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Earth's environment is changing at rates that threaten our sustainable well-being. The signs of this change have emerged across the globe, from the drying of the Aral Sea, to the shrinking of glaciers in alpine and polar regions, to the collapse of the North Atlantic cod fishery. The common thread is the driving force of human activity. But while the power of human influence on the environment has long been recognized, the nature of the interaction between natural and human systems is not fully understood. The need to understand this interaction motivated the recently released report to the National Science Foundation (NSF) from its Advisory Committee for Environmental Research and Education (ACERE 2009). The report, *Transitions and Tipping Points in Complex Environmental Systems*, does not just call for increased effort to understand the coupled dynamics of natural and human systems; it offers a clarion call to the NSF to lead a change in how environmental research is conducted.

The fundamental premise of the report is that our greatest environmental challenges emerge from the nature of coupled natural and human systems. Environmental systems by themselves are both complicated and complex; complicated, in that many agents act upon them; complex, in that there are feedback loops connecting the state of the system back to the agents, and connecting the actions of the agents to one another. When the system includes human action, the level of complexity increases, because humans change the system and also their behavior in response to the state of the system. Complex systems have complex dynamics usually characterized by so-called tipping points, abrupt changes in the state of the system caused by seemingly gradual change in its drivers. The sudden collapse of a fishery in response to a small percentage increase in fishing effort is one example. And in most cases, when a system crosses a tipping point, there is no going back. These tipping points—and the likelihood that we are rapidly approaching some of them—lent urgency to the committee's work.

That urgency is heightened by the recognition that the connections among agents and outcomes in coupled natural and human systems can span great spatial scales. For example, agricultural practices in the Great Plains produce nutrient loading that creates the notorious "Dead Zone" in the western Gulf of Mexico. It can be difficult to appreciate that small changes in one location can push the system past a tipping point whose consequences will appear hundreds of miles away.

Although professional scientists appreciate these issues, the report challenges our scientific understanding of these complex systems. We struggle to characterize the complexity of coupled natural and human systems, we are uncertain about our ability to predict where tipping points are likely to occur in specific systems, and we are constantly surprised by how human behavior changes in response to the state of the system. In general, we do not know all that we ought to about nonlinear behavior of component subsystems, and we do not understand the feedback loops. In light of this, the report calls upon the NSF to commit to a broad, interdisciplinary approach to coupled natural-human systems in which the social sciences and human dimension play an essential part, not merely a complementary or supplemental role. In fact, the report urges the NSF to take the lead among federal agencies in promoting such broad research. This recommendation will not be realized without the NSF taking on another suggestion in the report, which is to evolve a more effective mechanism for evaluating the merit and design of broad interdisciplinary environmental research and supporting it.

If professional scientists lack a full understanding of complex natural-human systems, public appreciation that such a level of complexity exists is even lower. This realization promoted another of the report's recommendations: to redouble the scientific and educational community's efforts to engage and educate the public about environmental systems. While this recommendation may seem odd in light of the efforts made and the dollars spent on public environmental education, survey after survey of public knowledge reveals the large gap between that knowledge and the facts. Moreover, the performance of US students lags far behind those from other countries on international assessments of science and mathematics. There is no escaping the conclusion that what we are doing is not enough.

This conclusion, that "business as usual" is insufficient, permeates the report. The report also urges that novel approaches are necessary to help policymakers develop a better understanding of complex systems and of the scale on which the interactions between natural and human systems play out. More cost-benefit research is needed on the consequences of taking or not taking action regarding environmental policies at any point in time. These distributional effects currently are very imprecisely known, and this uncertainty leads to disagreements that often block or delay collective action. The current impasse over international controls on greenhouse gases illustrates the issue.

The emphasis in the report is not that we are not making progress or that the NSF is not supporting strong programs; it is that we are not making progress rapidly enough in the face of such rapid environmental change. The report endorses the strong programs that the NSF supports but recommends that these must be expanded to include a different type of program, a broad, interdisciplinary one with enough support for enough time to make a rapid advance in our understanding of these challenging systems.

Although much of this material is familiar, there are features of the report that may still raise some eyebrows. In particular, two recommendations, if read outside of the full report, may leave some wondering whether the committee was much too zealous or, alternatively, was engaged too superficially.

The report recommends that the NSF "evolve from its primarily discipline-centered organization to one that better promotes and supports interdisciplinary approaches, and attracts more scientists and engineers to engage in collaborative and integrative research and education that addresses the nation's environmental challenges." Read alone, this may suggest that the committee recommends that the NSF become a mission agency rather than a science agency. This is not the case. The report makes clear that the NSF is and must remain a science agency. But among the agencies that support environmental research, the NSF has the most experience in recognizing representative research—research based on classes of problems and systems, and not on idiosyncratic case studies. It is not practical to expect that a redoubled effort in environmental research can address every challenging problem; we need research that discerns the most critical classes of problems, identifies common elements, and develops tractable approaches and case studies.

In addition, the report does not call for the NSF to abandon its support of traditional disciplines; instead, it advises the NSF to improve substantially its agility in attracting, evaluating, and supporting broadly interdisciplinary research. Additionally, the report notes that sustaining such programs in a time frame relevant to the career paths of scientists, engineers and educators, especially those in the junior ranks, is necessary to foster cross-disciplinary dialogue and synergistic collaboration. If we want to muster our best and brightest to this effort, we must not make pursuing interdisciplinary research and education a professional liability.

The report also recommends that the NSF "should lead the effort to ensure that the implementation of a well-designed and integrated system of observational sensor networks that measure critical environmental variables as well as the changes in key human activities with environmental consequences." Out of context, some might wonder if the committee knew about NEON, the National Ecological Observatory Network, whose early development was fostered under the aegis of AIBS. Indeed, the committee embraced NEON as an important part of what the members deemed essential for the future. The committee was also aware of other long-term sensor networks in place, such as the Long Term Ecological Research network, or in development, such as the Critical Zone Observatories and the Ocean Observatory Initiative. The new and essential component of the committee's recommendation is in the phrase "as well as the changes in key human activities with environmental consequences." This reflects the report's emphasis on understanding the feedback loops between environmental processes and human activity. The most extensive set of sensor networks imaginable will not provide robust data for understanding our environmental challenges if they remain uncoupled from key measures of human activity, or if they do not address clearly defined hypotheses, because it is no longer clear where natural systems begin and human ones end.

The blurring of the demarcation between human and natural systems emerges in the report as the key driver of its recommendations. If environmental science is to help us understand our environmental challenges, then environmental science must move forward very differently. It must be a sweeping movement of social, natural, and mathematical scientists, engineers, and educators working together. The NSF, in collaboration with other agencies, must lead that movement and find the ways and means to ensure its success.

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