ARENA

# River research and applications across borders

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ABSTRACT

Rivers flow across national borders, unfettered by political distinctions, and the ecological health of rivers is closely linked to their degree of connectivity. River research today is more global than it has ever been, but we show that river research, engineering, and management still operate within homegrown local paradigms. As a basis for this discussion, we studied the citation networks surrounding the most widely cited papers in our field, assessing the degree to which researchers have collaborated across geographical boundaries and fully drawn from the international literature. Despite gains over time, our field remains surprisingly and pervasively provincial. The likely

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explanation for provincial bias is that researchers are generally more familiar and comfortable with their own research methods, sites, and agendas. However, local focus has tangible consequences. For example, contrasting paradigms and differing approaches to river restoration and to flood-risk management show that opportunities are lost when we fail to learn from the successes and failures of other regions. As Sharp and Leshner (2014; p. 579) have argued, "the search for solutions needs to draw upon the talents and innovative ideas of scientists, engineers, and societal leaders worldwide to overcome traditional and nationalistic paradigms that have so far been inadequate to meeting these challenges."

## 1. INTRODUCTION

River-related research is an increasingly international enterprise. Researchers largely read the same journals, attend the same conferences, and top university programs are becoming melting pots of international academic talent. Many of us now regard ourselves as scientific citizens of the world. However, our group questioned to what extent international collaboration between river-related scientists and engineers has changed over time. To assess this, we surveyed the pattern of citations within the most widely referenced articles in river science published in the international academic literature. Citation counts are frequently used as a metric of academic productivity and quality (Thomson Reuters, 2008), and patterns of citations have been used to study the scientific process, including such topics as gender representation in published research (Lariviére et al., 2013; Caplar et al., 2017) and the disproportionate influence of high-profile journals (Lariviére and Gingras, 2010). Citation counts and networks are incomplete and imperfect metrics (e.g., Bornmann and Daniel, 2008; Perry and Reny, 2016; Walter et al., 2003), but they do provide a quantitative window into the research endeavor, including patterns of international collaboration and cross-pollination.

We utilized the Thomson Reuters *Web of Science* database to identify the 50 most cited journal articles in river science from seven recent calendar years, 2011-2017. All bibliographic databases have variations in coverage, but *Web of Science* is quite broad and, importantly here, provides analytical tools for quantifying citation networks forward and backward in time. We also analyzed the 30 most cited articles from several previous five-year snapshots: 1980-84, 1990-94, 2000-04, 2005-09, and 2010-14. The sample sizes above, 30 and 50 articles per time interval, were limited because *Web of Science* currently does not allow use of external scripts or fully automated database queries, so that analysis was time-intensive. In total, more than 33,000 citations were analyzed by geography and time, as outlined below.

We examined both the bibliographies of the most cited papers as well as all citations of those papers within the same time period. We categorized the region of origin of each most-cited paper (by institutional affiliation of the first author), along with the geography of all subsequent citations and references. For each region and for each time period, we calculated a cumulative metric of citation internationalism, the I-Factor. The goal of this work was to provide a data-driven basis for discussing how international we river scientists really are, how these patterns may have changed over time, and to explore the implications of global vs. local perspectives in river research and management.

## 2. TRENDS IN INTERNATIONAL RIVER SCIENCE

The period from 1980 through 2017 spans a marked shift in river-science publication. The 50 most cited papers in 2011-2017 (Figure 1) represent a broad international constituency: 10 from the USA and Canada (based on 1st author), 19 from China, 14 from European countries, 2 from Australia and New Zealand, and 5 from "Other Asia" (e.g., Korea and Japan). In contrast, the time periods prior to 2005-2010 were dominated by North American and European authors (Table 1). We completed an additional year-by-year analysis, which reveals the progressive emergence of Chinese-authored papers during this period.

The distribution of the most-cited papers shifts from >90% North American and European-authored in 1980-84 and 1990-94 to just 52% in 2011-17 (Table 1). The same explosion is evident in the total number of citations. Whereas total citations originating from the US, Canada, and Europe increased 297% between 1980-84 and 2011-2017 (normalized to 30 papers and a 5-year period), citations from all other regions increased 3195%. That increase begins around 2005 and is dominated by the increased number of

authors at Asian institutions. River science, like many other fields, is no longer the near monopoly of North America and Europe that it was just 30 years earlier.

Another indicator of the internationalization of river research is the proportion of top papers resulting from multi-national collaborations (Table 2). Such collaborations were defined here as author affiliations from more than one geographical region. While the sample of papers in each time interval is too small to draw universal conclusions, the 1980-84 interval is noteworthy in that none of those 30 papers showed collaboration outside of the geographical boundaries defined here. By 1990-94, however, 30% of the most cited papers included trans-regional collaborations, increasing to 37% for the 50 most cited papers in 2011-2017. Papers from Chinese authors tended to include more international collaborations, and the increasing proportion of these papers helped to drive this shift. In fact, European-authored papers were most internationally collaborative (outside the European region) in 1990-94 but tended to decrease thereafter. Such change may reflect, perhaps, the funding and organizational structure of the recent European Framework initiatives, which have served to encourage intra-European collaboration.

## 3. A PERSISTENT LOCAL FOCUS

In contrast to the signs of growing internationalism in authorship, the network of citations binding the river-science literature exhibits strong, persistent local biases. Our survey suggests that, rather than a new generation of scientific citizens of the world, and despite research papers being more readily available through online sources and open access, we preferentially read and cite papers from our own region, and our own papers are disproportionately cited by scientists from the same local region. Forty-six percent of the 50 most cited papers in 2011-17 garnered >50% of their citations from authors in their home country or region, and 74% were cited from their local region more than any

other region. Although several papers had broader international impact, the average citation count for all 50 papers was still 46% from each one's home region (Table 3). When normalized for the total number of citations from each region, all but two (48 of 50) papers were disproportionally cited by authors in the same region, in some cases by >300%.

Interestingly, the local preference in the river-science literature was weakest in the highest tier of the 50 most cited papers in 2011-17, with the top ten papers < 38% locally cited, rising to 53% in the next tier (ranked 11-20), leveling off thereafter at 45-50% locally cited. Thus, the ten most cited journal articles were more successful in attracting attention from a diverse, international audience; albeit still exhibiting a local preference. This pattern held true for the most recent time period (2011-17) as well as for the papers and citations ~5 and 10 years earlier (2005-09, 2000-04), but was not evident in the papers and citations from 20 and 30 years earlier (1990-94, 1980-84). In those earlier periods, there was no distinction in the percentage of local citations for the top ten papers.

The local bias in river-science citations was present for every geographical area with papers among the 50 most cited. Our goal in this bibliographic analysis was to assess local, self-referential biases in the literature, and track these biases in different regions and over time. The I-Factor (IF) is a proportion relating the number of local citations of each region's papers, normalized to the total number of citations from that specific region. For example, in the case of Europe:

$$IF_{EUR} = \frac{\dfrac{\text{Eur. cit. of Eur. papers}}{\text{all cit. of Eur. papers}}}{\dfrac{\text{Eur. cit. of all papers}}{\text{all cit. of all papers}}} \quad (1)$$

Values greater than 1.0 indicate local bias. For example, European papers published in 2011-2017 contained 34.0% citations of European papers; this percentage needs to be compared with and normalized to the percentage of all citations that comes from European papers (21.0% of all citations in our bibliographic pool). Thus, that 34% share of European papers in the bibliographies of European papers is 1.6 times higher than a random selection from across the full literature pool.

For the most recent time period (Figure 2), I-Factor values varied from a low of 1.6 for the European papers to a maximum of 7.2 for papers from Australia (however n=2 for this time period). Chinese-authored papers were also disproportionately locally cited, although this metric decreased substantially in 2011-17 relative to earlier time periods. Of the 19 papers in the past 7 years with first authors from a Chinese institution, 18 were most cited locally and were disproportionately locally cited when normalized to the total number of Chinese citations.

The preference for citing local literature was also present when looking within the bibliographies of the 50 most cited papers (vs. citations of those papers; above), and was present for all regions. I-Factor values for 2011-2017 ranged from 1.3 for European authors to a maximum of 4.0 for "Other Asia" authors. Interestingly, these bibliographic I-Factors were generally 10% to 20% lower than the citation I-Factors for each region for the same time intervals. Thus, whereas local citations from each region's broader scientific community helped to propel that region up the (perceived) hierarchy of most cited papers, the articles at the top of the most cited list tended to have a greater international perspective in terms of the sources they cite.

## 4. BARRIERS TO INTERNATIONAL RIVER SCIENCE

There are many reasons why authors and scholarly publications may disproportionately cite papers from their home region. Many of these reasons are understandable, whereas other drivers may include conscious or unconscious biases that authors and editors could work to remedy. One justifiable reason would be a strong geographical focus to the research. For example, Kaushal et al. (2010) documented "Rising stream and river temperatures in the United States," and that paper was 70.6% cited by other North American authors. At the same time, most papers that join the list of most cited do so, or should do so, because they find relevance with a broader scientific audience even when the study area is a local one. For example, Bendz et al. (2005; "Occurrence and fate of pharmaceutically active compounds in the environment, a case study: Hoje River in Sweden") received most of its citations (~60%) from other European authors, but less than 5% of those were Swedish. Apparently, the primary interest was not in the Hoje River itself, but rather the timely study of emerging pollutants that resonated with European researchers and, to a somewhat lesser extent, with scientists worldwide. Over the same time period, however, Lin and Reinhard (2005), a US-based team working on similar issues, were cited predominantly by US and Canadian authors and only 32.7% by European authors. Similarly, several Chinese-authored papers (albeit in the next 5-year window) focused on pharmaceutical river pollution, and these were cited overwhelmingly by other Chinese authors. This provinciality limits researchers from fully exploring and perhaps understanding scientific aspects that may enhance their own research at home.

Another possible explanation for the pervasive geographical bias in river-science citations is that the preference could represent – for the sake of discussion – a conscious decision to promote papers from the same region. The analogy suggested here is with personal self-citation, in which we authors may consciously include our own previous publications in the bibliographies of new papers. Part of self-citation is logical

coherence between linked studies as well as our personal familiarity with our own papers. Another motivation, most of us will admit, is the desire to promote our own previous scientific contributions and propel that signature forward. Self-citation is well recognized, and the Science Citation Index notes its occurrence. In contrast, geographical self- (local-) citations are neither tracked nor flagged.

We believe that the more likely and more widespread explanation for provincial bias is that many of us researchers are simply more familiar and/or more comfortable with our own research methods, sites, agendas, and those of research groups known personally to us. Such biases lead to a preferential reliance on this literature, which reflects a 'comfortable' set of regional research frameworks and questions. This preference is understandable, but it is arguably far from ideal. Science is widely perceived as a global meritocracy, in which the best studies find currency and propel future research, regardless of national origins or other biases. This is particularly important in river science, given that real-world applications are pressing, and solutions should be drawn from the best case studies and conceptual models available worldwide.

## 5. SOME IMPLICATIONS OF PROVINCIALISM IN RIVER SCIENCE

### 5.1 Regional Paradigms in Flood Management

Despite billions invested in flood-control infrastructure, flood damages have risen dramatically in the US (ASFPM, 2013), throughout Europe (European Commission, 2014), and around the world. Estimates of global flood losses range between 37 billion (Munich Re, 2018; 2008-2017) and 104 billion USD per year (UNISDR, 2015),

Flood management strategies vary markedly between regions, reflecting different scientific approaches as well as local engineering toolkits, cultural preferences, and local political imperatives. In the US, flood management through the 19$^{th}$ and early 20$^{th}$

centuries focused on channel and floodway constriction, in some places codified in an explicit policy of "levees only," and the failure of this early approach plus growing water-storage needs was followed by a surge of dam construction, largely in the latter half of the 20th century. Although interest in the US has begun to shift towards dam removal, and despite national policies to limit development on floodplains (e.g., under the National Flood Insurance Program; IFMRC 1994), structural flood control remains the political preference and engineering standard on most US rivers.

In contrast, the cutting edge of river science, engineering, and management in Europe has shifted towards accommodative strategies, often branded under distinctive national phrases such as “Making Space for Water” in the UK (e.g., Johnson and Priest, 2008; Wheater and Evans, 2009) or "Room for the River" in the Netherlands and Germany (e.g., Schut et al., 2010; Klijn et al., 2012; van Herk et al., 2015). This approach emphasizes accommodation of climate-driven increases in flooding through increased allocation of space to storage and conveyance during floods. In addition, flood management in Europe has shifted from local strategies to regional cooperation under the Water Framework Directive (WFD, 2000; Serra-Llobet et al., 2018). In the US, in contrast, floodplain land-use decisions continue to be made at the local level, where development pressure often trumps long-range planning and flood-risk reduction. North of the US border, however, flood management in Canada has begun to follow the European model and espouse the value of "freedom space for rivers" (e.g., Biron et al., 2014).

Flood risk differs in character on different rivers around the world, but the primary management goal translates almost universally – *convey flood flows through designated floodways and exclude that water from humans, human property, and crops*. But local flood-control toolkits have all the hallmarks of "path-dependency" (Liebowitz and Margolis, 1995; Berkhout, 2002; Sterman and Wittenberg, 1999), in which the current

technology was developed gradually or has been utilized for a long time. Path dependency tends to lead to "lock-in" of suboptimum and sometimes odd solutions (e.g., the QWERTY keyboard; David, 1985). Flood control is too important in society to rely upon path-dependent history, local engineering and scientific traditions, and inertia. Innovation should come from examining the full spectrum of successes and failures of flood-control tools tested on similar river systems all around the world.

## 5.2 Regional Paradigms in River Restoration

Improved understanding of the environmental impacts of water supply and flood management infrastructure, as well as evolution in societal values, have increased public pressure to restore degraded river systems. In North America, stream restoration became common in the 1980s, when notions of ecological 'stability' were widespread (Bernhardt et al., 2005). North American restoration projects typically aim to return ecosystems to "pre-disturbance" conditions (NRC, 1992), often interpreted as prior to European arrival in the Americas. In Europe, in contrast, most river systems flow through human-dominated landscapes and are so irrevocably changed that restoration can be better conceptualized as integrating native ecosystem functions into human-shaped ecosystems, an approach known as "reconciliation" (Dufour and Piégay 2009; Tockner et al., 2011; Palmer et al., 2014, Arthington et al., 2014).

Looking at real-world applications of these river-restoration paradigms, we see that many projects in North America seek to create idealized single-thread meandering channels, with banks fixed by boulders and large logs and channel geometry dictated by pre-assigned classification (Kondolf, 2006; Miller and Ritter, 1996; Malakoff, 2004, Lave, 2016). Although similar approaches were embedded in early river restorations in Europe, the Water Framework Directive (EC, 2000) has led to an increasing recognition of hydrogeomorphological dynamics and thus emphasis on the restoration of both

geomorphic and ecological processes that can drive and sustain restoration outcomes (Beechie et al., 2010; Habersack and Piégay, 2008; Kondolf et al., 2013). As a result, many recent European and Western U.S. projects aim to encourage *restoring function as well as form* to support a sustainable habitat assemblage and habitat turnover (Yarnell et al., 2015). Increasingly, river restorations are also being placed in a hierarchical framework that allows the spatial and temporal controls on fluvial processes across catchments to be recognised to ensure that process changes can be incorporated into restoration design (e.g., Gurnell et al., 2016).

River restoration, perhaps more than other areas of river management, is driven as much by social values as by scientific absolutes, in response to local needs and concerns. Thus, perhaps it is not surprising that regional approaches to restoration have coalesced into separate paradigms, albeit with some overlap with the paradigms of other regions. Nonetheless, we suggest that this provincialism results in missed opportunities as lessons learned from restoration successes and failures, regardless of region, serve to advance the science of restoration and rivers.

## 6. TOWARDS A MORE GLOBAL COMMUNITY OF RIVER SCIENCE AND MANAGEMENT

A citation count is an imperfect mirror of any one paper's significance, but mirrors do tend to reflect, and in this case reflect scientific interest, activity, and patterns over time and geographical regions. The scientific literature's most-cited papers should be among its most universal, serving as groundbreaking case studies, methodological breakthroughs, and new conceptual frameworks. But while river research and publication have become more international, we practitioners of river science still to an extent act as separate tribes, favoring our own local studies, conceptual frameworks, and paradigms by factors that range from ~2 to >5. There are many reasons why authors may disproportionately cite papers from their home region. Individually, this preference

is understandable and, in some cases, perhaps unavoidable. Across the scientific literature as a whole, however, local bias is a self-indulgence that we should work to remedy. In a scientific meritocracy, the most compelling studies become the most influential on future research, regardless of national origin, and provincial preference is an impediment to this merit-based goal.

River research is often highly applied. We suggest that the recommendation for future action is clear. The health of the world's rivers, and the people who depend upon them, require that **we researchers – and the managers and policy makers who apply this research – should look at the most compelling studies and the best management examples across the full international spectrum**. International river-science and other hydrological databases, homogenized and rigorously verified, could be exciting tools for quantitative comparative studies that would provide a more universal knowledge base across national boundaries. Additionally, the continued shift from subscription-only to open-access journals could help level the citation playing field, providing more uniform access to the scientific literature worldwide. And finally, we suggest that more international education programs are needed in order to train across river-science paradigms, using a broad range of management case studies, tool kits, and best practices. As we look to the future, increased engagement across political and intellectual physical borders should propel the field of river science into new and exciting directions.

## REFERENCES

Association of State Floodplain Managers (ASFPM) (2013). Flood Mapping for the Nation: A Cost Analysis for the Nation's Flood Map Inventory. Available at: http://www.floods.org/ace-files/documentlibrary/2012_NFIP_Reform/Flood_Mapping_for_the_Nation_ASFPM_Report_3-1-2013.pdf

Arthington, A. H., Bernardo, J. M., & Ilheu, M. (2014). Temporary rivers: Linking ecohydrology, ecological quality and reconciliation ecology. *River Research and Applications*, 30, 1209-1215.

Beechie, T. J., Sear, D. A. , Olden, J. D., Pess, G. R., Buffington, J. M. , Moir, H., Roni, P., & Pollock, M. M. (2010). Process-based Principles for Restoring River Ecosystems. *Bioscience*, 60, 209-222.

Bendz, D., Paxéus, N. A., Ginn, T. R., & Loge, F. J. (2005). Occurrence and fate of pharmaceutically active compounds in the environment, a case study: Hoje River in Sweden. *Journal of Hazardous Materials,* 122, 195-204.

Berkhout, F. (2002). Technological regimes, path dependency and the environment. *Global Environmental Change*, 12, 1-4.

Bernhardt, E. S., Palmer, M. A., Allan, J. D., Alexander, G. , Barnas, K., Brooks, S., et al., & Sudduth, E. (2005). Ecology - Synthesizing US river restoration efforts. *Science*, 308, 636-637.

Biron, P. M., Buffin-Bélanger, T., Larocque, M., Choné, G., Cloutier, C. A., Ouellet, M. A., et al., & Eyquem, J. (2014). Freedom space for rivers: a sustainable management approach to enhance river resilience. *Environmental Management*, 54, 1056-1073.

Bornmann, L., & Daniel, H.D. (2008). What do citation counts measure? A review of studies on citing behavior. *Journal of Documentation*, 64, 45-80.

Bracken, L. J., & Croke, J. (2007). The concept of hydrological connectivity and its contribution to understanding runoff-dominated geomorphic systems. *Hydrological Processes,* 21, 1749–1763.

Caplar, N., Tacchella, S., & Birrer, (2017). Quantitative evaluation of gender bias in astronomical publications from citation counts. *Nature Astronomy, 1,* DOI: 10.1038/s41550-017-0141

David, P. A. (1985). Clio and the economics of QWERTY. *American Economic Review*, 75, 332-37.

Dufour, S., & Piegay, H. (2008). From the myth of a lost paradise to targeted river restoration: Forget natural references and focus on human benefits. *River Research and Applications*, 25, 568-581.

European Commission (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for the Community action in the field of water policy. http://ec.europa.eu/environment/water/water-framework/index_en.html

European Commission (2014). A European Flood Action Programme. http://ec.europa.eu/environment/water/flood_risk/impacts.htm Last updated: 27/08/201.

Finer, M., & Jenkins, C N. (2012). Proliferation of hydroelectric dams in the Andean Amazon and implications for Andes-Amazon connectivity. *PLOS ONE*, 7, e35126.

Gurnell, A. M., Rinaldi, M., Belletti, B., Bizzi, S., Blamauer, B., Braca, G., et al., & Ziliani, L. (2016). A multi-scale hierarchical framework for developing understanding of river behaviour to support river management. *Aquatic Sciences*, 78, 1-16.

Habersack, H, & Piégay, H. (2008). River restoration in the Alps and their surroundings: past experience and future challenges. In H. Habersack, H. Piegay, and M. Rinaldi (Eds.), Gravel-Bed Rivers VI: From Process Understanding to River Restoration, pp. 703-737. Developments in Earth Surface Processes, Vol. 11, Amsterdam: Elsevier Science.

IFMRC (Interagency Floodplain Management Review Committee) (1994) Sharing the Challenge: Floodplain Management into the 2lst Century. Report to the Administration Floodplain Management Task Force, Washington, DC: U.S. Government Printing Office, Superintendent of Documents, 189 pp.

Ionnidis, J. P. A., Boyack, K. W., Small, H., Sorenen, A. A., & Klavans, R. (2014). Is your most cited work your best? *Nature*, 514, 561-562.

Jaeger, K. L., Olden, J. D., & Pelland, N. A. (2014). Climate change poised to threaten hydrologic connectivity and endemic fishes in dryland streams. *Proceedings of the National Academy of Sciences*, 111, 13894-13899.

Johnson, C. L., & Priest, S. J. (2008). Flood risk management in England: A changing landscape of risk responsibility? *International Journal of Water Resources Development*, 24, 513-525.

Kaushal, S. S., Likens, G. E., Jaworski, N. A., Pace, M. L., Sides, A. M., Seekell. D., Belt, K. T., Secor, D. H., & Wingate, R. L. (2010). Rising stream and river temperatures in the United States. *Frontiers in Ecology and the Environment*, 8, 461-466.

Klijn, F., Knoop, J. M., Ligtvoet, W., & Mens, M. J. P. (2012). In search of robust flood risk management alternatives for the Netherlands. *Natural Hazards and Earth System Science*, 12, 1469-1479.

Kondolf, G. M. (2006). River restoration and meanders. *Ecology and Society*, 11, 42.

Kondolf, G. M., Podolak, K., & Grantham, T. E. (2013). Restoring mediterranean-climate rivers. *Hydrobiologia*, 719, 527-545

Lariviére, V., & Gingras, Y. (2010). The Impact Factor's Matthew Effect: A natural experiment in bibliometrics. *Journal of the American Society for Information Science and Technology*, 6, 424-427.

Lariviére, V., Ni, C., Gingras. Y., Cronin, B., & Sugimoto, C. R. (2013). Global gender disparities in science. *Nature*, 504, 211-213.

Lave, R. (2016). Stream restoration and the surprisingly social dynamics of science. *Wiley Interdisciplinary Reviews-Water*, 3, 75-81.

Liebowitz, S. J., & Margolis, S. E. (1995). Path dependence, lock-in, and history. *The Journal of Law, Economics, & Organization*, 11, 206-226.

Lin, A. Y-C., & Reinhard, M. (2009). Photodegradation of common environmental pharmaceuticals and estrogens in river water. *Environmental Toxicology and Chemistry*, 24, 1303-1309.

Lowry, O. H., Rosebrough, N. J., Farr, A. L., & Randall, R. (1951). Protein measurement with the Folin phenol reagent. *Journal of Biological Chemistry*, 193, 265–75.

Malakoff, D. (2004). Profile - Dave Rosgen - The river doctor. *Science*, 305, 937-939.

Miller, J. R., & Ritter, J. B. (1996). An examination of the Rosgen classification of natural rivers. *Catena*, 27, 295-299.

Palmer, M. A., Filoso, S., & Fanelli, R. M. (2014). From ecosystems to ecosystem services: Stream restoration as ecological engineering. *Ecological Engineering*, 65, 62-70.

Palmer, M. A., Hondula, K. L., & Koch, B. J. (2014). Ecological Restoration of Streams and Rivers: Shifting Strategies and Shifting Goals. *Annual Review of Ecology, Evolution, and Systematics*, 45, 247-269.

Perry, M., & Reny, P.J. (2016). How to count citations if you must. *American Economic Review,* 106, 2722-2741.

Munich Re (2018). NatCatSERVICE – Overall and insured losses in US$ for flood/flash flood events worldwide 2008-2017. https://natcatservice.munichre.com/overall/. Last accessed 10/1/2018.

National Research Council (NRC) 1992. Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. Washington, DC: The National Academies Press. https://doi.org/10.17226/1807.

Schut, M., Leeuwis, C., & van Paassen, A. (2010). Room for the River: Room for Research? The case of depoldering De Noordwaard, the Netherlands. *Science and Public Policy*, 37, 611-627.

Serra-Llobet, A., Kondolf, G.M., Schaefer, K., & Nicholson, S. (eds) (2018). Managing flood risk: innovative approaches from big floodplain rivers and urban streams. Palgrave Macmillan, London, 162 pp.

Sharp, P. A., & Leshner, A. I. (2014). Meeting Global Challenges. *Science*, 343, 579-579.

Sterman, J. D., & Wittenberg, J. (1999). Path dependence, competition, and succession in the dynamics of scientific revolution. *Organization Science*, 10, 322-341.

Thomson Reuters (2008). Using bibliometrics: A guide to evaluating research performance with citation data (Whitepaper). Last accessed 18 Apr., 2018 from ips.clarivate.com/m/pdfs/325133_thomson.pdf.

Tockner K., Pennetzdorfer, D., Reiner, N., Schiemer, F., & Ward, J. (1999). Hydrological connectivity and the exchange of organic matter and nutrients in a dynamic river floodplain system (Danube, Austria). *Freshwater Biology*, 41, 521-535.

Tockner, K., Pusch, M., Gessner, J., & Wolter, C. (2011). Domesticated ecosystems and novel communities: challenges for the management of large rivers. *Ecohydrology & Hydrobiology*, 11, 167-174.

United Nations Office for Disaster Risk Reduction (UNISDR; 2015), Making Development Sustainable, the Future of Disaster Risk Management: Global Assessment Report on Disaster Risk Reduction 2015, UNISDR, Geneva, Switz.

Van Noorden, R., Maher, B., & Nuzzo, R. (2014). The top 100 papers: Nature explores the most-cited research of all time. *Nature*, 514, 550-553.

Walter, G., Fisher, K., Bloch, S., & Hunt, G. (2003). Counting on citations: a flawed way to measure quality. *Medical Journal of Australia*, 178, 280-281

Water Framework Directive (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Available from http://rod.eionet.europa.eu/instruments/516.

Wheater, H., & Evans, E. (2009). Land use, water management and future flood risk. *Land Use Policy*, 26, S251-S264.

Wohl, E., Angermeier, P. L., Bledsoe, B., Kondolf, G. M., MacDonnell, L., Merritt, D. M., Palmer, M. A., Poff, N. L., & Tarboton, D. (2005). River restoration. *Water Resources Research* 41, W10301, doi:10.1029/2005WR003985.

van Herk, S., Rijke, J., Zevenbergen, C., & Ashley, R. (2015). Understanding the transition to integrated flood risk management in the Netherlands. *Environmental Innovation and Societal Transitions*, 15, 84-100.

Yarnell, S.M., Petts, G.E., Schmidt, J.C., Whipple, A.A., Beller, E.E., Dahm, C.N., Goodwin, P., & Viers, J.H. (2015). Functional flows in modified riverscapes: Hydrographs, habitats and opportunities. *BioScience*,65, 963–972.

Zarfl, C., Lumsdon, A. E., Berlekamp, J., Tydecks, L., & Tockner, K. (2015). A global boom in hydropower dam construction. *Aquatic Sciences*, 77, 161-170.

**TABLE 1.** Number of river-science papers among the 30 most cited, by region and time interval.

| | USA & Can. | Europe | Austral./NZ/ Polynesia | China | Other Asia | Latin Am. & Caribbean |
|---|---|---|---|---|---|---|
| 1980-1984 | *18* | *11* | *1* | *0* | *0* | *0* |
| 1990-1994 | *19* | *9* | *1* | *0* | *0* | *1* |
| 2000-2004 | *20* | *9* | *1* | *0* | *0* | *0* |
| 2005-2009 | *7* | *11* | *3* | *4* | *4* | *1* |
| 2010-2014 | 14 | 4 | 3 | 8 | 1 | 0 |
| 2011-2017 | 6 (10 of 50) | 7 (14 of 50) | 1 (2 of 50) | 12 (19 of 50) | 4 (5 of 50) | 0 |

**TABLE 2.** Percent of international collaborations by region and time interval among the authors of the 30 most cited papers (blank if not papers during a time interval).

| | USA & Can. | Europe | Austral./NZ/ Polynesia | China | Other Asia | Latin Am. & Caribbean | ALL |
|---|---|---|---|---|---|---|---|
| 1980-1984 | 0% | 0% | 0% | | | | 0.0% |
| 1990-1994 | 16% | 44% | 100% | | | 100% | 30.0% |
| 2000-2004 | 35% | 11% | 0% | | | | 30.0% |
| 2005-2009 | 29% | 27% | 33% | 0% | 25% | 0% | 23.3% |
| 2010-2014 | 43% | 0% | 100% | 88% | 100% | | 60.0% |
| 2011-2017 | 33% (40% of 50) | 14% (21% of 50) | 100% (50% of 50) | 50% (42% of 50) | 25% (20% of 50) | | 37% (36% of 50) |

**TABLE 3**. Percent of local citations by region and time interval among the 30 most cited papers (blank if not papers during a time interval). Also shown are the total number and percentage of papers most cited locally (from home region).

| | USA & Can. | Europe | Austral./NZ/ Polynesia | China | Other Asia | All | Papers most cited from own region: | % |
|---|---|---|---|---|---|---|---|---|
| 1980-1984 | 70.5% | 61.9% | | | | 67.7% | 25 (of 30) | 83.3% |
| 1990-1994 | 70.7% | 55.4% | | | | 61.8% | 25 (of 30) | 83.3% |
| 2000-2004 | 56.0% | 61.2% | | | | 57.7% | 27 (of 30) | 90.0% |
| 2005-2009 | 51.2% | 56.4% | 29.2% | 59.9% | 45.7% | 51.1% | 24 (of 30) | 80.0% |
| 2010-2014 | 47.3% | 65.1% | 18.2% | 60.8% | | 50.0% | 22 (of 30) | 73.3% |
| 2011-2017 | *32.1%* | *53.2%* | *39.4%* | *55.4%* | *23.0%* | *46.0%* | *37 (of 50)* | 74.0% |

** Time periods with only 1 paper from region not calculated*

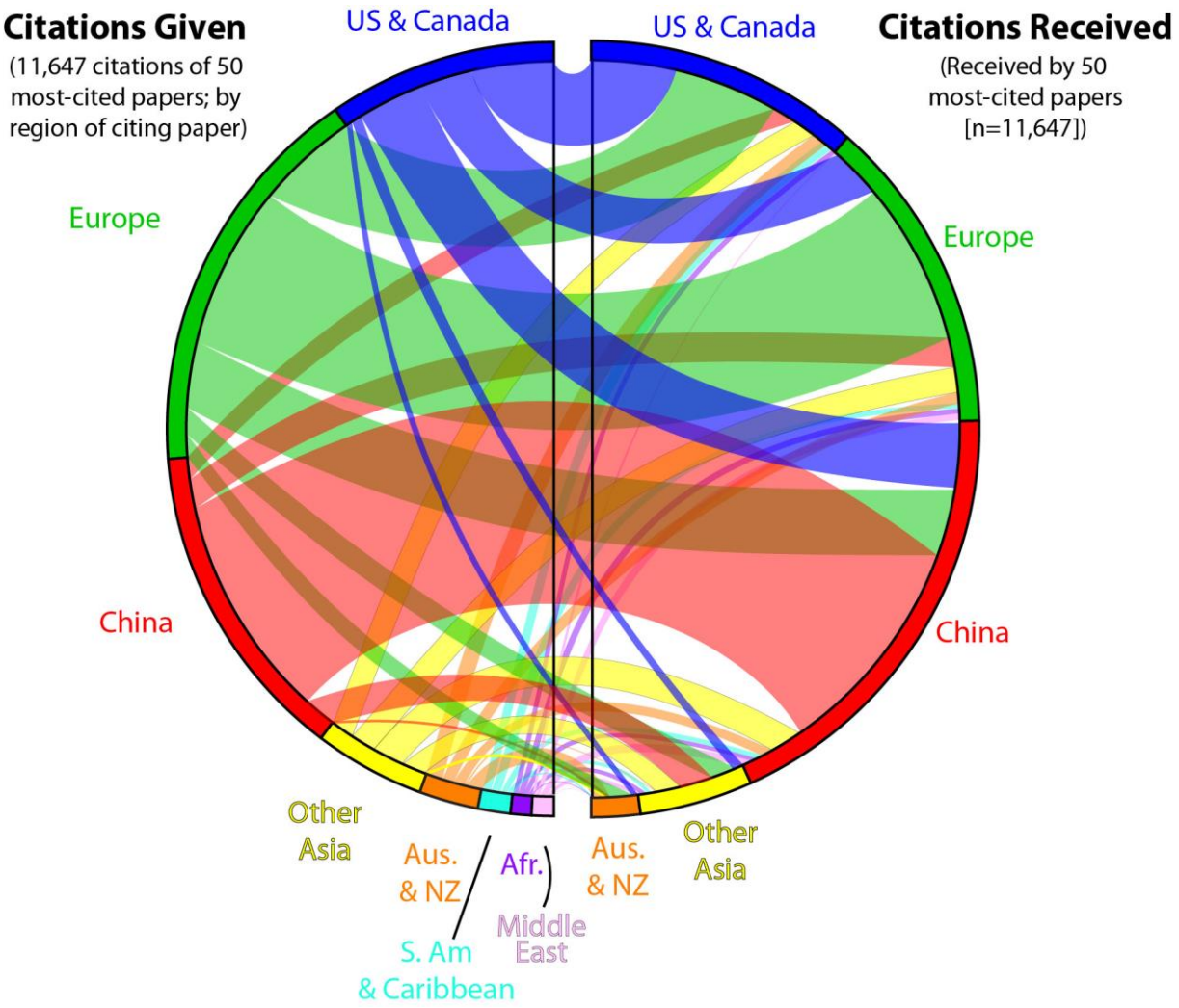


**FIGURE 1**. Network map showing the geographic origins of citations of the 50 most-cited papers in the general area of river science (see text) during the period 2011-2017, inclusive.

| Citations from USA/CANADA | of "Own" Papers | of "Non-Local" Papers |
|---|---|---|
| Number of Citations: | 842 | 1375 |
| Total number of Citations of those Papers: | 2685 | 8962 |
| Ratio (as %) | 23.9% | 13.3% |
| I-Factor | | 1.8 |

| Citations from EUROPE | of "Own" Papers | of "Non-Local" Papers |
|---|---|---|
| Number of Citations: | 1657 | 2238 |
| Total number of Citations of those Papers: | 3219 | 8428 |
| Ratio (as %) | 34.0% | 21.0% |
| I-Factor | | 1.6 |

| Citations from AUSTRALIA/NEW ZEALAND | of "Own" Papers | of "Non-Local" Papers |
|---|---|---|
| Number of Citations: | 173 | 408 |
| Total number of Citations of those Papers: | 505 | 11142 |
| Ratio (as %) | 25.5% | 3.5% |
| I-Factor | | 7.2 |

| Citations from CHINA | of "Own" Papers | of "Non-Local" Papers |
|---|---|---|
| Number of Citations: | 2297 | 876 |
| Total number of Citations of those Papers: | 4290 | 7357 |
| Ratio (as %) | 34.9% | 10.6% |
| I-Factor | | 3.3 |

| Citations from OTHER ASIA | of "Own" Papers | of "Non-Local" Papers |
|---|---|---|
| Number of Citations: | 244 | 835 |
| Total number of Citations of those Papers: | 1097 | 10550 |
| Ratio (as %) | 18.2% | 7.3% |
| Introspection Factor (IF) | | 2.5 |

**FIGURE 2**. Summary of citation patterns for the 50 most cited papers ("river[s]" in title) from 2011-2017, by region. The I-Factor is the relative proportion of local citations for papers from that region relative to non-local citations.