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Resilience has two meanings in the ecological literature, both related to system state and disturbance. Engineering resilience is the time of return to a global equilibrium following a disturbance. Ecological resilience is the amount of disturbance that a system can absorb before it changes state. Ecological resilience is based on the demonstrated property of alternative stable states in ecological systems, while engineering resilience implies only one stable state (and global equilibrium). The alternative meanings of resilience have significant implications for application of the concept to understanding and managing complex systems.

Resilience has been defined in two different ways in the ecological literature, each reflecting different aspects of stability. One definition focuses on efficiency, constancy and predictability – all attributes of engineers’ desire for fail-safe design. The other focuses on persistence, change and unpredictability – all attributes embraced and celebrated by evolutionary biologists and by those who search for safe-fail designs. Holling (1973) first emphasized these different aspects of stability to draw attention to the tensions between efficiency and persistence, between constancy and change, and between predictability and unpredictability.

The more common definition, which we term engineering resilience (Holling, 1996), considers ecological systems to exist close to a stable steady-state. Resilience is the ability to return to the steady state following a perturbation (Pimm, 1984; O’Neill et al., 1986; Tilman and Downing, 1994; Tilman, 1996). This idea of disturbance away from and return to a stable state is at the center of economic theory as well (Varian, 1992; Kamien and Schwartz, 1991).

The second definition, which we term ecological resilience (Walker et al., 1969; Holling, 1996), emphasizes conditions far from any stable steady-state, where instabilities can flip a system into another regime of behavior, i.e., to another stability domain (Holling, 1973). In this case, resilience is measured by the magnitude of disturbance that can be absorbed before the system redefines its structure by changing the variables and processes that control behavior.

The differences between these two aspects of stability – essentially a focus on maintaining efficiency of function (engineering resilience) versus a focus on maintaining existence of function (ecological resilience) – are so fundamental that they can become alternative paradigms whose devotees reflect traditions of a discipline or of an attitude more than a reality of nature. Those using the concept of engineering resilience tend to explore system behavior near a known stable state, while those examining ecological resilience tend to search for alternative stable states, and the properties of the boundaries between states.

Those who explore engineering resilience and the near equilibrium behavior of ecosystems operate in the primarily deductive tradition of mathematical theory (e.g., Pimm, 1984) that imagines simplified, untouched ecological systems, or they draw upon the traditions of engineering, that are motivated by the need to design systems with a single operating objective (Waide and Webster, 1976; De Angelis, 1980; O’Neill et al., 1986). These approaches simplify the mathematics and accommodate the engineer’s drive to develop optimal designs. However, there is an implicit assumption that ecosystems exhibit only one equilibrium steady state, or, if other operating states exist, that those states should be avoided.

On the other hand, those who emphasize ecological resilience come from traditions of applied mathematics and applied resource ecology at the scale of ecosystems, e.g., of the dynamics and management of fresh water systems (Fiering, 1982), of forests (Holling et al., 1977), of fisheries (Walters, 1986), of semi-arid grasslands (Walker et al., 1969) and of interacting populations in nature (Sinclair et al., 1990; Dublin et al., 1990). Since these studies are rooted in inductive rather than deductive theory formulation and in experience with the impacts of large scale management actions, it becomes clear that the variability of critical variables forms and maintains the stability landscape, and that when this variability is reduced, an ecosystem can flip from one state to another.

In economics, there has also been a focus on the single stable state. The history of economics has been to rapidly move from establishing the existence of a general equilibrium to issues of equilibrium uniqueness or stability. If multiple equilibria are shown to theoretically exist, then the challenge that is usually taken up is to theoretically eliminate stable states by proposing individuals’ strategic expectations and predetermined normative and social institutions. This approach does not examine or explain the conditions that can cause a system to move from one stability domain to another. However, the identification of multi-stable states due to path dependency (Arthur et al., 1987), chreodic development (Clark and Juma, 1987) and production non-convexities such as increasing returns to scale (David, 1985) has reintroduced multiple stable states to economics.

The existence, or at least importance, of multiple or a single stable state determines the appropriateness of an engineering or ecological approach to resilience. If it is assumed that only one stable state exists or can be designed to exist, then the only possible definition and measures for resilience are near equilibrium ones – such as characteristic
return time. That is certainly consistent with the engineer’s desire to make things work, not to intentionally make things that break down or suddenly shift their behavior. However, nature and human society are different.

See also: Ecosystem Services and Costing, Volume 2.

REFERENCES


