Risk and resilience in an uncertain world

Ecological disturbances are occurring with greater frequency and intensity than in the past. Under projected shifts in disturbance regimes and patterns of recovery, societal and environmental impacts are expected to be more extreme and to span larger spatial extents. Moreover, preexisting conditions will require a longer time to re-establish, if they do so at all. The word "unprecedented" is appearing more often in news reporting on droughts, fires, hurricanes, tsunamis, ice storms, and insect outbreaks. The causes and effects of these events are often exacerbated by human modifications of natural environments and influenced by technological developments.

At the same time, multiple events or different types of disturbances can undermine the ability of environmental systems to recover, and interacting disturbances can cause these systems to transition to new and undesirable states. For example, the combination of an expansion of impervious surface area, changes to hydrology and drainage systems, and wetland losses can interact to amplify the frequency and severity of flooding. In addition, actions that seek to manage individual rather than combined risks may induce unintentional consequences, increase the magnitude of impacts, or decrease resilience (the ability of an ecosystem to withstand or recover quickly from a disturbance). Furthermore, re-establishment may be to a new state or to what some call an "emerging ecosystem", whose properties then influence risks of and resilience to subsequent disturbances.

The need to proactively address risk and resilience is more pressing than ever. Managing complex ecosystems to maintain essential characteristics in the face of an uncertain future is challenging. Therefore, we offer a perspective on risk and resilience that encompasses interactions among ecosystems, social systems, infrastructure, and evolving technological capabilities. Management decisions need to concentrate on three topic areas: (1) risk assessment, monitoring, and mitigation; (2) natural resource use and ecosystem service management; and (3) linkages among humans, technologies, and emerging ecosystems.

More effectively managing natural resources and the ecosystem services they provide requires that scientists and managers anticipate shifts in disturbance regimes and analyze risk and resilience from broader perspectives. Whether and when risks and associated losses in ecosystem services are amplified or attenuated by future disturbances depends on how the environment, society, the economy, and technology respond. We cannot assume that practices that have worked in the past will be effective in the future. Just as future disturbance regimes differ from those of the past, tools to analyze, monitor, and manage them are also changing.

Ecologists have much to offer in this regard, because of their knowledge of how disturbances can affect ecosystems. Furthermore, ecologists are using new tools for detecting environmental change at different temporal, spatial, and organizational scales. For instance, the development of smartphones has led to an explosion of information sharing via apps and citizen-science initiatives. Information collected by individuals can be uploaded into mobile or web-based applications to help scientists assess change at regional and global scales. Technological advances in genomics and remote sensing have made it possible to study environments from the molecular to the ecosystem level using biomonitoring tools such as environmental DNA (eDNA) and instruments affixed to drones, submersibles, and satellites. Scientific understanding of the interactive effects of multiple disturbances is also evolving. Together, new technologies and new scientific concepts can help to address the interfaces between human and ecological systems. Combining these new tools and perspectives is essential for science, management, and planning.

We urge environmental scientists to design research that analyzes the effects of shifts in disturbance regimes and identifies ways to minimize adverse impacts. The kinds of information that we believe will be useful include mechanisms or conceptual models of impact, risk maps that identify susceptible areas, means to monitor and assess current conditions, indicators of pending change, potential influences on mitigation interventions, and data on the interactions between human and ecological systems. Case studies that focus on multiple scales – including local analyses of interest to landowners and regional analyses useful to watershed, state, and federal planners – are also valuable.

Because the future is uncertain and to some extent unknowable, it is imperative that ecologists become involved in the discussion and planning of future infrastructure and protection from the effects of altered disturbance regimes. Research can test and demonstrate the benefits of protecting or proactively managing important features and places, and processes that enhance provisioning of ecosystem services such as flood control and fire mitigation. It is time to demonstrate how ecological science, when applied to human–environmental systems, can reduce risks and enhance resilience in a complex, changing world.

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