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Learned Discourses: Timely Scientific Opinions

Timely Scientific Opinions

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Rules. All submissions must be succinct: no longer than 1000 words, no more than 6 references, and at most one table or figure. Reference format must follow the journal requirement found on the Internet at http:\\www.setacjournals.org. Topics must fall within *IEAM*'s sphere of interest.

Submissions. All manuscripts should be sent via email as Word attachments to Peter M Chapman (peter_chapman@golder.com).

Learned Discourses Editor

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INTRODUCTION TO 3 LEARNED DISCOURSES ON ECOLOGICAL VALUATION

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The primary question addressed by each of the first 3 Learned Discourses (LDs) in this issue is whether to count money in or out of ecological valuation. Each of these LDs takes a different perspective: one says count money in, another says include nonmonetary means of valuing ecological services, a third says use money when possible, but it is not always possible. All 3 LDs were developed following informal discussions at the Joint SETAC-Ecological Society of America Workshop on: Ecosystem Services, Environmental Stressors and Decision-Making, 28 September to 3 October, 2014, Shepherdstown, WV, USA.

We invite readers to read each LD and provide the authors with feedback. We also encourage responses (i.e., follow-on LDs) from readers. Enjoy!

THE RATIONALE FOR MOVING BEYOND MONETIZATION IN VALUING ECOSYSTEM SERVICES

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Throughout recorded history, scholars and people living close to the land recognized that human societies were dependent on their surrounding ecological systems. The industrial revolution with complex machines, energy efficiency, improved shelter, sanitation, medicines, and increased food production provided ways to insulate humans from nature, resulting in massive human population growth. Although many espouse that we are no longer tethered to the constraints of nature, community well-being is diminishing.

Since the concept of ecosystem services emerged in 2003 in the Millennium Ecosystem Assessment, a vocal contingent of economists and ecologists have pushed to monetize ecological goods and ecosystem services (Munns and Rea this issue), even arguing that to hold a perspective that something can have considerable value without being monetized is being dishonest or disingenuous (Calow this issue). However, monetizing all ecosystem services will inevitably lead to greater resource use as it transfers ethical decisions about resource use into a baseline currency no longer tied to the actual good or service. For example, in fisheries monetization of a commodity favors a put-and-take enterprise over the multiple nonmonetized services of natural streams or lake systems. Monetization inexorably leads to expanding wealth-inequity, as those with excess monetary wealth can disproportionally access resources.

Although informal economies (barter and trade) formed millennia ago, the formal field of economics arose with the industrial revolution and Adam Smith's 1776 publication of *An Inquiry into the Nature and Causes of the Wealth of Nations*, and subsequent notable works by Jevons, Ricardo, Marx, and Say. Their efforts to understand markets via labor and materials costs in comparison with the price of goods or rents, led to codification of fantastical economic assumptions. The precepts of neoclassical economics have been pilloried with both logic and empirical data (Keen 2011). Yet, practitioners of neoclassical economics enjoy unwarranted influence in setting policies that are driven by econometric faith rather than empirical economics data.

The deficiency of neoclassical economics is its assertion of an ethical dimension to free markets, holding that an individual acting from self-interest and knowing well the local pricing structure will make a self-satisfactory deal. By acting from pure self-interest in that context, individuals maintain and strengthen local and regional economies for all community members. One has to ignore most of what goes on in markets to hold this premise. Behavioral economics (a la Levitt's *Freakonomics* and Ariely's *Predictably Irrational*) refutes the existence of a rational, fully informed vendor or consumer. The ethical consumer, mythical or real, no longer matters in globally traded commodity markets; countries are only rewarded for an ever-increasing Gross Domestic Product (Parkinson 2014).

An alternative to neoclassical economics gave rise to ecological economics (Costanza et al. 1997), which explicitly attempts to quantify the flow of ecological goods and services. Yet ecological economics models still follow the basic approaches of neoclassical economics. To wit, the central question for ecological economics is "how large is the ecology that can fit within the economy?" which, following the single pillar of sustainability (McCormick et al. 2012), is not a useful way of looking at the issue.

A more interesting approach is that of economic ecology (O'Neill 1996), which emphasizes ecology over economics. Because economic ecology focuses on system dynamics that govern the provision of ecological goods and ecosystem services to society, it is not constrained by economic theory (specifically the theoretical flaws pervasive in neoclassical economics) (Keen 2011). Economic ecology fits the single-pillar model of sustainability, for evaluating the flow of goods and services, and for resonating with societal values that have not yet been, or perhaps can never be, monetized—such is the case when considering landscape values held by indigenous peoples or ranchers in Nebraska who have pushed back on the XL Pipeline traversing their lands.

The single pillar tenet is that an economy using anything in trade beyond the physical good or service (that is, some form of money) can only exist inside a society with accepted pricing policies. Those policies reflect the rate of provision of goods and services from the landscape in which the society is embedded. The economy can go away, as can the society, and the landscape continues—but the converse is not true—lose the landscape and the economy and society collapse. Thus, economic ecology provides a more appropriate approach to valuation of ecological services and goods. Neoclassical econometrics are unable to sufficiently and quickly expand or contract the economy when presented with annual and decadal fluctuations in ecosystem provisioning. A systems-based conceptual model of all the relevant ecological, social, and economic interactions, constraints, and drivers readily allows us to sort out which economic issues reside within a spatially and temporally defined social–ecological landscape. Effectively, the ecology sets the upper and lower constraints within which a society can try to sustain itself. The economy is merely an emergent property of a society sustaining itself within a landscape, relegating it to be less important than social cohesion and ecological capacity.

Schumacher's (1973) Buddhist economics, introduced in the mid-1960s, argues that modern economics is not sustainable and that a shift to value people more than capital accumulation is needed. Making this shift merely requires the will to do so. Neoclassical approaches will not get us there, as they only account for the individual or corporation accumulating capital, not valuing the enrichment of community and society as a whole. We should not always rely on monetized values when making decisions about complex social–ecological systems—there are situations in which decisions made with other value systems could predominate.

The three-pillar approach, in the end, is reduced to a single consideration—economics. The neoclassical insistence of monetizing everything, characteristically results in setting aside parts that are regarded as externalities in market cost–benefit equations and that therefore do not factor into those types of valuation. The single-pillar approach to sustainability focuses on the flow of ecosystem services toward societies embedded within and wholly dependent on surrounding ecological systems; economies are embedded within societies. The foundational arguments for the one-pillar metaphor over the three-pillar metaphor is a pointed refutation of the precepts of neoclassical economics and a shift that values people more than capital accumulation.

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WHY MONEY MATTERS IN ECOLOGICAL VALUATION

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The ecosystem services movement was a reaction against nature being taken for granted in decision making. Put a value on the services that we enjoy from ecosystems and there is a better chance of showing their importance in economic and social development (Norgaard 2010). Yet there are still concerns that the monetization of these services is at best inappropriate and at worst flawed on ethical grounds and in terms of basic principles (Kapustka and McCormick 2015). Here, I argue that these views are missing the point about the need for a transparent approach to valuation.

The first argument for monetization arises directly from the desire to show the worth of ecosystems. Putting constraints on the ways we use ecosystems in the economy, for raw materials and as a repository for wastes, by definition involves extra costs for producers and consumers alike. These are easily monetized and often appear as large costs for industry and society. Stating the benefits of protecting ecosystems in terms of money provides a convincing way of showing the importance of ecosystem services in the comparison of these costs and benefits.

A second argument for monetization arises from the need to capture public preferences in a transparent way—this follows from a basic proposition of welfare (neoclassical) economics that what matters in policy making is finding ways to enhance the welfare (sometimes called utility) of individuals within society. There are other possible policy aspirations that are sometimes confused with this focus on the individual. One is that there are societal values that can sometimes override individual values. These are the kinds of values that governments are supposed to take into account when making policy. However, in the human health context for example, the obvious difference between society putting a value on our lives as compared with capturing the value that we put on our own lives draws attention to the possible dangers with this kind of approach. Another assertion is that policies ought to take into account the intrinsic values that reside in nature. However, these values often turn out to be the values of those promoting the approach or are intended to make nature so valuable that no development would ever be possible.

Preferences and values are made most transparent when we trade in markets and the presumption from economics is that those trades will lead to a better state in terms of welfare. Some environmental goods are traded in markets such as commodities that include lumber and fish. However, most are not (they are so-called externalities) and the many techniques for capturing the way that we value these are aimed at making explicit our preferences transparently, in a way that can be used effectively in weighing the costs and benefits of environmental policy interventions (Hanley and Barbier 2009). Money is the index of utility and provides a common currency for the trade-off arguments. Methods are developing for capturing utility directly, but these techniques are at an early stage and the results cannot easily be used in cost-benefit comparisons (Krueger and Stone 2014).

There are well known challenges for capturing nonmarket values and using them as a better basis for environmental policy (Hanley and Barbier 2009). For example, valuation techniques, especially those that ask about willingness to pay for ecosystem services, make the presumption that those asked know enough ecology to provide rational responses. This is why ecosystem service approaches are increasingly framed in terms of final outcomes (e.g., clean drinking water, ability to fish and swim) rather than the complex ecological properties and processes that are behind them. Alternatively, when asked about hypothetical willingness to pay, which does not involve a hard cash transaction, people seem to overvalue ecological goods and services, and this certainly needs more research.

Kapustka and McCormick (this issue) raise even more fundamental concerns about the market model: that markets often fail to deliver because of externalities and this leads to the overexploitation of nature, that we do not operate as rationally as we should in making decisions based on preferences, and that aggregating across the people affected misses the point that some of these will be winners and some losers thus leading to increased inequality. However, the whole aim of the ecosystem services approach is to internalize ecological externalities so that they are not forgotten in policy development; this should have the effect of reducing not enhancing exploitation. Although behavioral economics is demonstrating deviations from some of the core assumptions of the neoclassical model, it is unclear how significant these are in terms of magnitude and pervasiveness (Robinson and Hammitt 2011). Finally, on inequality the presumption is that accumulating wealth is good because in principle the winners can compensate losers thus raising overall welfare; but, as noted by Piketty (2014), addressing this distributional challenge has to be a matter for governments.

Not all will want to accept a form of decision making that is based on the preferences of the individuals affected, even though it is fundamentally empowering. There are alternative models that seek to emphasize the limits that nature puts on economic development and this includes economic ecology (Kapustka and McCormick this issue). However, decisions still have to be made about what those limits mean for the economy and on balancing the inevitable tradeoffs between our activities and the environment. This begs the questions of who makes those decisions and how. Some might say let the ecologists decide, but as they move from the science (what is) to policy (what ought to be), value judgments will be exercised that need not coincide with those of the public at large. Others might argue for more government, but this inevitably involves politics that can cloud decisions. Yet others argue for a more spiritual approach, but intrinsic values are elusive. If the aim is to base decisions on what people want from ecosystems, in a way that can be weighed transparently against the costs of protecting ecosystem services, then monetization is something that should be embraced rather than avoided in taking the ecosystem services approach forward.

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ECOSYSTEM SERVICES: VALUE IS IN THE EYE OF THE BEHOLDER

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Ecosystem goods and services (hereafter ES) contribute to the welfare of people and society. People benefit when decisions affecting the environment enhance ES. In many situations, multiple options or alternatives exist for the environmental decision being made. Selection among these alternatives—perhaps with the objective to optimize delivery of ES and the benefits they provide relative to costs—is informed through understanding the values humans ascribe to ES.

Valuation is the act or process of estimating the worth, merit, or desirability of a wide variety of environmental conditions in common units that can be aggregated and compared (Munns et al. this issue). This definition has 2 key implications. First, value is in the eye of the beholder and must be defined from the perspective of that beholder. Although not without controversy, the ES concept is anthropocentric: the "beholders" are people and society. Thus, society provides the frame of reference for determining the value of ES and changes therein, with environmental decisions being made with these values in mind. The second implication stems from the notion of "common units." When values are quantified in monetary terms (aka monetization), the benefits of competing alternatives can be compared directly with the costs of implementing those alternatives, a process formalized in benefit-cost analysis. This is not to say that people only value money; indeed, any number of philosophical, spiritual, moral, and other beliefs and attitudes contribute to the values people place on ecosystems and the decisions affecting them. Rather, money is a convenient common unit with which to quantify, aggregate, and compare these values in the decision-making process. However, monetization is not always feasible, practical, nor desirable. In such instances, other approaches can be used to value changes in ES in nonmonetary terms that are useful to decision makers. Adamowicz et al. (2007) and SAB (2009) provide accessible descriptions of valuation concepts and methods.

Table 1 describes the different kinds of benefits that people receive from ES, and provides a convenient framework for describing economic valuation methods. The value of ES that are sold and bought in markets, such as food and fiber, can be revealed by the money exchanging hands in these markets (although market price might not reflect the full benefits of a good). Revealed preference methods can also be used to quantify the value of certain ES not traded in markets (nonmarket benefits), such as those that affect market goods directly or indirectly (e.g., for environmental amenities that affect housing prices), or the aesthetic or recreational amenities provided by natural places (inferred from the money people have spent to visit those places).

In the absence of information describing values as revealed by people's past and current behaviors, stated preference methods can be used to evaluate the tradeoffs people are willing to make to protect ecosystems. These methods depend on people's responses to questions asking how much they would pay to protect or enhance ecosystems and their services (willingness-to-pay), or to be compensated if such actions were taken (willingness-to-accept). Information typically is collected using survey instruments that offer choices among various environmental alternatives and the costs associated with each. Stated preference methods are useful for eliciting values of the direct-use, indirect-use, and nonuse benefits described in Table 1.

The neoclassical environmental economic approaches above are based on a unifying conceptual framework for considering social welfare that directly informs economic analysis of tradeoffs. A variety of other approaches, summarized by the SAB (2009) as social–psychological valuation methods, rely on the judgments of individuals and groups to inform environmental decision making. Included are various methods (multi-criteria decision making, Delphi methods, referenda, etc.) that seek to elicit the opinions and judgments that can help to uncover societal preferences and to rank the acceptability of alternative options under consideration. Although they do not lend themselves easily (if at all) to monetization, such approaches provide information about values people place in ES.

Neoclassical environmental economic approaches, and to some extent social–psychological valuation methods, consider social welfare to be the objective and assume ecosystems to be part of the economy. An alternative paradigm and set of valuation approaches have been proposed by ecological economists who consider the economy to be one component of a broader environment system (Adamowicz et al. 2007). Generally speaking, this paradigm shifts the focus from humans to ecosystems, and defines value in terms of biophysical stocks and flows instead of directly in terms of human welfare. Various methods can be used for deducing value from this vantage, including those based on energy flow, and on comparisons of the ecological footprints required to support individuals and human communities. Despite the attractions that ecological economics offers to the issue of valuation, it has yet to converge on a central set of theories and core framework of analysis needed by environmental policy and decision making. Until these are developed, the usefulness of ecological economic approaches to environmental decision making will be limited.

Table 1. Types of ecological benefits categorized by benefits type[a]

Benefit category	Explanation	Examples
Market	Generally relates to products that can be bought or sold	• Food and water sources: Commercial fish and livestock, game fish and wildlife, drinking water • Building materials: Timber • Fuel: Methane, wood • Clothing: Leather, fibers • Medicines: Nature-derived pharmaceuticals
Nonmarket		
Direct-use	Directly sought and used or enjoyed by society; includes both consumptive uses and nonconsumptive uses	• Consumptive recreational: Fishing, hunting • Nonconsumptive recreational: Boating, swimming, camping, sunbathing, hiking, bird watching, sightseeing, enjoyment of visual amenities
Indirect-use	Indirectly benefit society; may be valued because they support offsite ecological resources or maintain the biological and/or biochemical processes required for life support	• Maintenance of biodiversity • Maintenance and protection of habitat • Pollination of crops and natural vegetation • Dispersal of seeds • Protection of property from floods and storms • Water supply (e.g., groundwater recharge) • Water purification • Pest and pathogen control • Energy and nutrient exchange
Nonuse	Benefit does not depend on current use or indirect benefits; individuals might value the resource without ever intending to use it or might have a sense of environmental stewardship; includes bequest value, existence value, and cultural or historic value	• Perpetuation of endangered species • Wilderness areas set aside for future generations

[a]Adopted from USEPA (2006).

Quantifying values is largely the purview of economists and other social scientists, yet natural scientists have important contributions to make. We should strive to understand the kinds of things—the endpoints—that economists can value, and then quantify those endpoints in addition to traditional measurements. This is analogous to ensuring that field and laboratory studies measure the endpoints required as input by models. Measurements can be linked to valuation endpoints through ecological production functions. We should continually ask ourselves whether we are measuring the right things to inform decisions.

From a policy standpoint, reducing uncertainty is a lynchpin in decision making. When natural scientists provide the kinds of information needed for economic analysis, a wider range of options can be evaluated. When changes in ES are monetized, tradeoffs among policy alternatives become more transparent (Calow this issue), ideally reducing both uncertainty and unintended consequences. Despite the uneasiness with and perceived shortcomings of neoclassical economics (Kapustka and McCormick this issue), environmental protection will be well served by embracing the values of ES as seen in the eyes of the beholder.

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NANOMATERIAL ENVIRONMENTAL RISK ASSESSMENT

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Although engineered nanomaterials (NMs) have been the focus of intense research during the last decade, issues related to developing a scientifically based environmental risk assessment (ERA) framework for such materials within existing legislation remain unsolved. Research to date suggests that there may be particle-specific complexities that demand a more NM-targeted approach to estimating environmental exposures and testing toxicological effects. Identified complexities are, among other issues, related to: the dynamic nature of NM exposure due to changes in nanoparticle properties over time, not least in complex media; specific particle-related uptake and internal distribution mechanisms; and the limited ability to routinely measure and predict NM concentrations in relevant environmental compartments. The following also pose challenges in addressing potential ecological risks of NMs: the limited number of studies testing potential long-term and population-relevant effects; and, the lack of proper guidance on how to include results from nonstandard testing in ERA.

To address these issues, an international workshop was held on November 9, 2014 in Vancouver prior to the Society of Environmental Toxicology and Chemistry (SETAC) North America meeting. Through 7 invited talks and a panel discussion, 2 overarching charge questions were addressed: 1) Is it prudent to assess environmental risk based on current knowledge and understanding of NM fate and effects?, and 2) How may we direct future research to address potential uncertainties and data gaps?

To focus the workshop the invited talks (Table 1) represented different aspects of NM research where the workshop organizers had identified a priori: potential uncertainties, data deficiencies, and specific challenges related to ERA of NMs. In addition to highlighting some of the current issues in NM research, the presentations provided a solid basis for discussions among workshop participants.

Nanomaterial environmental risk assessment should take known uncertainties and limitations into account

In the face of pragmatic challenges in assessing NM risk based on current knowledge, workshop participants advocate that ERA be carried out with an understanding of uncertainties, challenges, and limitations in NM effect and exposure assessments, many of which lead toward future research needs. Some major challenges were identified through discussions among workshop participants:

- Risk assessment should focus on what we are trying to protect. Process-based and mechanistic effect models may be a scientifically sound approach to link measured effects to effects on protection goals. Good communication is needed among researchers, regulators, and practitioners to ensure effective assessments are conducted using appropriate input parameters.
- Some of the current challenges related to ERA of NMs may originate from the way we perceive, talk, and test toxicity in general. For example, test procedures are optimized for testing dissolved toxicants, and particulates settling out of the medium are unacceptable by definition. Thus, the language and terminology used to describe fate, exposure, and biological effects of NMs, in addition to the test procedures, need to mature to properly embrace specific particle complexities.
- There is an ongoing challenge with current standard test guidelines that do not take specific particle complexities into account. Therefore, there is a need to allow the inclusion of relevant nano-tailored studies in ERA. This requires additional guidance for ranking and selecting studies according to quality and relevance of individual studies.
- In addition, more and, in some cases, different kinds of information are needed beyond information found in the current published literature, in order to predict realistic environmental risks of engineered NMs. Examples are effect assessments during long-term and more realistic exposure scenarios, including assessments that incorporate dietary exposure to NM associated with the food of animals.
- There is evidence that release patterns of engineered NMs into the environment, and consequently exposure routes, may affect bioavailability and bioaccumulation of NMs, which in turn will impact toxicity. Therefore, advancing understanding of NM environmental fate to predict realistic temporal and spatial exposures is of major importance.
- Although still not routine measures, tools used to assess engineered NM exposures and environmental concentrations are improving, albeit with differing success for different materials. It has become clear over the last years that apart from the characterization of pristine materials,

Table 1. List of invited speakers and titles of presentations

Valery Forbes	Isn't it time to bring chemical risk assessment into the 21st century?
Hans-Christian Holten Lützhøft	Potential nanomaterial enhanced conflicts
Jeffery Steevens	Life cycle approach for nanotechnology assessment: A framework for assessing release and hazard
Frank von der Kammer	The challenge to measure environmental concentrations of manufactured nanoparticles
Samuel Luoma	Bioavailability and bioaccumulation of metal based engineered nanomaterials in aquatic environments: Concepts and processes
Leanne Baker	Implications of exposure route and particle aging for the fate and effects of nanomaterials in aquatic environments
André Gergs	A plea for the use of process-based effect models in the environmental risk assessment of engineered nanoparticles

there is a pressing need for methods that can support the understanding of aging processes and quantify NMs in complex samples and at low concentrations. Lacking information about exposure and toxicity controlling properties of NM, it appears difficult to prioritize the development of analytical tools for certain objects of measurement.

- Appropriate toxicity assessments are lagging behind and long-term studies evaluating population-relevant endpoints are still largely missing from the open literature. This prevents a process-based modeling approach to more realistically address hazard and eventually risk of engineered NMs for ERA protection goals. In this regard, ecotoxicity studies where no effect is reported are equally as valuable as studies that demonstrate an effect, and their publication must be encouraged.

Proposed directions for future research to address uncertainties and data gaps

To focus future NM research, we need to explore how models can be used to take a top-down approach to identify: 1) what types of data and information are needed, 2) what parameters best predict NM-specific hazard and effects on protection goals (e.g., populations), and 3) the information needed to make sense of the dynamic nature of different particle characteristics interacting with environmental components. This should be done with knowledge that:

- The requirements for NM characterization are increasing, and efforts must be focused on relevant characteristics because there is still a need for a hypothesis-driven and systematic approach to test how NM characteristics affect uptake, fate, and effects.
- The generation of data for ERA of NMs should be directed through the use of process-based models and value of information analyses. Data useful for parameterizing such models are needed and will require increased focus on long-term testing of individual level sublethal and lethal effects, bioavailability, and uptake and elimination kinetics. These should all use environmentally realistic release and exposure patterns. Studies demonstrating an effect, as well as no effect, are valuable, and specific language and terminology may be needed to adequately describe NM fate, exposure, and effect.
- Although progress has been made in the ability to measure the most relevant NMs in the environment, this research area requires continued focus to: 1) address measurement of difficult particle types (i.e., particles where contrast to natural particles or materials is low), and 2) provide methods from which protocols for routine measurement can be developed.

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WHOLE-SYSTEM PERSPECTIVES IN RIVERS: INSIGHTS AND IMPLICATIONS

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Rivers are at the nexus of land-use change and environmental management. They are responsive to land-use change and, through their network of connections, can spread potential impacts to nearby and distant habitats. Concordantly, there is growing scientific appreciation that rivers are more than a sum of their parts. This Learned Discourse examines how whole system perspectives of rivers could be integrated into environmental management and watershed-scale planning.

INSIGHTS FROM WHOLE RIVER SYSTEM PERSPECTIVES

There is emerging scientific appreciation that consideration of rivers as whole systems can provide insights into their dynamics and functions (McCluney et al. 2014; Moore 2015; Moore et al. 2015). Rivers represent vast tree-like networks of connections. Connections can operate both in upstream and downstream directions, driven by downstream flows of water and its properties and materials (e.g., sediment), and by upstream movements of migratory fishes (e.g., salmon).

The connectivity of rivers can make them more sensitive to the cumulative impacts of multiple development projects (McCluney et al. 2014; Moore 2015). Land-use changes are propagated downstream and upstream through vast river networks. For example, 75% of the water in the Athabasca River (AB, Canada) has been allocated to oil sands development; this project has been associated with altered hydrology and elevated water contamination in the area adjacent to the development area downstream but also to distant downstream habitats (Dubé et al. 2013). Reciprocally, loss of downstream fish habitat can degrade upstream fisheries, such as proposed project developments in the Skeena River estuary (BC, Canada) threatening upstream salmon fisheries throughout the Skeena River (Carr-Harris et al. 2014). Thus, whole river system perspectives reveal that river networks can spread project impacts across hundreds, if not thousands, of kilometers.

Another recent scientific insight from whole river system perspectives is that rivers can function as natural “portfolios” that provide stability due to their linkages and their branching network structure (McCluney et al. 2014; Moore et al. 2015). Analogous to an economic stock portfolio, downstream habitats in rivers can integrate upstream hydrological, climatic, geological, and biological diversity and naturally dampen variability. Recently, we discovered that larger catchments which integrate more diversity, have greater stability (less variability) in water flows, water temperatures, and First Nations salmon fisheries catches (Moore et al. 2015). However, loss of local diversity within river networks could compromise the stability of the whole (Moore 2015).

IMPLICATIONS

These insights from whole system perspectives of rivers offer opportunities and challenges for accurate assessment or prediction of impacts of development projects. Proper consideration of the consequences of development projects in river systems will entail shifts in focus toward broader quantification of temporal dynamics and multiple spatial scales of impact. These are not trivial challenges.

Temporal dynamics

Rivers are inherently dynamic systems; hydrographs annually rise and fall, habitats constantly shift due to deposition and erosion, nutrients and contaminants episodically spike, and fish populations shift in time and space. These dynamics will lead to two fundamental challenges.

First, this inherent variability will challenge the statistical power of monitoring and assessment efforts. From a formal statistics perspective, statistical power is inversely proportional to the standard deviation. From a common sense perspective, it is more challenging to understand how things change with a baseline that is a constantly moving. Thus, sufficient quantification of baselines and effects of proposed projects will entail extensive data collection across time, a challenge for recent efforts such as that regarding biological impacts of oil sands mining in the Athabasca River (Dubé et al. 2013).

Second, variability (or lack of variability, stability) is a key dimension of river systems that should be incorporated into project assessment and watershed planning. Not only is variability a key driver of river dynamics, but variability also defines the reliability of production of river derived goods and services. Thus, changes in variability will impact river ecosystems and biodiversity, but also will alter how people benefit from riverine processes. Human impacts may alter the variability of key processes without impacting the long-term average; for example, watershed development can lead to flashier hydrographs. Alternatively, subtle erosion of diversity within river networks could erode the natural capacity of rivers to dampen variability (Moore et al. 2010). Thus, the variability of river processes should itself be assessed and quantified.

Spatial scale

Given that rivers can propagate impacts of development projects in both upstream and downstream directions, there is a need for robust consideration of the spatial scales of impact.

First, individual development projects should define zones of influence that match the true spatial scales of impact. Examples of scientific data that could guide the spatial scale of influence would be the dispersal of contaminants and other materials such as sediment as well as the distance of migrations of fishes across their life cycle.

Second, given the potential for far-reaching project effects, there is a need for appropriate consideration of the impacts of multiple projects within a watershed. Watershed cumulative effects assessments, as noted in Dubé et al. (2013), entail assessment of the current state of watersheds as well as examination of risks associated with alternate development scenarios. Recently, there have been efforts in a set of watersheds across Canada for watershed-based cumulative effects assessments (Dubé et al. 2013). However, cumulative effects assessments in Canada are generally considered “impotent,” with little true consideration of additive impacts of multiple development projects (Duinker and Greig 2006).

Meeting these challenges will entail shifts in current practices and legislation. One pathway is empowering and encouraging development of watershed management plans that have legislative teeth. In contrast to current environmental assessment practices and cumulative effects assessments, watershed management plans can be proactive rather than reactionary, and integrative rather than piecemeal. Furthermore, watershed monitoring plans could enable high quality and open access monitoring to not only better quantify assessment of impacts across time and space but also encourage public trust. Together, these shifts could substantially improve efficiency and improve sustainable development of watersheds. Regardless of the pathway, there is a need and opportunity to incorporate whole system perspectives into environmental assessment, decision making, and planning in watersheds.

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