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Putting Resilience Theory into Practice: The Example of Fisheries Management

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Resilience theory offers lawmakers a different way of thinking about natural resources management. This new viewpoint is increasingly appropriate as climate change interacts with other anthropogenic stressors like habitat destruction, biodiversity loss, and pollution to increase the unpredictability of the earth's complex natural systems while simultaneously directly changing the location and availability of many resources, from water to timber to fish. This article uses the example of marine fisheries to illustrate (1) how climate change and its interactions with other stressors are changing natural resources; (2) what these changes mean for traditional legal management standards; and (3) how resilience theory can suggest a different approach to managing natural resources in a changing world, increasingly known as the Anthropocene.

We should start by defining our terms, especially because "resilience" carries a number of connotations. People commonly use "resilience" to invoke what theorists call *engineering resilience*—the ability of a person, thing, or system to *resist* a shock or disturbance or to *bounce back* to its former state. Engineering resilience plays a large role in actual engineering, such as when architects design skyscrapers in Los Angeles and San Francisco to withstand earthquakes. However, we can also apply the concept of engineering resilience to people and ecosystems, such as when we denominate a community "resilient" after it bounces back from a tornado or other natural disaster.

Engineering resilience embodies one of the underlying conceptions of nature that informs most U.S. natural resources law. Specifically, an expectation that natural systems will exhibit engineering resilience assumes a rather steady-state view of nature—i.e., that there is an equilibrium balance of nature to which natural systems will return after a shock or disturbance. Nature conceived of from an engineering resilience framework is knowable, predictable, and largely controllable. As a result, when lawmakers recognized that human exploitations of natural resources could themselves constitute shocks and disturbances to natural systems, they enacted natural resources statutes that assume that humans are always pretty much in control of ecosystems. This assumption is perhaps most obvious in the reigning legal presumption that managers *always* have conservation and restoration options—i.e., that we can keep important systems from changing in the first place and that we can restore any system that we've already changed to its previous state. However, the assumption manifests in other ways, as well. Consider the federal Endangered Species Act (ESA)—a statute that, by its very subject matter, acknowledges that humans can disturb natural systems to the point of jeopardizing other species. While the ESA can certainly be adapted in some respects to new climate change realities, the important point here is that Congress assumed that the fates of species lie almost entirely within human control. Thus, the ESA provides little guidance in how to apply its conservation mandates (and the expenses that they entail) to species doomed to extinction as a result of complex system dynamics, such as those that result from climate change impacts. However, in a revealing contrast, the ESA's Endangered Species Committee ("God Squad") and national security provisions do allow humans to *choose* to let species go extinct if species survival interferes with conflicting human priorities. 16 U.S.C. § 1536(e)–(j).

Basing natural resources law on the engineering resilience of natural systems can work, at least for a while, especially in small-scale systems over the short-term and in the context of relatively minor or short-term disturbances, because natural systems *do* exhibit engineering resilience to a certain degree. The problem is, that's not the only kind of resilience that's important to understanding them.

As ecologists have recognized, there is no "balance of nature"—no optimal steady-state to which natural systems will return. Instead, natural systems exist in continual flux, subject to drivers and influences occurring at multiple spatial and temporal scales. Moreover, most systems can exist in multiple relatively stable configurations, transforming from one to another as a result of crossing an *ecological threshold*. In this model, the ability of a natural system to absorb shock and disturbance *without* crossing an ecological threshold is known as the system's *ecological resilience*. Brian Walker & David Salt, *Resilience Thinking: Sustaining Ecosystems and People in a Changing World* 62–63 (Island Press 2006). A very common example is the ecological resilience of freshwater ecosystems to nutrient pollution (nitrogen and phosphorus). Streams and lakes can absorb a certain amount of nutrient pollution and still retain their essential characteristics and functions—clear water, coldwater fisheries, and so forth. At some point, however, the nutrients will overwhelm the stream or lake and eutrophication will occur, resulting in a new system dominated by algae growth and warmer water.

The immediate importance of ecological resilience for natural resources management is twofold: first, human activities can effectively lower the thresholds for system transformation; and second, such transformations can severely undermine conservation and especially restoration as policy goals. For example, biodiversity is widely recognized as an important component of ecological resilience. Biodiversity can be broken into two components: functional diversity and response diversity. Functional diversity refers to the number of species

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that perform roughly the same function in the ecosystem. Response diversity refers to the variation in how species in the same functional group respond to shocks, disturbances, and stress. The more species that are extirpated from a given system—such as a result of logging in a tropical rainforest—the greater the likelihood that the system is losing both functional and response diversity, and the greater the chance that its ecological resilience to other disturbances—such as climate change—has been reduced. Moreover, once the rainforest has transformed into something else, humans may not be able to restore the original rainforest, *even if* we can reintroduce the missing species from somewhere else: Threshold crossing is often easier in some directions than in others.

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Ecological resilience also has deeper implications for natural resources management, as the developing discipline of *resilience theory* is demonstrating. As noted, one of the tenets of contemporary ecology is that natural systems are always changing. In 2002, Lance Gunderson and C.S. "Buzz" Holling described a four-phase infinity-loop cycle of change in ecological systems, which they termed the *adaptive cycle*. Lance H. Gunderson & C.S. Holling, eds., *Panarchy: Understanding Transformations in Human and Natural Systems* 34 (Island Press 2002). The four phases are rapid growth, such as when a forest regenerates after a fire; conservation, such as when the forest reaches maturity and remains relatively stable for decades; release, such as when the next fire destroys the large trees; and reorganization, such as when colonizing plants and animals potentially compete with the former natives to establish themselves in the former forest. In addition, systems are linked across temporal and spatial scales through nested adaptive cycles, a phenomenon that Gunderson and Holling termed *panarchy*.

Panarchy embodies a systems perspective on natural resources, and the panarchical interactions of nested adaptive cycles add complexity and unpredictability to natural systems, revealing an avoidable element of management chaos that current natural resources law needs to acknowledge. For example, coral reef ecosystems are generally ecologically resilient to periodic changes in ocean temperature occurring because of changes at a higher system level, such as during an El Niño or La Niña event. Indeed, the Great Barrier Reef in Australia has endured for at least 8,000 years, despite these recurring temperature fluctuations. However, in March through May of 2016, changes in ocean temperature occurring because of disturbances at the planetary climate-level scale (climate change) exacerbated ocean temperature increases caused by the 2016 El Niño event. As a result, 90 percent of the Great Barrier Reef in Australia bleached, a phenomenon that occurs when coral polyps expel their symbiotic (and colorful) algae. Prolonged coral bleaching leads to coral death, and estimates as of June 2016 were that one-third to one-half of the Great Barrier Reef will die. Thus, the panarchical interaction of the "normal" El Niño/La Niña oscillation with the ongoing disturbance of the planetary climate system overwhelmed the Great Barrier Reef's ecological resilience to ocean temperature increases, leaving the world with a considerably diminished and increasingly vulnerable coral reef ecosystem.

For law, panarchy means that the same management action in a system won't always generate the same response. For example, if a larger-scale adaptive cycle is in the conservation phase, its relative steadiness can temper the relative unpredictability of a reorganization phase occurring at a lower scale. Thus, a consistent regional climate can help to ensure that the forest that grows back after a controlled management fire looks a lot like the forest that was burned. In contrast, if the climate system is itself reorganizing, the same prescribed fire may burn out of control, or different species may colonize the regenerating ecosystem, which may not end up being a forest at all.

The ecological resilience and thresholds, adaptive cycles, and panarchy of resilience theory mean that natural systems are not nearly as knowable and controllable as U.S. law often assumes. Given these new insights, we would probably write natural resources laws differently today, at the very least adding larger margins of safety and probably framing resource management as a continuously monitored and reviewed experiment subject to constant modification—i.e., as adaptive management. To add to the current mismatch, moreover, we are also now dealing with another element of complexity and unpredictability: anthropogenic climate change. In resilience theory terms, there is good reason to believe that the planetary-scale climate system has been in a conservation phase for approximately the last 12,000 years, since the last ice age, a geological period known as the Holocene. However, anthropogenic forcing in the form of greenhouse gas emissions is disturbing the relative stability of the climate. Disturbance at this very-high-level adaptive cycle has consequences for all the linked natural cycles below it—i.e., every ecosystem on the planet.

The combination of climate change and resilience theory, therefore, demand some reworking of U.S. natural resources law. Marine fisheries provide a good specific example both of this need and of the change of regulatory perspective that resilience thinking could provide.

Marine Fisheries and Maximum Sustainable Yield

Like other natural resources laws, marine fisheries laws assume the general predictability of fisheries resources—i.e., that we know approximately where particular species range and in approximately what numbers. This assumption is embodied in both international and U.S. law in the goal of "maximum sustainable yield" (MSY).

Under the third United Nations Convention on the Law of the Sea (UNCLOS III, which the non-party United States generally accepts as customary international law), coastal nations must enact conservation measures for marine resources "designed to maintain or restore populations of harvested species at levels which can produce the maximum sustainable yield, as qualified by relevant environmental and economic factors." UNCLOS III, art. 61(3). Moreover, the coastal state must promote "optimum utilization" of these species, so if it cannot harvest the entire allowable catch itself, it is supposed to allow fishers from other nations to do so. UNCLOS III, art. 62(1), (2). Similarly, under the United States' Magnuson-Stevens Fishery Conservation and Management Act, management measures in federal fishery management plans "shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery for the United States fishing industry." 16 U.S.C. § 1851(a)(1). "Optimum" yield, in turn, "is prescribed on the basis of the maximum sustainable yield from the fishery, as reduced by any relevant social, economic, or ecological factor; . . ." 16 U.S.C. § 1802(33)(B). In contrast, "overfishing" occurs when "a rate or level of fishing mortality [] jeopardizes the capacity of a fishery to produce the maximum sustainable yield on a continuing basis." 16 U.S.C. § 1802(34). Thus, both international and U.S. law promote—even demand—the "full" exploitation of fisheries resources.

In the United States, while NOAA and the regional Fishery Management Councils thus have discretion in how they define the optimum yield, fishery management remains legally grounded in MSY. MSY is a scientific term of art from fisheries biology. Congress consciously adopted this scientific term into the Magnuson-Stevens Act, H.R. Rep. No. 94-445, 1976 U.S.C.C.A.N. 593, 614-615 (Aug. 20, 1975), and, consistent with biologists' use of the term, the National Oceanic and Atmospheric Administration (NOAA) defines MSY to be "the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological, environmental conditions and fishery technological characteristics (e.g., gear selectivity), and the distribution of catch among fleets." 50 C.F.R. § 600.310(e)(1)(i)(A).

Nevertheless, setting MSY as the goal presents a number of problems for healthy marine ecosystems in the Anthropocene. First, for both scientific and political reasons, achieving MSY without crossing into overfishing is, as a practical matter, very difficult. Indeed, a number of scientific reports indicate that humans' ability to rely on wild-caught ocean fisheries is declining and may disappear. The United Nations Food and Agriculture Organization (FAO) notes that capture of wild marine fish levelled off in about 1980, despite increased commercial fishing effort, U.N. FAO, *The State of World Fisheries and Aquaculture* 2 & 3 fig. 1 (2016), suggesting that humans have reached the limits of marine fishing. In addition, "the share of fish stocks within biologically sustainable levels decreased from 90 percent in 1974 to 68.6 percent in 2013," and areas like the Mediterranean and Black Seas are experiencing "alarming" reductions in catch. *Id.* at 5. Instead, aquaculture is now supplying an increasing share of fish and seafood worldwide, especially in China. *Id.* at 2. Even ignoring climate change, the future of marine wild fisheries is in considerable doubt: In 2006 Boris Worm and his colleagues predicted that all commercial marine fisheries would collapse by the middle of this century. Boris Worm et al., *Impacts of Biodiversity Loss on Ocean Ecosystem Services*, 314 Science, 787, 790 (Nov. 3, 2006). These statistics suggest that MSY-based fisheries management has not been successful even on its own terms, even acknowledging other pervasive problems like illegal fishing.

Second, MSY-based fisheries management makes it exceedingly difficult for managers to consider system dynamics in a constantly changing world. While optimum yield calculations under the Magnuson-Stevens Act can clearly take account of ecosystem dynamics, the MSY calculations on which they are based focus on specific stocks, 50 C.F.R. § 600.310(e)(1)(i)(A), perpetuating a data gap and translation problem between the MSY and optimum yield calculations. One consequence has been the severe overexploitation of apex predator species like tuna and swordfish and the well-documented phenomenon of "fishing down the food web," where fishers over time are forced to target smaller species as the most desirable big species disappear. In ecological resilience terms, therefore, commercial fishing has already reduced both the total biodiversity and the functional diversity of global marine ecosystems.

In addition, fishing to MSY *by definition* reduces the overall populations of the target species from their natural maximums and assumes that fish are "surplus" if they are not needed for replacement breeding. H. Rep. No. 94-445 (1975), *reprinted in* 1976 U.S.C.C.A.N. 593, 615. As a result, in addition to ignoring what the "surplus" fish might be doing in and for the dynamics of larger ecosystem, MSY figures the natural population of a given fish stock as, essentially, too large. The resulting systemic reduction in fish populations is also exacerbated because fishers target the largest members of the species, which tend to be the most prolific breeders; thus, fishing disproportionately reduces the breeding capacity of many species. In terms of ecological resilience, therefore, the pursuit of MSY reduces targeted species' resilience to other kinds of shocks and disturbances in the system by reducing both response diversity (the lack of prolific breeders) and the species' simple numeric chances of survival.

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For all of the above reasons, MSY-based fishing also disturbs the panarchical interactions of nested marine ecosystems in ways that are, at best, poorly understood. However, historical studies strongly suggest that marine fishing has been undermining both the engineering and ecological resilience of marine ecosystems, making ecological thresholds easier to cross. For example, extirpation of sea otters along the U.S. Pacific coast led to the transformation of many kelp forest ecosystems because the loss of sea otters allowed sea urchins to multiply unchecked, decimating the kelp on which they feed.

On the east coast, in the Chesapeake Bay, the historical severe overexploitation of shellfish, which naturally filter water, is probably contributing to the bay's water quality problems now. Jeremy B.C. Jackson et al., *Historical Overfishing and the Recent Collapse of Coastal Ecosystems*, 293 Science 629, 629–638 (July 27, 2001).

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Finally, calculating MSY assumes constant environmental conditions. As NOAA's definition emphasizes, MSY is calculated "under prevailing ecological, environmental conditions" and reflects a long-term average of sustainable take under those conditions. 50 C.F.R. § 600.310(e)(1)(i)(A), (iv). However, if marine environments are constantly changing, there is no scientifically valid way to calculate MSY because there is no way to know how the targeted population will respond on a long-term basis. But this is exactly our current situation. Indeed, environmental conditions in the ocean have been changing for a long time, exacerbated now by climate change. As noted, overfishing is itself a significant driver of marine environmental change. Land-based pollution and habitat destruction have profoundly altered coastal ecosystems around the world. Moreover, because many coastal ecosystems serve as nurseries for species that then migrate to deeper waters, the impacts of coastal alteration ripple into deeper marine ecosystems. Toxic and plastic pollution affect every marine ecosystem on the planet, even the Southern Ocean around Antarctica. Climate change is warming the ocean, altering marine currents and causing species to migrate poleward, both of which are creating new configurations of species and altering ecosystem function. Changing marine currents can also create or exacerbate hypoxic or "dead" zones—areas of low oxygen traditionally resulting from nutrient pollution. Arctic Ocean sea ice is melting. Finally, as the ocean absorbs carbon dioxide from the atmosphere, the pH of the ocean is dropping, interfering with organisms' abilities to form shells and other life functions.

We currently have very little idea what all of these changes to marine ecosystems mean for particular species except that many of those species are, in fact, responding to these changes. John H. Barnhill, "Maximum Sustainable Yield," *in* S. George Philander, ed., *Encyclopedia of Global Warming and Climate Change* 899–901 (Sage Reference 2012). As a result, we now live in a world of deep uncertainty about the current and future status of not only individual marine species but also entire marine ecosystems. R. Ian Perry, "Dealing with uncertainty—implications for fisheries adaptation," *in* Organisation for Economic Cooperation and Development (OECD), *The Economics of Adapting Fisheries to Climate Change* 149–58 (2010); *see also* Rögnvaldur Hannesson, "Climate change, adaptation, and the fisheries sector," *in* OECD, *id.* at 247–75. Within that uncertainty, however, it is clear that anthropogenic stressors are significantly reducing the ocean's resilience, both engineering and ecological, primarily as a result of long-term failures in governance. Edward Miles, "Fisheries management and governance challenges in a changing climate," *in* OECD, *id.* at 159–65. Moreover, at least some marine ecosystems, especially coral reefs and the Arctic Ocean, are almost certainly already transforming. Hannesson, *supra*, at 250–52. Given these realities, and the acknowledged failures of fisheries governance, pursuing MSY-based fishing goals calculated on the basis of old realities can only be viewed as a tactic for increasing the odds that all marine ecosystems will transform, transform drastically, and transform in ways that reduce the biodiversity and complexity of the ocean—and global human commerce, cultural integrity, and food security. As the OECD noted in 2010, "deterministic fisheries models [like MSY] . . . may have led some people to believe that sustainability of fisheries revolves around maintaining steady stock levels and steady catches over time. This is unlikely to be desirable for stocks the growth and reproduction of which depend critically on a fluctuating environment, and it may even be impossible to attain." Hannesson, *supra*, at 262.

Incorporating Resilience Theory into Marine Fisheries Law

So, what does resilience theory counsel instead?

First, resilience theory counsels that change in natural systems is always expected as a result of complexly interacting adaptive cycles. Second, moreover, transformation of ecosystems is possible. Third, as a result, management measures that worked today may not work tomorrow, particularly if managers already know that disturbances are at work at multiple scales—for marine species, fishing, habitat destruction, pollution, climate change, and ocean acidification.

Putting these lessons into practice, we need to begin by defining what we are trying to achieve in marine fisheries management in a climate change era. Resilience theory actually offers little guidance here; ecological resilience and panarchy are system properties, not normative goals. The political process behind law, therefore, could—even if fully informed by resilience theory—self-consciously choose to exploit all marine resources as fast as possible before climate change-driven threshold crossings render the fisheries we depend upon commercially extinct. Notably, however, that political decision essentially gives up on long-term marine management and *guarantees* the worst of all possible ocean futures when the fate of the ocean is still deeply uncertain. Let's posit instead that the most important goal of marine fisheries management in a climate change era should be to maintain functional marine ecosystems that are ecologically resilient to climate change, promoting marine biodiversity and complexity despite a changing climate and prioritizing ecosystem function over human exploitation.

Given that normative goal, the stressors humans have already imposed on the marine environment, and the deep uncertainties regarding the future of marine ecosystems, resilience theory counsels us to manage to *minimize* human disturbances of these systems. However, many of the existing anthropogenic ocean stressors are not amenable to immediate reduction. Because of long lag times of the planetary climate and carbon systems, climate change and ocean acidification cannot be eliminated for centuries or a millennium, respectively. Existing coastal habitat destruction is unlikely to be reversed and will be complicated by rising sea levels. New pollution of the ocean has been reduced, but removing legacy pollution in the form of plastics, toxics, and nuclear waste poses a considerable challenge. In contrast, reducing land-based pollution, especially contaminated runoff, is technologically feasible and can result in some fairly immediate improvements; the problem is more often that the political will to implement such measures is lacking.

Commercial fishing, on the other hand, is subject to immediate reduction, and reducing the allowable catch is a recognized strategy for improving species' health. Miles, *supra*, at 171. Several organizations, scientists, and scholars have proposed that fisheries management needs to be far more precautionary, ecosystem-based, and flexible than it has been in the past, all of which also counsel for reduced catch limits. *Id.* at 167–71. Moreover, the goals of fisheries management must become more nuanced to reflect biological realities: "sustaining the resilience of fish populations requires that we seek to preserve their age and geographic structure rather than manage only their biomass." *Id.* at 168.

In addition, fisheries law should increase the use of marine protected areas, marine reserves, and marine spatial planning to protect areas of special biological importance and reduce fishing pressures. *Id.* at 167–68. While reducing commercial fishing is always a political hot potato, nations have been willing to do it to protect marine ecosystems that they acknowledge to be fragile. Many coral reef marine protected areas around the world either eliminate fishing entirely or severely regulate it. Similarly, in light of disappearing sea ice, first the United States and then the Arctic nations collectively agreed to forbid commercial fishing in the Arctic Ocean until its ecology and vulnerabilities are better understood. In the United States, both states (out to three miles from shore) and the federal government can establish marine protected areas through a variety of existing legal authorities. In addition to increasing protections for areas such as nurseries and breeding grounds, these governments should be looking to protect areas newly made important because of climate change impacts. Ocean warming, as noted, tends to drive marine species toward the cooler waters around the poles. However, ocean acidification occurs most intensely in colder waters. "Sweet spots" are thus likely to emerge in the more temperate regions of the ocean, where the effects of both ocean acidification and warming are attenuated enough to support diverse assemblages of species. These areas should be searched for and protected.

Resilience theory, however, can prompt even more radical changes in marine fisheries management by shifting how we

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frame management choices. Normal politics tends to evaluate changes in management only in the short-term, framing efforts at long-term conservation as a choice between business as usual and forced economic damage to the fishing industry. A resilience theory perspective instead gives more weight to the longer-term view of fisheries management, re-figuring the business-as-usual path as a choice that is increasingly likely to drive a growing number of marine ecosystems across ecological thresholds into unpredictable but probably less productive transformed states. From this new perspective, we can recognize that commercial marine fisheries are likely to decline in the next few decades regardless of what we do in law, but that certain legal choices now can increase the odds that we will still have productive marine ecosystems at the end of the twenty-first century and beyond. As such, the most effective governance change to promote marine ecological resilience at this point is arguably to institute a worldwide phaseout of commercial wild marine fisheries (and possibly other significant kinds of fisheries, such as large recreational fisheries), coupled with an increased reliance on well-regulated use of the more environmentally benign forms of marine aquaculture—a global industry that already has been on the rise in response to increasing demands for fish.

By acknowledging a world of continuous change and reduced human control over nature, resilience theory thus suggests a wide range of potential changes to marine fisheries management for a changing ocean. Even the most modest of these, however, should inspire comprehensive amendments to both domestic and international fisheries law, particularly to their emphases on MSY. Full incorporation of resilience thinking, in turn, demands a longer-term and system-based perspective on marine management, empowering humans to make choices now to strengthen the ecological resilience of marine ecosystems to the changes that are still coming, increasing the chances that the ocean will remain a complex and biodiverse natural system far into the future.