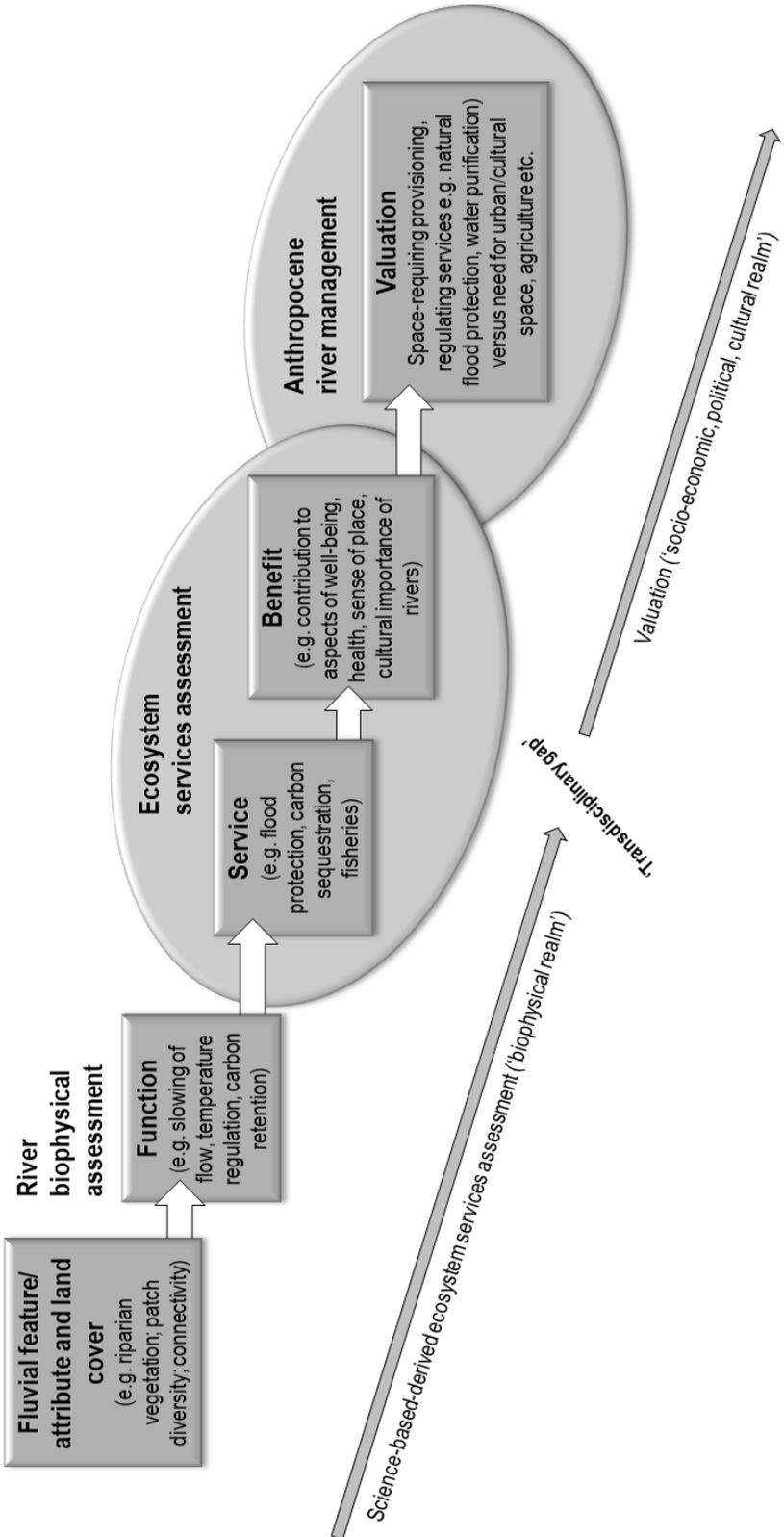


FIGURE 2.2. The cascade model of Haines-Young and Potschin (2010), emphasizing the transdisciplinary “gap” between science-based ecosystem assessment methodologies and the valuation of these ecosystems by society. More effective transdisciplinary frameworks are needed to educate society about the benefit of ecosystem services for underpinning wider social livelihoods.

unproven in either a systematic or a statistical sense. As mentioned above, it is imperative to merge our knowledge of earth systems and human systems with the qualitative approaches prominent in the environmental humanities to effectively value the benefits healthy ecosystems provide to society.

### *Rapid and Novel Assessment of Riverine Ecosystem Services*

The importance of effective tools has already been emphasized above. In seeking to improve Anthropocene rivers, managers need specific tools to improve the information base on hydromorphological character and condition across entire sector lengths (i.e., upstream, mid-reach, downstream). While this is important to reduce issues introduced by shifting baseline syndrome, tipping points may vary from place to place within watersheds as some sectors may naturally be more robust than others. In addition, some sectors are more prone to anthropogenic alteration than others; for example, most large urban settlements are constructed in downstream reaches. While degradation of ecological integrity is typified by loss of landscape diversity, impairment of ecosystem function, and structural simplification, the relative importance of physical habitat degradation compared to other pressures (e.g., diffuse pollution) is not fully clear. Large and Gilvear (2015) emphasize therefore that any methodology aimed at quantifying or even simply defining the ecosystem services that rivers provide needs to be able to assess a “triple bottom line” of heterogeneity, connectivity, and dynamism both in a meaningful way and at appropriate spatial and temporal scales. The rapid uptake of remote sensing we have seen over the past decade for mapping and monitoring river status and health at multiple, often hierarchical, scales in the catchment context has potential value in assisting meaningful assessment.

### *Assessing Ecosystem Service Provision Using Virtual Globe Technologies*

For a range of earth systems including freshwaters, Brown et al. (2016) conclude that we need to improve our criteria for diagnosing human impacts on the connectivity, integrity, and resilience of critical zone processes. Panoptic mapping tools including Google Earth and other virtual globes (e.g., Microsoft’s Virtual Earth, NASA’s World Wind) offer much potential for such assessments of rivers of the Anthropocene. A key advantage is that these mapping tools are free and easily accessible and offer global coverage of both heavily modified and less disturbed catchments. Potential users of these tools simply need the skill sets to identify relevant riverscape-scale features and the ability to extract riverscape features/attributes from remotely sensed data at appropriate scales. The outputs for managers and planners are science-based protocols for assigning riverscape features, or “attributes” to individual river ecosystem services within a robust, widely accessible metric-based system. Visualization tools like Google Earth can therefore help bridge the gap between researchers and those who need most to be reached with the results of research—policy makers and the population that lives in affected catchments.

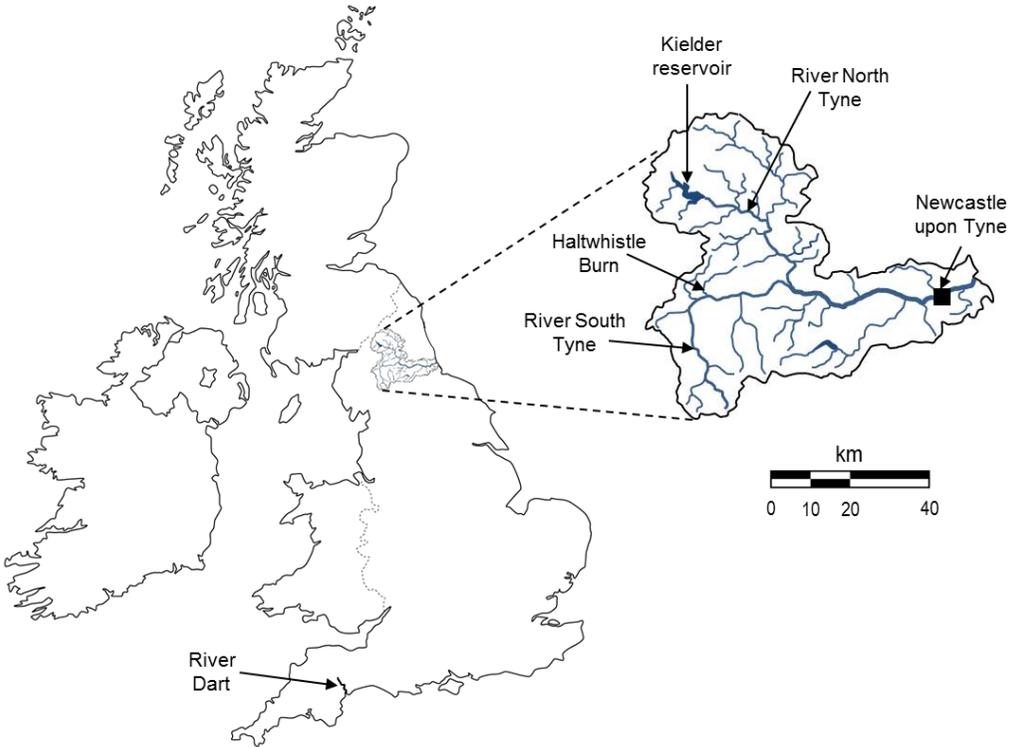


FIGURE 2.3. The River Tyne and the River Dart, U.K., showing locations referred to in the text.

The hydrological, geomorphological, and ecological linkages of water and sediment with biota within river systems drive the relationship between river processes, habitat provision, and ecosystem service delivery (Thorp, Thoms, and Delong 2006, 2008; Large and Gilvear 2015). Attributes of rivers that enhance heterogeneity, connectivity, and fluvial dynamics within river corridors enhance ecosystem service provisioning while at the same time being identifiable via remote sensing techniques. Efforts are under way (e.g., Large and Gilvear 2015) to develop Google Earth–based protocols for assessing the role of physical and biotic attributes initially on eight widely recognized ecosystem services. In the tool, Provisioning ecosystem services were defined as those of fisheries, agricultural crops, timber, and water supply; Regulating services were flood mitigation, carbon sequestration, and water quality control. In the first iteration of the tool, Supporting services were limited to the umbrella term “biodiversity.” Cultural services were not specifically included, reflecting the difficulty of developing transdisciplinary assessments of rivers.

Here we apply the ecosystem services assessment tool to the River Tyne, United Kingdom. The Tyne (fig. 2.3) has two main tributaries, the North and the South

Tyne, and in total covers 2,933 square kilometers. The river has a mean annual discharge of  $34\text{m}^3 \text{ s}^{-1}$  (Jones, Lister, and Kostopoulou 2004) and is flanked by the North Pennine mountains to the west, the Cheviot Hills to the north, and the North Sea to the east (Environment Agency 2000). The majority of the population live in the Lower Tyne Valley, with the highest concentration in the urbanized east and coastal strip (Large and Gilvear 2015). While two-thirds of the catchment area is agricultural, and these activities have led to a mix of upland moor, forest, and arable land and pasture (Large and Gilvear, 2015), the Industrial Revolution—and particularly the coal-mining, ship-building, and heavy engineering industries—is central to the socioeconomic and cultural histories of the Tyne.

Figure 2.4 shows the resultant output of the ecosystem services assessment tool as a variety of indices, including a “feature/attribute” score and a “total ecosystem services” score. Two further indices can be calculated at the whole-river scale: a total individual ecosystem system score for each of the eight services identified and, summing these, a total ecosystem services score for the main river channel as a whole. Figure 2.4b compares the North Tyne, impounded in its upper reaches by Kielder Reservoir, to the less regulated River South Tyne (fig. 2.4a). Downstream from this confluence the traditional name “River Tyne” is used. The ecosystem service scores display a distinct “sawtooth” sequence, with “troughs” reflecting declines in ecosystem service delivery of the river at that specific point in the catchment. In the case of the Tyne, this ecosystem service decline is directly associated with human modification in the form of small urban centers, fluvial engineering in close proximity to the channel for transport infrastructure, impoundment in the form of Kielder Reservoir on the River North Tyne, and, importantly, the spatial footprint of the city of Newcastle upon Tyne toward the downstream end of the main river channel. Figure 2.4c describes an alternative scenario, that of increase in ecosystem service delivery for the River Dart in Devon, U.K., where sedimentation following decommissioning of an in-channel weir resulted in the (unintended) consequence of ecological improvement via alluvial woodland formation (F in fig. 2.4c).

The tool has already been taken up in the United Kingdom by several non-governmental bodies, including River Trusts, so it would appear a Google Earth assessment based on identifiable fluvial attributes is relevant to a wide sector of users, planners, scientists, and the general public. It is hoped that with development of the approach it can (a) highlight unintended consequences of actions in river systems, (b) evidence shifting baselines affecting conservation management and restoration, and (c) effectively demonstrate opportunities for win-win synergies between environmental management disciplines in specific parts of catchments where optimization of ecosystem service delivery is a desired objective (Everard and McInnes 2013). In the Tyne and other U.K. catchments, reorienting the EU Water Framework Directive goals of “good ecological status” toward maximized ecosystem service provision can potentially deliver greater societal benefit within multiple-use river landscapes (Stanford and Poole 1996; Everard 2011).

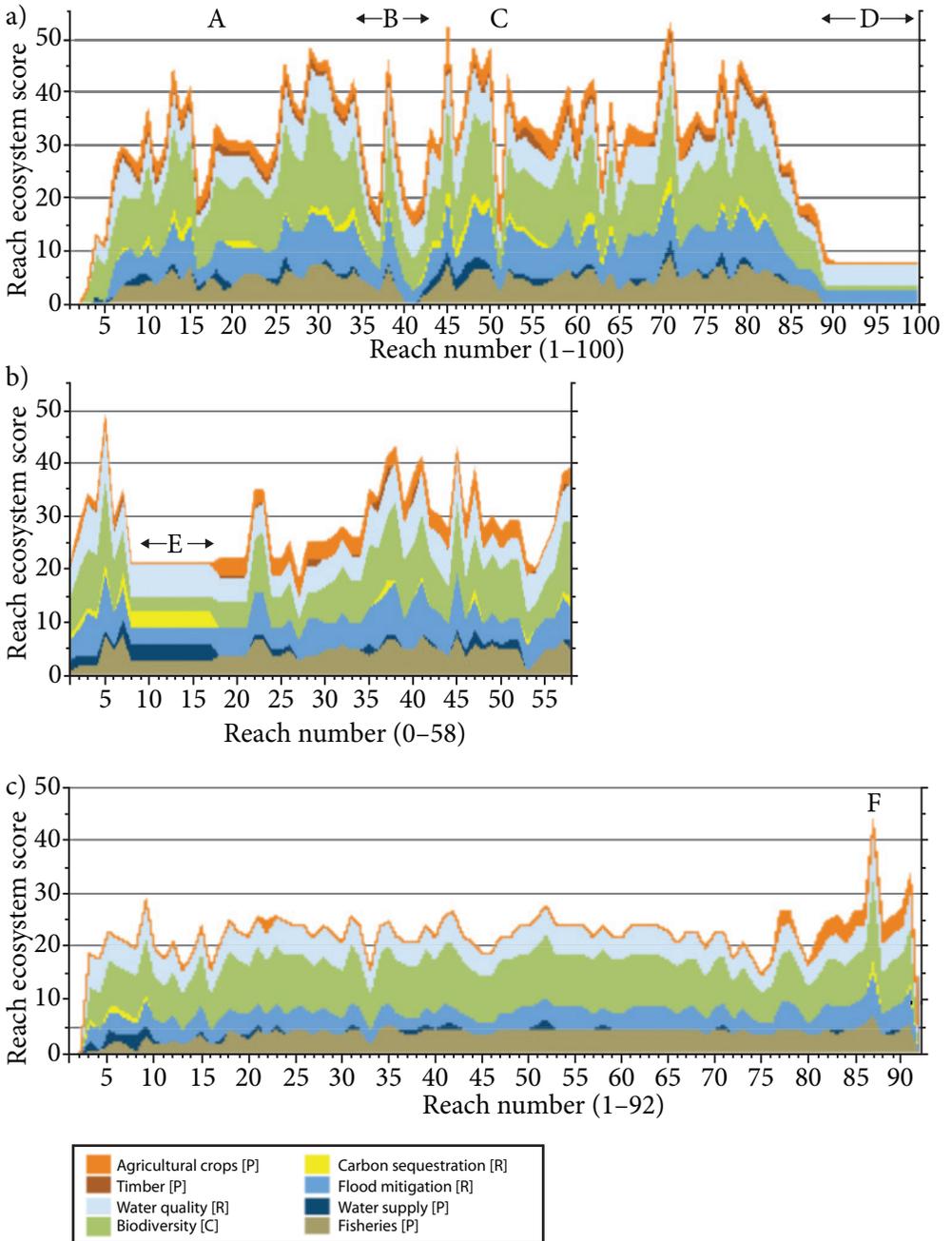


FIGURE 2.4. Downstream patterns in ecosystem service scores and total ecosystem service scores based on Google Earth assessment of ecosystem services from fluvial features (Large and Gilvear 2015). (a) River South Tyne and River Tyne, (b) River North Tyne to its confluence with the South Tyne, (c) River Dart, Devon, U.K. A–D: decline in reach ecosystem service score due to urban settlements of Alston (A), Haltwhistle (B), Haydon Bridge (C) and Newcastle upon Tyne (D); E: Kielder Reservoir. F: increase in ecosystem service provision due to localized sedimentation following decommission of a weir on the River Dart.

## TOWARD WATERSHED-SCALE TRANSDISCIPLINARITY

What constitutes a healthy Anthropocene river? As numerous researchers (e.g., Vorosmarty et al. 2010; Carpenter et al. 2011; Sponseller et al. 2013) have attested, the multiple roles that water plays in both minimally and intensively manipulated ecosystems raise numerous challenges for efforts to reverse degradation. Perhaps most problematic is the lack of truly integrative approaches linking “supporting,” “provisioning,” and “regulating” ecosystem services with “cultural” ecosystem services. Despite this, the ecosystem service concept resonates with river scientists as it emphasises the need for healthy system structure and function, while at the same time concentrating attention on what makes rivers so valuable to human society. Rivers in the Anthropocene offer a range of services beyond those underpinned by ecological diversity; even simplified urban rivers still provide ecosystem services and can still function as havens of tranquillity and meaning. Most reference scenarios for restoration have some pristine view on what a channel should look like at their centre, despite the fact that wilderness channels are not the most beneficial for humans. In Scotland, a scheme run by WWF in the mid-1990s called “Wild Rivers” faltered as a result of the public’s negative perception of the term “wild.” Elsewhere, many rivers under intense human pressure have huge value in terms of their religious significance and often sacred nature, while recreation is also a major user of the world’s freshwater systems.

Finding ways of properly integrating these socioeconomic and sociocultural aspects with more traditional life science and geomorphological approaches to ecosystem service-based management is a fundamental need as we move further into the Anthropocene. Numerous issues remain to be addressed (table 2.1). For effective and cost-beneficial restoration, managers of rivers like the Tyne need to know with what aspects of physical habitat and at which locations in catchments intervention will lead to the greatest improvements in ecological condition and protection/enhancement of ecosystem service delivery. Managers also need to know what *kinds* of intervention are appropriate, and *where*.

In terms of the first issue listed in table 2.1, it is undeniable that while patchiness is awkward to manage, the patch mosaics arising from heterogeneity, connectivity, and dynamism are essential to riverscape-scale (Thorp, Thoms, and Delong 2006, 2008) relationships between fluvial features, land cover types, natural ecosystem functions, and river ecosystem service delivery (fig. 2.5). Given that the riverscape is where people live, Anthropocene river management requires improved understanding of these relationships between people and the physical system they inhabit and its natural and cultural ecology. Carpenter et al. (2009) have described this as a need for improved understanding, which can only come from enhanced knowledge transfer between environmental scientists, geographers, social scientists, industry practitioners, and the general public (see also Newson and Large 2006). Key to managing degraded Anthropocene rivers worldwide is greater appreciation in a range of communities for the value of heterogeneity, connectivity,

TABLE 2.1. Persisting Management Issues Associated with Anthropocene Rivers

Issue	Details
Management	Rivers and streams are individually unique, patchy, discontinuous, and strongly hierarchical systems [ <i>i.e., they are awkward to manage</i> ].
Data gaps	Existing applied approaches for capturing geomorphological data are highly dependent on intensive fieldwork and monitoring; this is unlikely to be resourced at sufficiently extensive scales to meet management needs. While a large number of hydrometric monitoring stations have gone out of service since the mid-1980s, data-gathering capacity from remote-sensing has increased almost exponentially.
Habitats and flows	Fully integrated ecosystem service-based approaches/assessments are not yet operational, and there is a pressing need to collate data to describe the habitats on which biotic function depends over the full range of flows.
Classification	Robust, process-based geomorphological typologies incorporating full dynamic assessment over the whole flow regime are needed to better define river variability [ <i>currently impracticable due to lack of communication between individual disciplines</i> ].
Modification	Reliable spatial data (and maps) of channel modification are lacking [ <i>need for enhanced communication of scientific needs and data requirements to politicians, managers, and the general public</i> ].
Hydrological variability	Little attention is paid to natural hydrological variability within riverine systems, despite the fact that this factor has a defining role in the hydromorphology of the system [ <i>hard to manage running water systems without this scientific insight</i> ].
Shifting baselines	Problematic for those using human perceptions of change to inform river policy making or management.

and dynamism in the landscape. Natural features of rivers interacting with natural flow dynamics positively enhance heterogeneity, connectivity, and fluvial dynamics within river corridors and in turn enhance ecosystem service provisioning (Large and Gilvear 2015). On the other hand, human modifications that simplify or degrade these attributes have tended to simplify river ecosystems and degrade ecosystem service delivery, or what nature does for us, with the main exception being increased supply of products from manipulated river systems (timber, fisheries, water supply from impoundments, etc.).

#### *Riparian Communities and the Growth of “Crowd-Sourcing”*

In 2011, the U.K. Department for Environment, Food, and Rural Affairs (DEFRA) announced a reemphasis on a catchment or watershed-based approach to restoration. The stated vision was to “provide a clear understanding of the issues in the catchment, involve local communities in decision-making by sharing evidence, listening to their ideas, working out priorities for action and seeking to deliver integrated actions that address local issues in a cost effective way and protect local resources” (Defra 2011). This mandate clearly also applies to the River Tyne but was perhaps more succinctly described by the Tyne Rivers Trust (2012) as “action to improve our rivers, and action to raise awareness and educate people about

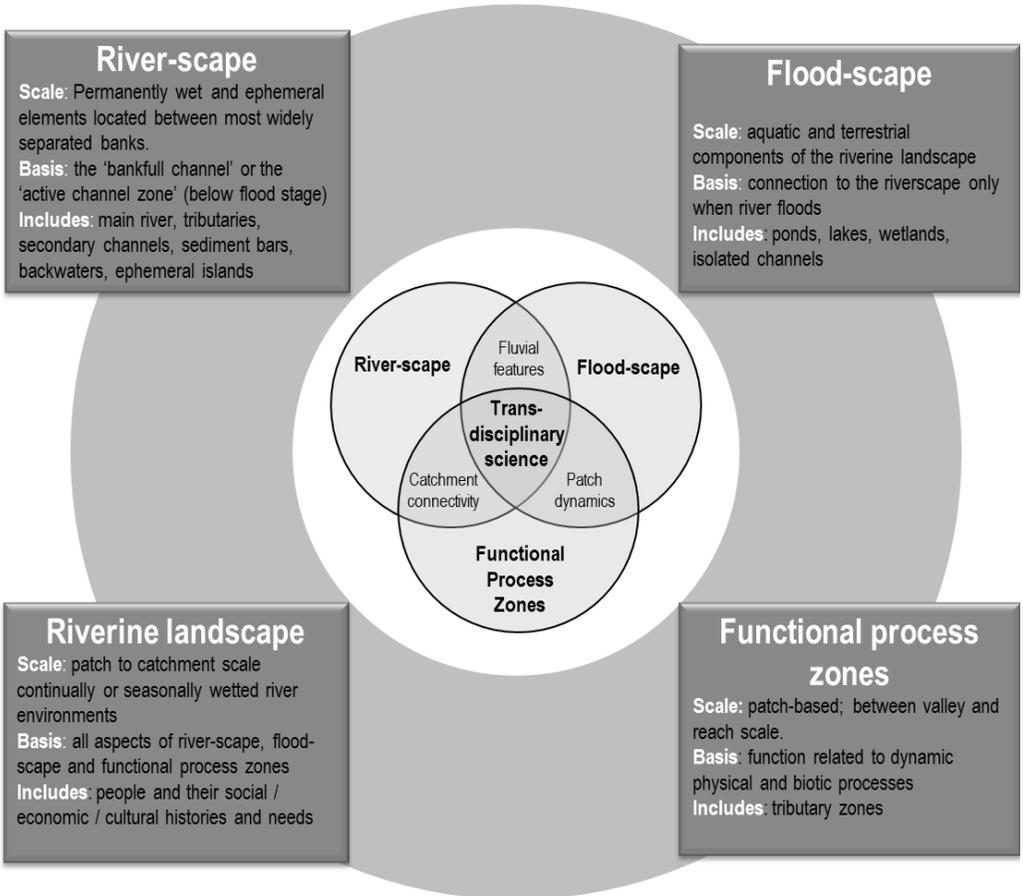


FIGURE 2.5. The terminology used in the riverine ecosystem synthesis of Thorp et al. (2006, 2008) adapted to show the potential central role for transdisciplinary river science.

the importance of rivers.” The Rivers Trusts are relatively small environmental charities entrusted by the U.K. government to produce plans for whole catchments, which in the case of the Tyne entails an area of almost 3,000 km<sup>2</sup>. In the United Kingdom organizations like the Rivers Trusts are now deemed essential to achieving action on the ground, via what the Tyne Rivers Trust (2012) refers to as “perpetual partnerships,” helping to offset the personal and generational amnesia associated with the evolution of our river histories. In their *River Tyne Catchment Plan* published in December 2012, the Tyne Rivers Trust produced a publicly informed “wish list” of proposed projects that aims to deliver better rivers within the wider Tyne catchment and to increase community involvement in local decision making. The intention is to engage and educate those who are not aware of the importance of rivers, create robust and resilient watersheds to cope

with weather extremes and climate change, and make the best use of all available resources, research, and evidence to support work across the catchment and deliver the targets set out in legislation like the EU Water Framework Directive and the EU Habitats Directive (Tyne Rivers Trust 2012). Of importance here is that when the United Kingdom leaves the European Union similar legislation will be enacted to succeed the Directives.

As an example of this new consultative approach in action, Newcastle University has worked in close partnership with the Tyne Rivers Trust on a project focused on Haltwhistle Burn, a small (42 km<sup>2</sup>) rural subcatchment of the River Tyne (Starkey and Parkin 2015; Starkey et al. 2017). Funded by the U.K. government's Catchment Restoration Funds Project and the Natural Environment Research Council, this "total catchment approach" seeks to improve fish populations, water quality, and hydromorphology and reduce flood risk. The major objective in establishing future priorities for the catchment is to engage with the local community by using established natural runoff management, with the ultimate aim of producing a catchment management plan for Haltwhistle Burn. The involvement of local communities in knowledge production will avoid the pitfalls of shifting baseline syndrome. It is intended that the experiences gained during the Haltwhistle Burn project will be transferred to other Anthropocene watersheds where Rivers Trusts are responsible for on-the-ground management via partnership with local communities. The ambition is to maximize the size of catchments addressed; science-based approaches have traditionally only been aimed at relatively small experimental catchments.

Figure 2.6 illustrates observations submitted by local residents in early 2014, as a result of efforts to encourage a "community monitoring" approach. If we are to advocate "citizen science" as a component of a transdisciplinary approach to Anthropocene catchment management, there are a number of considerations to address. What are the key participant needs and motivations for engagement and recruitment? What training and data collection resources are required to ensure good quality and consistent observations? How should the data gathered be managed, analyzed, visualized, disseminated, and shared? What are the key ethical and social, economic, and practical considerations? For maximizing the sustainability and legacy of a citizen science or "volunteered geographical information" project such as that at Haltwhistle Burn, a key objective is finding a way to encourage volunteers to carry the process into the future. Findings from the Haltwhistle Burn indicate it is best to engage on a local level and to ensure citizen science is related to a relevant topic or issue that directly affects riparian communities (e.g., flooding), with findings constantly fed back to the community using effective visualization tools such as the annotated hydrograph in figure 2.6. While citizen science = knowledge coproduction = new power, citizen science is not just about knowledge coproduction; the project can, and should, aim to have a variety of social benefits. For example, one citizen scientist from the Haltwhistle community stated, "I'm starting to understand the wider picture," and another said, "I'm really getting into

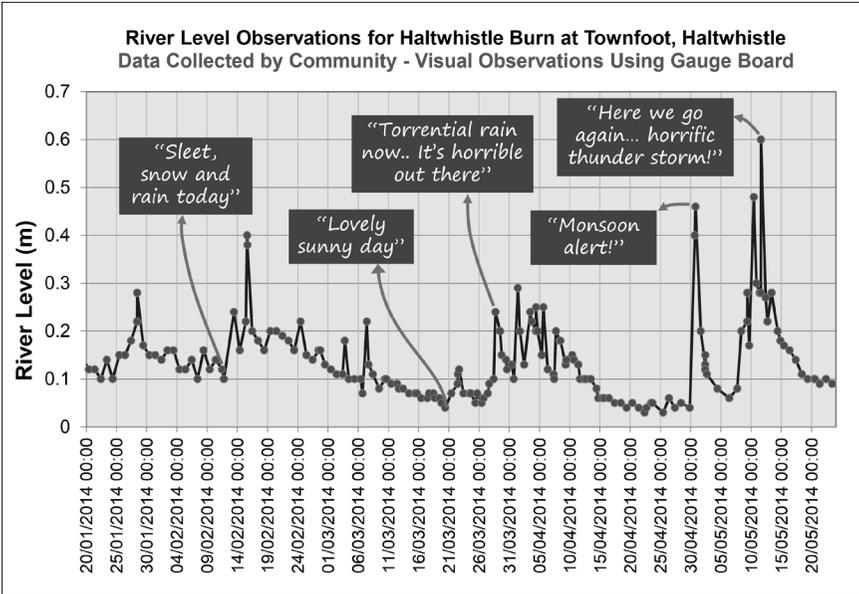


FIGURE 2.6. Citizen science via crowd-sourced data in action in the Haltwhistle Burn catchment. Local community river level and weather observations were collated via the social media platform of Twitter (@HaltwhistleBurn) and a purpose-built “community river, weather and flood” Android mobile phone app.

this science stuff.” Using volunteers, information and data can be gathered over a wide area. While “any data is better than no data,” it is vital to maximize the credibility of citizen science observations, and therefore protocols are needed to limit error and uncertainty and create metadata (i.e., information or data that explain the data). One of the biggest challenges associated with a citizen science approach is getting professional scientists to accept, appreciate, and actually use the data to support decision making and to underpin evidence-based policy (European Commission 2013). If this can be achieved, there are a wide range of potential applications for this type of data, including catchment modeling and flood warning schemes, as well as ongoing monitoring of natural flood management initiatives.

CONCLUSION: IMMEDIATE PRIORITIES FOR ANTHROPOCENE RIVER MANAGEMENT

Recognizing the advent of the Anthropocene raises challenges for how we perceive our rivers should behave. It also raises challenges in terms of how we can ensure their sustainable futures. In January 2014, a transdisciplinary workshop, “Rivers of the Anthropocene,” held at IUPUI in Indianapolis, brought forward a number of important questions. How do scholars from different disciplines frame the problems of environmental change differently? In what ways does a transdisciplinary

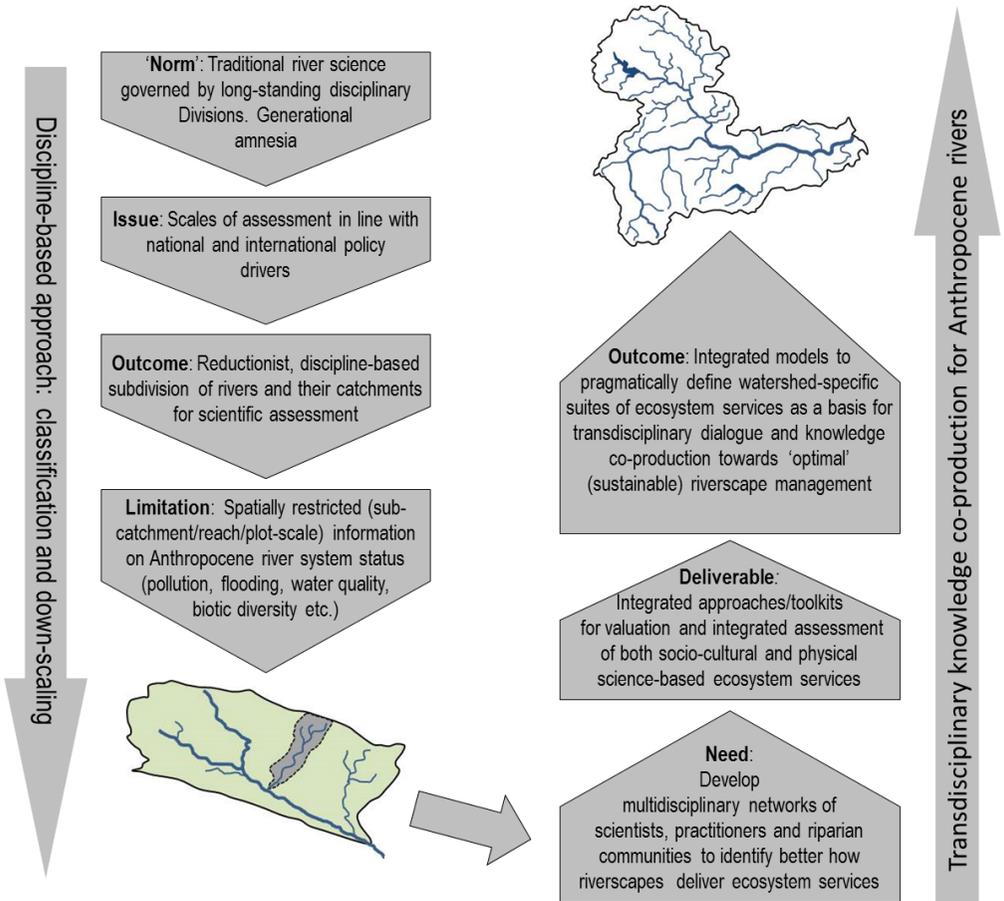


FIGURE 2.7. Issues and limitations of “traditional” river science with its often reductionist outcomes and the positive deliverables and outcomes offered by transdisciplinary approaches aimed at better integration of sociocultural and physical science-based ecosystem services.

perspective alter their approach? What problems does it create, and what are the most effective ways to solve them? How can we reframe ideas and approaches that are embedded in traditional disciplinary constructs? In seeking answers to these questions, we need models of human-environment interaction that account for both emergent environmental phenomena and the agency of human societies. The challenge is to make these meaningful in terms of multiple scales (time, population, geography), forms of flow (interaction, feedback), and properties of change (emergence, agency, rate, cause and effect). In coproducing scientific knowledge on these models it is vital to engage with as wide a range of user, practitioner, and academic communities as possible, in order to develop new, transdisciplinary approaches based on riverscape ecosystem services (fig. 2.7). Google Earth and other freely available virtual globes offer a great deal of potential, as do

frameworks such as the ecosystem services “cascade model” of Haines-Young and Potschin (2010).

For better management of our Anthropocene river systems we need to advance appreciation of how habitat features in riverscapes underpin ecosystem service provision. This exercise should aim to reduce the need for “expert judgment” to determine what constitutes “optimal” ecosystem service delivery. Approaches using science-based tools run the risk of lower uptake in more populated watersheds, where system dynamism is seen as an inherent threat rather than a mechanism to ensure sustained ecosystem service delivery. There is a need to involve stakeholders, policy makers, and the general public in knowledge production to increase our understanding of how both more pristine and more intensively used riverscapes deliver ecosystem services in their own right; both simple and more complex habitat types can ultimately deliver similar levels of societal benefits.

Carpenter et al. (2009) point out that while sustainability science is motivated as much by fundamental questions about interactions of society with its surrounding environment as by compelling and urgent social needs, many aspects are currently based on assumptions rather than data. For example, one of the biggest issues in assessing the implications of shifting baselines syndrome is a lack of empirical evidence that it actually occurs (Papworth et al. 2009). Carpenter et al. (2009) advocate expanding basic research on social-ecological systems and building on disciplinary strengths while at the same time bridging disciplinary divides to create the new knowledges needed to build our Anthropocene watersheds into resilient social-ecological systems. Protocols linking relevant science with an informed public have been advocated for some time. For example, Stanford and Poole (1996) describe iterative protocols for involving scientific research and public opinion in adaptive ecosystem management, and Ostrom (2009) advanced a generalized framework for analyzing sustainability of socioeconomic systems. Thus far, however, there has been difficulty in assessing cultural ecosystem services (Schaich et al. 2010), and an immediate priority must be finding ways of effectively integrating cultural ecosystem services with supporting and provisioning ecosystem services in rapid assessment methodologies. Allied to this is the need for widely accessible decision-making tools and guidelines that implicitly recognize societal valuation of ecosystem services in terms of what nature still does for us in our Anthropocene river systems.