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EDITORIAL

Managing Canada's land- and seascapes for multiple ecosystem services in the Anthropocene: introduction to the Food, Fiber, Fuel, and Function collection

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Reconciling production with conservation in the Anthropocene

As the world recovers from the worst ravages of the COVID-19 pandemic, and we assess a "new normal" that will define much of the next decade, many of us hope that we will find new energy to address the global challenge of managing our relationships with the environment. In particular, we must develop strategies to reconcile our need to use the environment to provide food, energy, and other basic necessities while preserving all the other ecosystem services on which we depend for a good life.

As noted by decades of research in the broad area of planetary health, including the Millennium Ecosystem Assessment (MEA 2005), the IPBES Global Assessment (IPBES 2019), and the Sustainable Development Goals (UN General Assembly 2015), humanity's impact on the biosphere is enormous and growing (Rockström et al. 2009). We live in the Anthropocene, a time defined by what some scholars describe as "the great acceleration" where many significant indicators of both economic activity and environmental degradation are rising exponentially (Steffen et al. 2015a). Humanity is exceeding a "safe operating space" in terms of our impact on biodiversity, nutrient cycling, and the climate, threatening ourselves with the very real prospects that major ecosystems from the Amazon to the Great Barrier Reef and to the polar ice sheets will become irrevocably changed over the next two generations (Steffen et al. 2015b).

At the same time, unprecedented amounts of data give us hitherto unimaginable abilities to measure human impacts on the environment. Technological innovations including artificial intelligence, robotics, and broadband accessible worldwide also provide us with a platform to develop new tools to mitigate our impact on the planet (Weersink et al. 2018; Rotz et al. 2019). In short, by applying the data revolution to agriculture, fisheries, and forestry we may be able to both better understand and more sustainably manage the environment.

But data and information alone will not solve our complicated and problematic relationship with the environment. We must also consider how and what we are managing and governing, and what kind

of relationships we want to have with the natural world. Research on natural resource management and governance has recently recognized the importance of approaches that reflect the complexity of involved interests, actors, and worldviews. As such, participation, both in research and decision-making, can help to move from a top-down approach to pathways that reflect the diversity of relationships people have with others and the natural world (Mann et al. 2015). Indigenous, local, and scientific knowledge systems together function as a base for innovation and new insights (Tengö et al. 2014). In the Canadian context, "Two-Eyed Seeing," not only features the perspective of knowledge coexistence rather than integration of Indigenous knowledge and Western scientific knowledge, but also asks knowledge holders to put their knowledge in action (Reid et al. 2021). Together, a responsibility to take action, the recognition of the variety of human–nature relationships, and the need of a transformation towards sustainability, has brought to the forefront the idea of "Earth Stewardship", a social–ecological framework for sustaining healthy human–nature relationships in a rapidly changing world (Chapin 2020).

This collection picks up on many of themes from this broad literature and presents a collection of essays, research papers, and perspective pieces drawn from the first two years of work by a team of researchers funded by the Natural Science and Engineering Research Council of Canada called ResNet.

Research in action: an introduction to ResNet

ResNet is a research network, funded primarily by the Natural Science and Engineering Research Council of Canada, of academic, government, and industry partners, alongside nongovernmental organization collaborators, from across the country that work to improve monitoring, modelling, and governance of ecosystem services in Canada's working landscapes. More specifically, ResNet brings together scholars and resource managers from a range of backgrounds to identify paths for sustainable land- and seascape management to ensure biologically diverse, resilient, and adaptive social–ecological systems amid the complexity of competing values, stakeholders, and political jurisdictions.

ResNet's work is unfolding through a series of six exemplar land- and seascapes across Canada. In each of these model landscapes, we have launched a series of co-designed investigations into the provision, modelling, and governance of multiple ecosystem services (**Fig. 1**). ResNet also features three themes, which apply theory and compare and contrast landscapes to build knowledge about governance, modelling, and monitoring of ecosystem services. Ultimately, we hope to synthesize the knowledge generated across regions and themes to produce tools to manage these ecosystems beyond our research area and at larger scales (Bennett et al. In press).

Structure and content of this collection

This collection consists of papers introducing nearly all the ResNet land- and seascapes and themes. In particular, the first four papers are rooted in specific regions from across Canada while the final four papers are cross-cutting essays that explore themes related to governance, modelling, and monitoring.

The first landscape paper is from Sherren et al. (2021) and introduces the agricultural dykelands and tidal wetlands in the Bay of Fundy on Canada's East Coast. The dykes and "aboiteaux" first introduced by early French settlers on the Nova Scotia side of the Bay protect nearly 20 000 hectares of land for residential, industrial, and commercial uses. Yet maintaining dykes, especially in the face of sea level rise, is costly, and the dyke system is being redesigned to balance those benefits provided by dykes with the benefits provided by tidal wetlands in nondyked areas. As Sherren and co-authors explain, there are complex trade-offs between different ecosystem services and between beneficiaries,

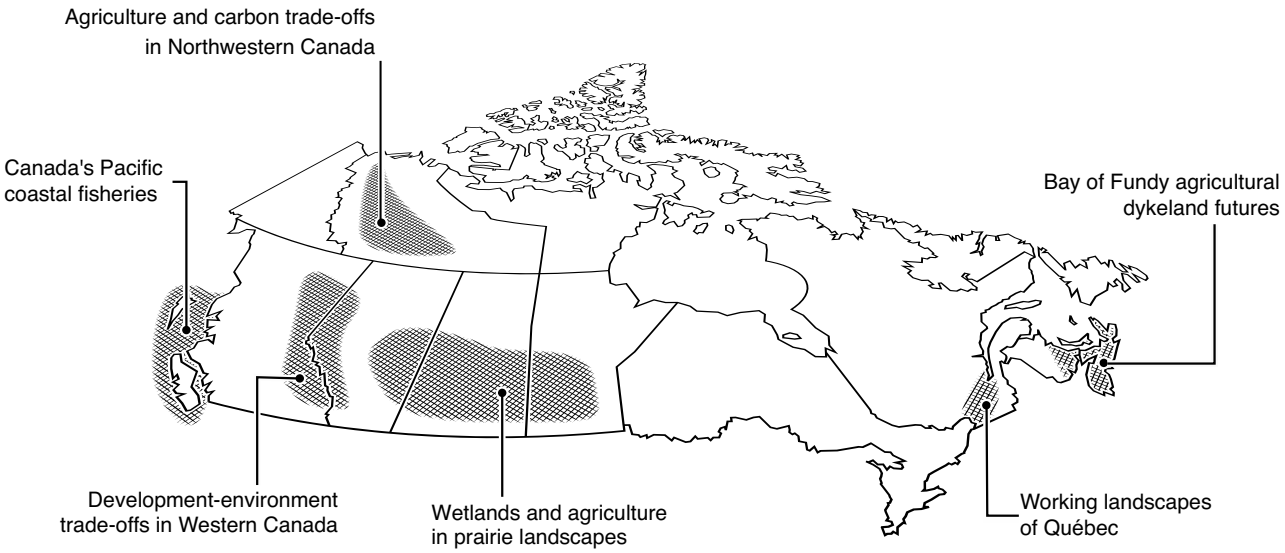

Fig. 1. The six ResNet land- and seascapes.

as well as some critical knowledge gaps about how ecosystem services are delivered that impede decision-making.

Cimon-Morin et al. (2021) bring us to Québec, where they explore systematic conservation planning as a decision-support framework to help manage complex working and urban landscapes for multifunctionality. The authors present an operational framework, divided into mapping and spatial planning stages, to assist in the protection and restoration of ecosystems to ensure ES provision. One important aspect of this approach is that it is based on finding complementarities between beneficiaries and services, pointing out that restoration might usefully focus on areas with gaps between demand and supply of ecosystem services

KC et al. (2021) dig deeper into the management of Canada's working landscapes under changing environmental conditions. This paper explores the potential northward expansion of agriculture and examines the potential impact of climate change on food production and other ecosystem services in Canada's North. The authors present modelling outputs showing the potential for up to 2 000 000 km^2 to become suitable for farming in the coming 60 years. However, KC et al. (2021) also show that if forests and wetlands are cleared and ploughed for potato, wheat, corn and soy, the ecosystems could release 15 gigatonnes of carbon into the atmosphere and cause loss of other regionally important ecosystem services, such as cultural, recreational, and food-providing hunting. Engaging local communities in discussions about the future of agriculture in the region is an important feature of carefully planning for the future of Canada's North in a changing climate.

Minnes et al. (2020) turn to opportunities that encourage collaboration in working landscapes, using conflict over agricultural drainage in Saskatchewan as a model system. Applying a conflict-transformation and social–ecological systems framework to interviews with stakeholders from a variety of sectors, the authors elaborate on how to build relationships and develop a shared understanding for managing competing priorities for the land. Inclusivity, empowerment, and the ability to adapt to changing concerns of involved actors emerge as important features to successfully manage conflict around "wicked problems" in working landscapes. Conflict over ecosystem service trade-offs is rarely straightforward, and it is critical that people develop institutions that prioritize sustainable

and equitable outcomes explicitly attend to the complex social dynamics that underlie contentious management issues. It is not sufficient to design a process that attends only to the material or ecological dimensions of the conflict without also creating a process to facilitate relationship building and shared understanding.

Green et al. (2021)'s paper is the first paper not rooted in a particular landscape; instead, this paper explores the potential role that novel agri-food technologies may have in providing producers with new tools to increase food production while reducing impact on ecosystem services in Canada. While technologies such as vertical farming, cellular protein, and precision agriculture are promoted as being useful for increasing global food security while enhancing ecosystem services, this paper also explores more critical arguments that nontechnological challenges stand in the way of achieving better food systems. The authors conclude that new technology is not a panacea; even with its great potential to help farmers produce more food on less land with fewer inputs, such outcomes are not inevitable. We must do better with economic incentives to protect the environment, better training and education of the next generation, and improved data integration.

Kerr et al. (2021)'s paper explores the use of the ecosystem service concept in Canadian government decision-making. The authors find that while there is great interest in the concept of ecosystem services, there also appears to be an implementation gap due to lack of staff familiarity and expertise with key concepts, a lack of regulatory mandates, and competition with similar and emerging approaches. The authors suggest that novel concepts require internal support and should be accompanied by clear guidelines and training.

Thierry et al. (2021) explore ecosystem service models. While ecosystem service models have traditionally focused on estimating provision of services, most existing modelling efforts do not consider the delivery of these services to specific human communities. Thus, while ecosystem services as a concept is often presented to evaluate the importance of nature to human well-being, formal models are not well-positioned to do so since they leave the final link to human well-being relatively unexplored. The authors present a series of social–ecological factors that could be added to ecosystem service models to better capture outcomes of landscape change for human well-being.

Finally, Firkowski et al. (2021) propose the use of a network approach to monitor biodiversity and ecosystem services across space and time. The authors conceptualize a new integrated, multiscale and multilayer framework for monitoring social-ecological systems, built on Ostrom's framework (Ostrom 2007). Using maple syrup production in southern Québec as a case study, the authors discuss how causal network models could be used to integrate knowledge on drivers of change to detect the unintended effects of human activity.

Key themes explored in this collection

Overall, the contributors to this collection hope that the individual papers are useful contributions in terms of our understanding of the ecosystem services of Canadian working landscapes and how they can be more sustainably managed towards multifunctional landscapes. In addition to these individual and region-specific contributions, we hope that this collection provides insights into a number of important cross-cutting themes.

The first overarching theme surfaced by this collection relates to holism, reductionism, and the role of data. While data give us the ability to better monitor—and hopefully manage—ecosystem services, the very nature of data is contested. In this collection, therefore, we hope to expand the conversations around data beyond a traditional academic approach where data simply mean that which is derived from formal scientific processes, that are peer reviewed, and thus largely fall in the domain of

academics. In treating data more broadly, this special issue has tried to engage with both scientific as well as traditional and local ecological knowledge. In particular, a key theme from this special issue is that developing a holistic understanding of how different types of knowledge bring different insights all of which are crucial to developing a less reductionism, more democratic, and emancipatory approach to ecosystem management (Fraser et al. 2006).

A second, and related, theme connects to the role of the so-called "expert" versus the role of the "lay-person" or community member. Traditionally, natural resource management has privileged expert-led, top-down management, but this has led to some well documented failures such as Leopold's (1949) famous account, *A Sand County Almanac*, of the ecological devastation that emerged after park managers extirpated local wolf populations to promote deer populations for hunting. This collection builds on an emerging call from the interdisciplinary environmental sciences to manage ecosystem services through a better job of blending top-down management approaches with participatory, community engaged, and "bottom-up" paradigms.

A third cross-cutting theme relates to technology. In particular, the concern that the future is deeply unsustainable echoes the 200-year-old Malthusian debate over population growth and collapse while excitement over the data-driven revolution shares a lot of similarities with techno-utopianism. The field of science and technology studies suggest that technology is never a panacea; if we want the upcoming data revolution in natural resource management to support public and environmental goods, we must democratize the processes by which technologies and knowledge are deployed. Democratizing technology means that those in power authority, which includes scientists, must use their platforms not only to engage with local communities but also elevate their perspectives.

Finally, a fourth and closely related issue that is a focus of ResNet work is that of multifunctionality—the ability of Canadian working landscapes to provide multiple ecosystem services—and the potential for landscapes to simultaneously hold different relationships with different groups of people. Each of the papers in this collection take on the concept of multifunctionality to explore the extent to which it is possible for landscapes to serve the needs not only of multiple human communities, but of plant and animal communities as well.

To return to the issue of planetary health and the grand sustainability challenge that opened this introductory essay, we have all been shocked by the events of 2020 and 2021. Between the global pandemic and the ecological disruptions linked with climate change, the work of interdisciplinary scholars working on social–ecological systems has never been more important. As we look forward into the 21st century, which may hold even greater disruptions and demands that we understand our relationships to the natural world, it is vital that we use our collective wisdom to democratically build the collaborations and governance mechanisms needed to move human society back within planetary boundaries.

Author contributions

EMB, EDGF, and KJW conceived and designed the study. EMB, EDGF, and KJW contributed resources. EMB, EDGF, and KJW drafted or revised the manuscript.

Competing interests

The authors have declared that no competing interests exist.

Data availability statement

All relevant data are within the paper.

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