Biology at the macrosystem scale

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In the midst of the winter of 2020–2021, infections and deaths from the novel coronavirus are peaking. At any given time, outbreaks are amplified in some regions more than others, with peaks and troughs shifting as viral population dynamics interact with human metapopulations, prompting waves of transmission that propagate around the globe. With each evening's news report, the scale of biology is compactly demonstrated: a single virion, measuring one billionth of a meter (~10^{-9} m) in diameter, becomes a part of a pandemic that influences humans across the Earth, a little over ten million meters (10^7 m) in diameter.

In introductory science textbooks, biology is conceptually organized within nested scales: molecules within organelles within cells, organs and tissues within organisms, populations and communities within ecosystems, and so on. But this traditional hierarchy of biological organization – where lower scales fit neatly within higher ones – is challenged in nature: for example, complex microbial ecosystems can be nested within individual organisms, or even tissues (think of the community of symbiotic microorganisms inside the gut of a caddisfly). Although such phenomena require reconciliation within the existing hierarchy, the trope persists: in every ecology and biology textbook on our bookshelves, the "scaling" figure occurs in the first chapter. While its place in concept lies somewhere between the landscape and the globe, the macrosystem scale is – so far – absent from the standard hierarchy, yet it may appear there over time, if the promise of the field is realized.

The challenge of macrosystems biology is to conduct quantitative, interdisciplinary, and systems-oriented research that helps us understand interconnected patterns and processes from regional to continental scales. Indeed, macrosystems biology seeks not a single holy grail but rather a collection of grails, requiring effective collaboration across population and community ecology, biogeography, and biogeochemistry, and possibly other disciplines, all at once. It's no real surprise that, since its emergence approximately 10 years ago and in light of its inherent complexity, the discipline has yet to reach its full potential.

The papers in this Special Issue describe many of the ongoing challenges in macrosystems biology, and the development of new tools to address them. For example, Patrick *et al*. provide evidence that preserving biodiversity locally and regionally promotes macrosystem stability, implying that the reduced diversity affiliated with environmental homogenization can be a destabilizing force. Likewise, Ballantyne *et al*. describe regional-scale overestimates of terrestrial CO_2 uptake as measured by eddy covariance towers, possibly resulting from bias in tower site selection, and possibly because carbon taken up in the tower footprint is transported through groundwater and released from lakes and streams, a rebalancing the towers do not detect. These are just two of multiple non-mutually exclusive possibilities, and application of tools like data assimilation may help discern whether such mismatches across biological scales are errors, insights, or, more likely, both.

Other tools address the difficulty of clearly attributing cause when drivers interact and change over time, as discussed in this issue by Rollinson *et al*. as nonstationarity. The need to integrate data across scales is as trumpeted a truism as occurs in ecology, an imperative where novel approaches in data assimilation (like those described by Zipkin *et al*.) hold both promise in assessing models and making inferences, as well as challenges in minimizing bias.

Tromboni *et al*. explore how metacoupling applies to the field of macrosystems biology, simultaneously evaluating nearby and distant connections with both ecological and socioeconomic dimensions, while LaRue *et al*. analyze the language of and themes in macrosystems biology to demonstrate that working across scales in self-identified macrosystem studies is actually quite similar to doing so in other ecological disciplines. In addition, Farrell *et al*. discuss the importance of honing skills in collaboration to tackle macroscale problems and a mismatch in the training required for macrosystem scientists and practitioners to succeed.

The traditional scaling hierarchy depicts how biology is organized across space spanning at least ~16 orders of magnitude, from the cell to the planet, but fails to demonstrate how influence transmits between scales. Success in the field of macrosystems biology could help reimagine how we depict biological scaling. Global pandemics can be framed as macrosystems phenomena, where some of the controls across scales are reasonably well understood (viral population dynamics), some more speculative (the food–wildlife–disease interface), and some seemingly intractable (the intersection of human behavior, politics, and public health). The reports in this Special Issue capture the current state of macrosystems biology as dynamic and filled with potential as the discipline moves into its next phase.