TOWARD A STABLE EARTH SYSTEM … OR A JOURNEY TO POINTS UNKNOWN?

Patricia Dove

Dear Friends. As our final issue of *Elements* goes to press for 2015, the news bulletins over the past year call out for introspection about the future. For example, critical events have precipitated a tremendous migration from the Middle East to points unknown. This massive current of humanity is a reminder of the broader fact that our entire civilization has embarked on an uncharted journey. As the year ends with seven billion people, we continue the march to a world population of nine billion within only 35 years.

What does the future hold for Earth's environments and human civilization as our population grows exponentially? This question has been around for decades, but the urgency is new. The urgency is now.

One hopeful approach is to integrate the best data that exists today into a picture that assesses vulnerabilities. By evaluating our proximity to critical thresholds of environmental change—tipping points—or to unacceptable levels of loss of resilience, a science-based analysis of risks from planetary changes becomes possible.

This is indeed the approach taken by 28 renowned scientists who are developing the concept of "planetary boundaries" (Steffen et al. 2015). These boundaries are the proverbial "line(s) in the sand" that should not be crossed if we wish to avert a high risk of destabilizing the Earth system. While recognizing the many shortcomings of attempting to describe the complexity of Earth's environments, Steffan and his coworkers first identify Earth system processes and potential biophysical thresholds, which, if crossed, could generate unacceptable environmental change for humanity (Stockholm Resilience Center 2015). Using this science-based approach, they have developed a paradigm that puts the risks of these changes into perspective. Their approach integrates the (continued) development of human societies with their impacts on the Earth system.

The planetary boundary concept proposes nine parameters within land, water, and air settings that are critical to the functioning of the global system. The scientific community has generally agreed that these parameters regulate critical Earth system processes: 1) Climate change; 2) Change in biosphere integrity (biodiversity loss and species extinction and their implications for the functioning of ecosystems); 3) Stratospheric ozone depletion; 4) Ocean acidification; 5) Biogeochemical flows (phosphorus and nitrogen cycles); 6) Land-system change (e.g. deforestation); 7) Freshwater use; 8) Atmospheric aerosol loading (microscopic particles in the atmosphere that affect climate and organisms); 9) Introduction of novel entities (e.g. organic pollutants, radioactive materials, nanomaterials, microplastics). These parameters help define globally aggregated boundaries, which are complemented by regional-level boundaries for biosphere integrity, biogeochemical flows, land-system change, and freshwater use.

While there is much that we don't fully know about each parameter, and how they interrelate, the "planetary boundary" construct offers a powerful way to evaluate major Earth processes that are being changed by human activities.

Our readership recognizes the urgency of understanding these systems. Moreover, I suspect that most of us are actively working in related areas. If so, please pause to receive your *golden epaulettes*. You have earned them for seeking new knowledge in spite of social skepticism about science.

Still wondering if you qualify? Then take this simple test: Are you deciphering the past responses of Earth environments to change, investigating behavior of modern systems, or considering how to best manage or sustain resources? Or are you teaching the next generation about these issues and the challenges? If you answered yes to any of these, then *congratulations*!

Can you pause to admire your nouveau accoutrements? No. There is no time. You and our colleagues have found ample evidence that some variables will likely have highly nonlinear responses to increasing human pressures on Earth systems. This is particularly likely to be true of parameters affecting atmospheric properties and climate. These systems may react with cascading and/or coupled consequences that are irreversible on a human timescale.

To take current knowledge to the next level, an increasingly integrative approach will be required. For example, there is an urgent need to deconvolve the complexities and cross-scale interactions in natural systems. This is particularly important for determining the threshold for rapid changes, or tipping points, which are not yet well established for any large system. We also need to know if the progressive growth in population will cause Earth's environments to suffer a similar progression in environmental degradation or loss of resilience that could trigger an environmental tipping point. Such a point simply must not be crossed.

For societies, sensible planning demands preparations for the coming changes. But changes to what? How do we prepare for a mind-melting increase from seven billion to nine billion people? By using the "planetary boundaries" paradigm, which is rooted in natural science, we have a useful framework for where to redouble our efforts. In research, education, and policy, the time is now for societies to choose pathways for our future development and to safeguard a stable and resilient Earth system.

Patricia Dove, Principal Editor

Steffen W and 17 coauthors (2015) Planetary boundaries: guiding human development on a changing planet. Science 347, doi: 10.1126/science.1259855

Stockholm Resilience Center (2012) Tipping toward the unknown. http://www.stockholmresilience.org/21/research/research-news/9-23-2009-tipping-towards-the-unknown.html, Accessed 14 November 2015