National Science Foundation
Advisory Committee on Environmental Research and Education

White Paper

An AC-ERE Perspective on Convergence

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I. Background

In the last AC ERE meeting, the Committee had a spirited discussion of several of the NSF "Big Ideas," from the perspective of environmental research and education. For some (e.g. Navigating the New Arctic), an environmental perspective is obvious. For others, however, it is not immediately apparent how an environmental perspective might affect the internal development of the Big Idea. One of the latter is Convergence, one of the process-related Big Ideas. NSF charged the committee to describe examples of environmentally related issues that could be developed relatively quickly as research initiatives within the overall theme of Convergence.

Critical to this charge is a clear description of what "convergence" is, i.e. what is the change in the practice of environmental research that could be promoted through NSF support. The Committee's understanding of this term, based in part on the recent NAS report (NAS 2014) and on the discussion at the last meeting with the NSF, is that in essence, Convergence is a deep interdisciplinary approach to scientific problems. There are three main components of Convergence that are relevant in the examples discussed below.

- In the examples discussed in the NAS report, most of which are biological or biomedical, Convergence can be characterized as bringing an end-to-end approach to problem solving, from the most basic understanding to the science that underpins treatments and solutions. It thus encompasses what has become known as solution science in the sustainability literature (e.g. NAS 2016, Matson et al. 2016).

- Convergence is also characterized by the transformative effect that the transfer of tools, methods, theory, and understanding from one field to another can have, e.g. when insights from physics and engineering fundamentally change our understanding of how biological systems function. This can also include the ways in which the development of new measurement or information technologies from one field could substantially affect others.

- And third, Convergence is often associated with developing the science needed to address large, complex, and critical social issues. One might even argue that creating the scientific underpinning for addressing such issues ultimately requires Convergence, in the sense that addressing important and devilishly complex problems requires new ways of thinking that transcend narrowly disciplinary approaches to science.

Environmental research and education ought to be an important test-bed for NSF in its development of the Convergence initiative. The most pressing environmental issues simply cannot be addressed without the full and integrated participation of many disciplines. For example, widespread concern over the causes, consequences, and remedies for deforestation and forest degradation cannot be understood without fundamental research in ecosystem ecology, but also in economics, decision sciences, and in many parts of the world, political economy. Consequences of these large land use changes also require expertise in atmospheric sciences, biogeochemistry, soil processes, and so forth to fully understand, and to chart a path towards more sustainable uses of the land. Another example is the challenge of addressing chronic air pollution. This challenge, once thought to be solved in the developed world, but which has become critical in many cities of the developing world, requires not only fundamental research in the atmospheric sciences, but also engineering, biology and ecology, and economics/social sciences, to design potential solutions in a cost-effective way.

These are just two examples, but they reflect the fact that environmental issues are often the consequences of both large and local economic forces, and the design of solutions requires fundamental understanding of not only the physical, biological, and ecological systems involved, but also engineering, economics, and societal decision-making as critical contributors.

There are also good examples of Convergence in the intellectual backgrounds of many environmental scientists. Theoretical ecology was transformed in the 1970's and 1980's by the introduction of mathematical techniques borrowed from physics and engineering. Mathematical analyses of the stability of complex systems transformed the way that ecologists thought about the relationship between diversity and stability in complex ecosystems. The introduction and broad use of simulation modeling that has been made possible by advances in electrical engineering and computer science has completely changed the way that young environmental scientists are trained in all disciplines.

NSF itself has also already taken some steps in its own programs and initiatives that move towards Convergence. The history of programs like Coupled Natural and Human Systems, and several of the SEES initiatives reflects an appreciation that understanding the interplay of complex environmental systems and human-driven systems demands the close collaboration of physical and natural scientists, economists, engineers, and social sciences. But one of the factors that would extend the notion of Convergence beyond the existing experience is treating the problems and questions to be investigated as true end-to-end challenges – i.e. finding and sponsoring projects that accelerate our understanding of solutions at the same time as they accelerate our understanding of the problems themselves, that explore the interactions between understanding and decision-making, and that employ teams of scientists that are collaborating in novel ways.

II. Examples for Consideration

The AC-ERE, in order to respond to the NSF's request, has considered possible examples of issue areas that may serve as environmentally-oriented examples that could be pursued as part of the Convergence Big Idea. Our criteria in selecting the examples below are, first, the breadth of the problem that has been identified. For example, does the issue in fact demand the close collaboration of several different disciplines in such a way that methods, techniques, and technologies common to one can in fact begin to transform another? Can the scientific questions to be investigated be jointly framed by a collaboration of different disciplines, rather than be a collection of separately phrased questions? And does the issue encompass an end-to-end approach, i.e. from understanding an issue to formulating a solution and providing a scientific foundation that decision-making can take advantage of?

Our second criterion is our own assessment of the readiness of both individual disciplines and possible collaborations to actually undertake projects that will exhibit Convergence as a property. There are some problems and scientific communities in which we can already foresee the types of collaborations and proposals that could be written very quickly. There are others that will take different degrees of community development. In our view, part of the Convergence challenge for NSF is recognizing that there inevitably will be a substantial amount of community development involved. Not every problem, and not every possible combination of disciplines are equally ready for Convergence, but a concerted effort by NSF over time can move these communities towards performing their research in this way.

A. Designing Cities to Reduce Emissions

More than half the human population of the Earth has been estimated to now live in urban areas. In the developed Western countries, the percentage of city dwellers already exceeds 80% in most countries. We are now an urban species.

Cities are also the locus for the vast majority of economic activities, for employment, and for the production and trading of goods and services. They have been calculated, for example, to be the source of more than 70% of global greenhouse gas emissions. For many years they have been the primary focus of programs to reduce air pollution caused by sulfur and nitrogen emissions from manufacturing, energy production, and transportation. And in the developing world, especially in countries with extremely rapid recent economic growth, e.g. China and India, cities are among the most highly polluted places on the planet, incurring tremendous costs in morbidity and mortality. These environmental trends raise several important questions. How can cities continue to expand, as many are doing, renew their infrastructure, provide economic opportunity, and at the same time increase their overall energy efficiency and reduce emissions?

This challenge is not just a problem to be resolved by better urban planning. Understanding how one might reconcile the potentially conflicting goals for increasing economic opportunity, improving the resilience of urban infrastructure, and bending the curve on emissions will require close interaction of engineers, atmospheric scientists, ecologists, health scientists, and political scientists. A convergent end-to-end understanding that builds on new methods for measuring the environmental influence that cities have, and extends to research on how decisions about individual behaviors might be accepted will ultimately be needed.

Is there a community of scientists and engineers that is ready to take on this challenge in a way that epitomizes Convergence? In this case, the answer is an emphatic yes. Collaborations of atmospheric scientists, ecologists, engineers, and public policy researchers are already effectively organized around urban challenges, have published important review articles, and are poised, we believe, to make research advances very quickly, given the appropriate opportunities. There is fundamental science to be done here, that really can only be done if the disciplines involved learn from each other, and if they are able to make the translation of their jointly developed knowledge to the realm of decision-making.

B. Early Warning Systems

The first challenge of studying and creating early warning systems for environmental challenges is understanding the systems themselves well enough to create plausible forecasts and/or indicators of incipient change. The second part of the challenge, however, is constructing warnings in such a way that they are heeded, and understanding how and why people process warnings the way they do. Society has seen multiple examples of the challenges involved in physical systems, especially those concerned with severe weather warnings. Substantial progress in understanding the physical systems has improved the ability to deliver early warnings; but the knowledge of how best to deliver those messages in ways that are heeded has lagged behind. Convergence work is seminal in such early warning systems, because these systems require simultaneous knowledge of how the system(s) under study work and are connected, what the tipping points or incipient state changes will be, and how society can retroactively or proactively respond at, or before, state change.

There are many specific examples of how research on early warning systems might proceed. They include:

The intersection of climate science and modeling, ecological modeling and systems analysis, epidemiology, and evolutionary biology, which can be collectively used to understand emergent pattern of human disease outbreaks and transmission. Current work in this area includes exploration of the degree to which current disease outbreaks can be predicted using coupled climate, ocean circulation, and ecological models (e.g., forecasting malarial outbreaks with sea surface temperature anomalies); and meta-analysis of the emergent patterns of pathogens in geographic, ecological and biodiversity space.

Experimentation in and abstraction of the tipping points of systemic destabilization across a wide range of physical, ecological and societal systems. Current work points to fundamental similarity in system behavior at the point of state change (so called "squealing" as the system rapidly shifts between alternate states as a bifurcation point is reached) among systems as seemingly diverse as freshwater lake trophic dynamics, global ocean circulation and global financial markets.

Are there communities of scientists who are positioned to conduct the kind of interdisciplinary research in these areas that would constitute a Convergent approach? We believe that the answer is yes, and in this case the communities are more apt to be concentrated around very particular case studies. However, because the types of problems that would benefit from an early warning approach are widespread, careful nurturing by NSF could encourage an acceleration of the kinds of collaborations that would be needed.

C. Environmental Security

The term environmental security encompasses the intersection between threats to the environment and the security and safety of both human and ecological systems that depend on it. Socio-environmental scholars have defined it as “the proactive minimization of anthropogenic threats to the functional integrity of the biosphere and thus to its interdependent human component (Barnett, 2001).” Others have highlighted the security and spatial implications more directly by defining it as the “relative public safety from environmental dangers caused by natural or human processes due to ignorance, accident, mismanagement or design and originating within or across national borders.” (The Millennium Project 1998) In both these conceptualizations environmental security considers a wide range of socio-environmental stressors that can threat the long-term sustainability of natural resources (e.g. water, forests, air) and negatively impact individuals, households, communities and populations that rely on them for their well-being. These implications are made more complex because many of these resources cross national borders and their scarcity may lead to national security problems, can exacerbate and act as a threat multiplier of existing negative socio-economic states such as poverty, food insecurity, gender inequality and warfare, especially in less developed communities and regions, or scarcity and unequal distribution of resources can act as a driver of collaboration and joint governance of resources (UNEP 2004).

This area of inquiry could benefit substantially from the purposeful design of inter and transdisciplinary analytical approaches that consider both the social and ecological (but also infrastructural and technological) causes and the implications of environmental degradation, scarcity and conflict. Examples of disciplinary and interdisciplinary approaches that have grappled with these issues include international relations and global governance; political ecology; peace and conflict studies; science technology and society; resilience studies; food, water and human security; and institutions and the commons.

Not surprisingly, the science of environmental security remains a challenge not only terms of understanding drivers and causal relationships (Buhaug 2015), feedbacks and anticipating tipping points, but also in terms of creating actionable knowledge that informs governments and other decision-makers. Existing analytical and methodological approaches that can converge to support science to understand and promote action related to environmental security include: spatial analysis across scales (e.g. remote sensing, GIS), systems thinking and modeling (including integrated assessment models and agent-based models), case-study based research, meta-analysis of case study libraries, big data and data mining; social experimentation and randomized trials, vulnerability, adaptation and risk assessments frameworks; complex systems.

Our judgment in this case is that environmental security encompasses a range of problems that would clearly benefit from a convergent approach towards research. But while a community could be mobilized to form convergent collaborations and make progress, it would need to be nurtured over some period of time to make the same sort of advances that are already possible for cities and early warning systems.

III. Building Convergent Communities

There are several challenges that the NSF will face as it pursues Convergence in environmental research and education. One is that not all environmental problems will require convergent science in all its dimensions. Significant advances will still continue to be made within the confines of the traditional disciplines. But problems that can be defined as end-to-end challenges, where each of the components will require fundamental advances to be made, and where systemic solutions appear to be a primary mode of problem-solving, can clearly benefit from convergent approaches.

A second challenge is that Convergence will inevitably require nurturing the various scientific communities involved to be ready to contribute. In the examples outlined above, there are different degrees of readiness on behalf of the communities of scientists and researchers who are interested in each topic. NSF can employ different means to encourage and support interdisciplinary communities that have the potential to create convergent collaborations, but are not quite experienced enough or ready to do so. This is a problem that NSF has encountered before, and programmatic solutions similar to Research Coordination Networks might be in order.

Third, the difficulties of reviewing Convergent proposals will be similar to the existing difficulties of reviewing interdisciplinary proposals. Great progress has been made within the NSF in this regard. But for Convergence, the central problem is not necessarily finding excellence in each individual component of an interdisciplinary proposal – it is finding the value of the collaboration itself – i.e., what is the added value of approaching a convergent ideal, as opposed to having excellent, but relatively unconnected disciplinary contributions in a project.

IV. Summary

The AC-ERE's conclusions are that environmental research provides multiple examples of where Convergent approaches to research would be highly productive. There is already a history of convergent research within many of the scientific disciplines involved in environmental research, so in some ways there is already a degree of readiness and acceptance of such collaborations. There are examples of environmental challenges for which there are communities of researchers that are ready now to collaborate in a convergent manner, and examples where some degree of community-building would have to occur, but where the potential is high. While challenges of preparation, and review will face the convergent science, in all cases there are existing processes and experience on which NSF can build.

References

Barnett, Jon. 2001. The Meaning of Environmental Security: Ecological Policy and Politics in the New Security Era. Zed Books. London, UK. 159 pp.

Buhaug, H. (2015), Climate–conflict research: some reflections on the way forward. WIREs Clim Change, 6: 269–275. doi:10.1002/wcc.336

NAS. 2014. Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond. National Academies Press. Washington, DC. 152 pp. DOI 10.17226/18722

NAS. 2016. Transitioning Toward Sustainability: Advancing the Scientific Foundation: Proceedings of a Workshop. National Academies Press. Washington, DC. 82 pp. DOI: 10.17226/23533

Matson, Pamela., W. Clark, and K. Andersson. 2016. Pursuing Sustainability: A Guide to the Science and Practice. Princeton University Press. Princeton, NJ. 248 pp.

The Millennium Project. URL: http://millennium-project.org

UNEP and ECSP. 2004. Understanding Environment, Conflict, and Cooperation. United Nations Environment Programme. 60 pp.