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ENVIRONMENTAL REALISM

Challenging Solutions

Kristan Cockerill, Melanie Armstrong, Jennifer Richter, and Jordan G. Okie

Environmental Realism

"The authors offer a bracing synthesis of particular case studies of environmental 'solutionism' in action and theoretical research into the complex ways that human societies and biophysical environments have developed and interacted over time."
—**Vera Norwood**, *Emerita Professor, University of New Mexico, US*

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CHAPTER 1

Why Challenge Solutions?

Abstract Labeling a problem "environmental" creates a pervasive belief that science and technology can, should, and will generate solutions for issues ranging from pandemic disease to stream functions to nuclear contamination. These, however, are "wicked problems" that defy simple or long-term solutions, but rather must be continually managed. Further, what are defined in the twenty-first century as "environmental problems" are often the consequence of perceived "solutions" implemented in a previous era. The perception of these issues as problems is derived, in part, from Enlightenment ideas segregating *Homo sapiens* from nature and a belief that humans can contain or control biophysical processes. Solutionist thinking and language perpetuates a self-referential problem-solution-problem cycle that begs the question of what constitutes a "solution" and simultaneously elides the reality that human systems and biophysical systems are inseparable.

Keywords Solutionism · Wicked problem · Human-culture divide

Following the 2009 L'Aquila earthquake in Italy, six seismologists and one government official were convicted of manslaughter for not predicting the risk that an earthquake would pose to people and property. The magnitude of 6.3 quake killed 300 people and left the city in ruins. The legal case prompted outrage within the scientific community and

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spotlighted key issues in how physical phenomena, risk assessment, and public expectations connect (Kolbert 2015; Nosengo 2012, 2010; Hall 2011). In an open letter to Italy's president, the American Association for the Advancement of Science representative Alan Leshner (2010) wrote, "It is manifestly unfair for scientists to be criminally charged for failing to act on information that the international scientific community would consider inadequate as a basis for issuing a warning." Although the defendants were acquitted on appeal, scientists report the initial verdict had a chilling effect on what they are willing to say to the media or to public officials. Indicted scientists characterized this case as a "warning to researchers, who may find themselves in legal trouble because of the way non-scientists such as public officials or journalists translate their risk analyses for public consumption" (Hall 2011). Several years after the case was settled, when asked about the longer-term impacts from the legal action, an Italian geologist noted that "it had pushed scientists in Italy to become latter-day Cassandras, always erring on the side of catastrophe" (Kolbert 2015).

The events following the Italian earthquake exemplify what research has suggested: People view the biophysical world as increasingly within human control. Rochford and Blocker (1991) found that though people attach disparate meanings to flooding "disasters," such events are often "interpreted as within the bounds of scientific prediction, if not control" and they are, therefore, "contested events in which blame is allocated and conflict ensues." More recent research finds similar results, showing the public's distinction between "natural and human-induced hazards is slowly vanishing" (Wachinger et al. 2013). This has potentially serious implications, as public officials may be blamed not only for their response (or perceived lack thereof) but also for the severity of a biophysical event itself (Wachinger et al. 2013). Indeed, studies show that throughout the twentieth century, US voters failed to reelect incumbent officials in elections following floods and drought (Achen and Bartels 2004) and officials in India are punished in reelection following years with low rainfall (Cole et al. 2012). Even if not blaming officials for an event, voters who "believe that government could have done more to prevent the level of damage, . . . are willing to attribute blame and punish incumbents accordingly" (Arcenaux and Stein 2006).

In the following pages, we argue that simultaneous shifts in language and thinking are required to fully acknowledge that "natural disasters" or "environmental problems" are both mislabeled and are often catalyzed by human attempts to predict and control biophysical processes. We employ an interdisciplinary approach to examine the deeply intertwined relationships among human biology, human culture, and the planet's ecological, geological, and atmospheric systems. In doing so, we embrace environmental realism, which acknowledges that biophysical phenomena (e.g., floods, earthquakes) are "normal" and are core to the planet's history and function. Further, environmental realism accepts that *Homo sapiens* are fully part of the planet's complex systems. If human society wishes to engage in beneficial and long-term environmental management practices, it requires collapsing dualisms between humans and biophysical systems and reducing solutionist language that binds us to false perceptions of both.

Establishing social institutions to control biophysical events, and then blaming those who manage those institutions for any failure to control has a long history in human societies. Achen and Bartels (2004) report that some scholars think Egyptian pharaohs were held responsible for annual Nile flooding and when the river did not flood it may have shortened their reign and their lives. During the plague years of the fourteenth century, political and religious leaders were discredited for failing to defend the common welfare, and one result included an increase in social and political movements that targeted disliked minorities, including Jews (Achen and Bartels 2004). What is new in modern society is the role that science plays in public expectations about control of, and risk from, biophysical events. There is now a social expectation that scientists, and those who use scientific data, can and should produce impossibly precise knowledge of biophysical systems and subsequently provide accurate predictions of potential impacts from biophysical phenomena (e.g., floods, earthquakes, epidemics) so that individuals may avoid harm. The Italian earthquake case is an obvious example. There are other, more pervasive examples, as people routinely ignore potential risks in their environment—by building in earthquake zones, flood prone areas, water-scarce areas, and on steep slopes—while they simultaneously balk at paying high insurance rates (Nossiter and Schwartz 2006; Orts and Spigonardo 2013; Hanscom 2014; Bramwell 2014). People also manage their bodies in ways that produce health risks, choosing unhealthy behaviors like smoking or consuming fatty foods, knowing that they are increasing their personal risk of becoming ill or dying young. The availability of private health and property insurance perpetuates the belief that people can mitigate the impacts from biophysical systems through individual best practices. At the same time, governments establish zoning, building, and health codes, which help create a belief that social institutions can manage biophysical systems. If biophysical systems can be controlled, then there is no (or less) risk, and hence, no need for insurance.

People create governments as well as institutions to protect their human rights, individual well-being, and personal property. In liberal democracies, an inherent tension exists between governments and citizens in part because people make investments in their well-being and their property, predicated on societal stability, and anticipate that government will work to protect those investments. When citizens charge governments with protecting them from risk, and governments respond by building systems to mitigate risk, public perception of how much risk they might encounter in their daily lives shifts.

Large-scale demonstrations of governance have attempted to mitigate risks from biophysical phenomena. In doing so, social systems have established risk management as a principal way that governments protect a "basic" human right to live without threats to body or property. Moreover, governments accrue power and authority by demonstrating how they are managing risk and by recruiting citizens to join in the social work to mitigate risk. The interplay between governments that promise to protect citizen health and property, and the citizens who turn to government to "solve" issues like flooding, earthquakes, disease, and waste management, is deeply rooted in our cultural systems.

Governing well implies meeting public expectations, and therefore, public institutions seek efficient, one-time solutions to problems that emerge from the stochasticity of biophysical systems. Ideologically, this widens a perceived gulf between nature and culture, in which social institutions must be separate from the biophysical world to attempt to control it. Further, when our attempts to control fail, there must be someone to blame. The expectation that people can live without risk exists in pervasive tension with the expectation that individuals and social institutions will maintain less risky conditions and that scientists will provide the knowledge needed to reduce or eliminate risk.

Because scientists have been successful in illuminating ways to predict and contain some risky processes, especially on smaller geographical or temporal frames, such as local, seasonal flooding or single-tree lightning strikes, this limited achievement "tempts us to simply turn to scientists and say: 'Tell us what will happen . . . '" (Sarewitz et al. 2000). The perception that scientists can predict the future equates knowledge of the biophysical present with future risk. People transform the idea of a risk into a problem, which they then expect to be solved and eliminated. This represents an overly simplistic cognitive fixation on discrete problems designating pre-packed, commensurate solutions.

Alas, most significant issues facing humankind, including persistent poverty, crime, and a diverse array of environmental issues, are "wicked," not in the sense of being evil but rather because they are embedded in complex systems, can be defined or framed in multiple ways and at their core are about human values. These wicked problems are intractable and can never be solved. As Rittel and Webber (1973) stated in their influential article on wicked problems, "[A]t best they are only re-solved—over and over again." Although several decades have passed since Rittel and Webber had concluded that "wicked problems" must be managed rather than "solved," a social and political emphasis on solving these types of problems persists.

Scholars and others do increasingly recognize that "solutions" often catalyze new problems. In describing the history of water management, for example, Solomon (2010) writes, "intensified use of water and other vital resources were followed by population increases that in turn so increased consumption that they ultimately depleted the further intensification capacity of the society's existing resource base and technologies. Such resource depletions thus presented each society with a moving target of new challenges requiring perpetually new innovative responses to sustain growth." Defries (2014) describes this cycle as the "big ratchet" in explaining how agriculture has continuously "solved" human crises only to generate new problems, requiring new solutions. This idea of a cyclical relationship among problems and solutions begs the question of what constitutes a solution.

The word "solution" as commonly used and understood implies an end-state where a problem has been "fixed," and therefore, will no longer require attention. The "fix" may be perceived to be technical, social, individual, or some combination of these. Solution-seeking represents a quest for stability, predictability, normalcy, and certainty, and does not recognize the cyclical structure of problems and solutions. When collective groups share and act upon a desire for stability and predictability, they develop a common worldview that scholars have deemed "solutionism."

The term "solutionism" has been used for decades in diverse ways. It may have been used first by Huntington in 1957 to note that the "new conservative" movement was in part "a critique of utopianism and 'solutionism'" (Qtd in Quinion 2013). Although solutionism is perhaps most commonly applied to ideas surrounding technological innovation, it is definitively not limited to the techno-fix, which has been well documented as a flawed approach to addressing social problems (Fox 1995; Huesemann and Huesemann 2011; Morozov 2013). The general idea of “solutionism” has been critiqued as being simplistic and misleading (Quinion 2013; Morozov 2013; Baker 1984). In 1959, Hodnett cautioned readers to “Beware of ‘solutionism’—the flabby optimism that there is a simple answer and that it will yield to the magic of a personality, ‘brainstorming,’ sitting down and talking things over, or other tribal nostrums.” Alluding to some of the broader social implications of solutionism, in 1984, Baker defined the term as “the belief that for every problem there exists a solution; and successful persons are those who solve problems.”

To be clear, we recognize different kinds of problems and the multiple terms used to delineate them. Rittel and Webber (1973) differentiate between wicked and tame problems; Schumacher (1977) discusses divergent and convergent problems; Glouberman and Zimmerman (2002) define simple, complicated and complex problems; while Ackoff (1974) and Horn and Weber (2007) describe “social messes.” A key factor in each of these categorizations is the level of complexity, and hence, the “solvability” of the problem. Wicked, divergent, and complex problems, as well as social messes, are all similarly characterized as not having a singular endpoint (i.e., no definitive solution). Tame, simple/complicated, and convergent problems, on the other hand, do have singular solutions. Examples include math problems, developing a vaccination, or constructing a building or bridge to meet specific load requirements. These are not necessarily easy problems to solve, but they do have a clearly defined endpoint. Using the language of solutions is appropriate for these kinds of problems. Our concern lies in applying this same solutionist language and subsequently the same expectations to problems that will not have clearly defined or singular endpoints.

There is evidence that solutionism, expressed more broadly, is a pervasive cognitive trait that limits social action. Maxwell (1991) posits there “is the belief that there must be a perfect solution, somewhere, to every problem,” and this reduces the incentive to make an incremental social change because people are expecting and waiting for that definitive, perfect solution. Further, she believes “solutionism is not a well-recognized phenomenon and that it gets much of its power from this lack of recognition” (Maxwell 1991). Indeed, when presenting the idea for this book to students, friends, and colleagues, we encountered initial resistance to the very idea that there may not be solutions to pressing problems as well as resistance to the idea that people do expect solutions. In fact, one early anonymous reviewer, after expressing support for several ideas in the manuscript, expressed uncertainty "about how serious the 'solutionism' problem really is."

Yet, Maxwell's (1991) premise aligns well with current understandings of human cognition and subsequent behavior. From an evolutionary perspective, making sense of the world and ensuring survival relied on knowing what might happen under particular circumstances. Being able to readily identify a potential problem (i.e., risk of being eaten) and then solve that problem (i.e., avoid the risk by running away) enabled *Homo sapiens* to flourish. People are subsequently prone to seek and imagine patterns even where no patterns exist because this provides a sense of certainty to what are often highly stochastic, nonlinear and unpredictable phenomena (Kahneman 2011). This tendency to imagine patterns where they do not exist is known as a *clustering illusion*, and it provides a false sense of security because predictions are derived from a perceived but nonexistent pattern. Further evidence of a human desire for certainty is found in an overreliance on numerical data. Because numbers are perceived as "certain," people are inclined to accept quantitative statements or arguments, even when they are specious (Seife 2010). This contributes to expectations that science, which often speaks the language of math, can find concrete solutions to perceived problems.

Despite the numerous cautionary notes about solutionist thinking, the cognitive appeal of solutionist ideas has allowed the word "solution," with the concomitant notion of permanence or stability, to thoroughly permeate contemporary society. Advertisements and business slogans are rife with solutions. In fact, Dow Chemical has trademarked the slogan, *Solutionism: The New Optimism*. Federal funding agencies and graduate school programs highlight "solving problems" as their focus. The MacArthur Foundation, host of the "genius grants" has established the 100&Change grant to award $100 million to "help solve a critical social problem" (MacArthur 2016).

Calls for interdisciplinary education and research often hinge on the premise that individual disciplines have failed to solve society's most pressing problems, and hence, interdisciplinarity is needed to do what individual disciplines could not (National Academy of Sciences 2005; Repko 2008; Jacobs 2014). In assessing the role of higher education to advance a more sustainable future, Hart and colleagues (2016) conclude the number one lesson is, "universities must realize that the well-honed academic habit of studying problems without emphasizing solutions is ever more troubling in today's world." Political speech relies on solutionism. For example, a transcript from a 2016 US Republican candidate debate features 22 references to "solutions" or "solving" problems (The Washington Post 2016). Particularly relevant to our premise, a search for the phrase "environmental solution" within the Google Books database finds a marked increase in the number of entries since 1990. The emphasis on solutions is so pervasive it is very difficult to not use the term "solutions" in reference to perceived problems. The subsequent reaction is not to assess the feasibility of solving any particular problem, but to consistently seek a new approach that promises it will find *the solution*.

Drawing evidence from across multiple disciplines, we argue that labeling problems as "environmental" or "disasters" reflects deep-seated cultural values rooted in Enlightenment ideology about the concept of nature and the perfectibility of the human condition. Embedded in this ideology are assumptions about biophysical systems and the human relationship to these systems, assumptions about what science is and what it can or should do, and assumptions about risk. Further, calling these phenomena "problems" establishes a self-referential expectation that there is a solution. Language, history, and biology bind humans to a worldview oriented toward solution-seeking. People build institutions and infrastructure around the expectation that their interactions with the world will be comprised of problems and solutions. As perceived "solutions" are promulgated, people adjust to their new realities even as they seek, through language, and advance toward, through biology, a new turn in the cycle of problems and solutions.

This basic premise that environmental realism must avoid focusing on solutions will surely elicit diverse reader reactions, provoking discussion and debate. First, for those who are unconvinced about the pervasiveness and potential implications of solutionism we encourage you, in your daily life, to observe where and under what circumstances you encounter specific language or the concept of "solving" environmental problems. Second, we want to be clear that nothing in our argument is intended to give license to abdicate human responsibility for our role in creating or exacerbating risk to ourselves and other species. We recognize that complex historical, political, economic, and cultural interactions affect how solutionist thinking is made manifest in addressing biophysical phenomena. Finally, we are not fatalistic. Rather, as our final chapter highlights, we are optimistic about current and potential human ability to address the concerns we raise.

Cycles: Problems, Solutions, and the Malthusian-Darwinian Dynamic

Because a wicked problem has no solution, if people engage in solution-seeking regarding a wicked problem, they are already caught in a cycle of perceived solutions generating new problems. This problem-solution-problem cycle is especially pernicious when considering environmental topics because it resists accepting the fundamental integration of human systems and nonhuman biophysical systems. Events like floods, epidemics, and earthquakes pose risks to humans and subsequently are often labeled "environmental problems" or "natural disasters." This creates a perception that the relationships among social and biophysical systems are problematic rather than normal (Fig. 1.1).

Basic ecological and evolutionary principles demonstrate the danger of expecting that science-derived knowledge and/or technological innovations can offer concrete, singular solutions to humanity's challenges. Two interacting ecological and evolutionary forces, together referred to as the Malthusian-Darwinian Dynamic (MDD), influence all human and

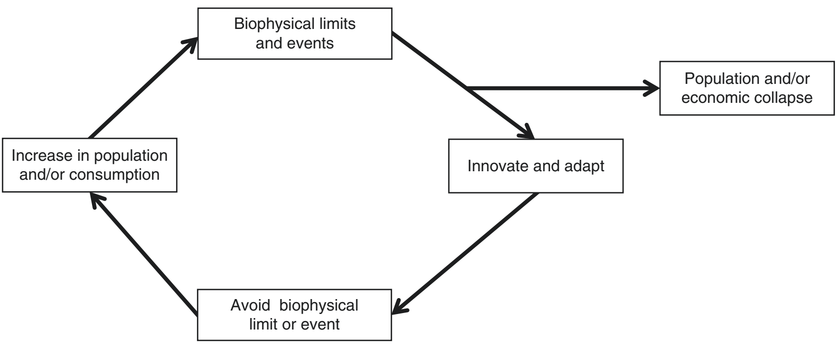

Fig. 1.1 The problem-solution-problem cycle: Although innovations and adaptations allow humans and other lifeforms to temporally circumvent biophysical limits, increases in consumption and population lead to new limits requiring further innovations.

nonhuman populations (Nekola et al. 2013a; Lotka 1922) and serve as an explanation for the ratcheting effect of the problem-solution-problem cycle that Defries (2014) describes. A consequence of the Malthusian component of the MDD is that increases in population size and per capita consumption lead to increases in a population's total consumption until resource limits are reached; a consequence of the Darwinian component is that populations innovate and adapt through biological and/or cultural evolution to circumvent these limits. Thus, the defining characteristic of the Malthusian-Darwinian Dynamic is that, following innovation, an intrinsic tendency to expand in population size and consumption until facing even stronger limits leads to the requirement for a new and more complex innovation to address challenges associated with these new limits. Considered over long periods of time, all populations, species, and civilizations—from local through global scales—necessarily exhibit problem-solution-problem cycles as a consequence of the MDD. The MDD provides a sobering reminder of what societies bind themselves to with the commitment to innovation and growth.

The MDD involves cycles of growth, resource shortages, environmental limits, and innovation; it does not guarantee that a population can innovate or adapt (i.e., "solve" a problem) in time to avert negative consequences of resource shortages, devastating epidemics, widespread famine, or debilitating warfare that can underlie societal collapse. Human history and the ruins of ancient societies in Mesopotamia, Egypt, Rome, Mesoamerica and many others vividly demonstrate this. Indeed, considering twentieth and twenty-first century advances in the scientific understanding of biophysical systems show that a belief in innovation as a "solution" to the MDD is misplaced. As has been firmly established in quantum mechanics, nonlinear science, chaos theory, complexity science, and ecological theory, inherently stochastic processes underpin all complex systems (including human systems). This fundamental stochasticity means there is no assurance that humans can produce timely innovations (i.e., temporary solutions) to any complex problem. Thus, basing the fate of human societies on this belief is dangerously short-sighted.

We draw attention to the evolutionary history of the problem-solution-problem cycle not to cry out over a particular fate to which human society is bound but to illustrate how the push toward solutionism and the solutions-based language circulating today are not unique in our social or biological history. Recognizing that all populations live with limits and so-called problems, and in a world where environmental phenomena operate outside human control, opens the possibility that humans can better understand and contextualize their desire to solve these unsolvable wicked problems. Rather than continuing to perpetuate the problem-solution-problem cycle, people could accept complexity and subsequently better focus on building futures that are liveable, sustainable, and just.

Language Matters

In this book, we call into question the very premise of "environmental problems" and expected "solutions." We seek change in how language is used and subsequent expectations about the relationships among people and biophysical systems. This text marks an intersection between the philosophical and the practical. The mindset that there are "environmental problems" that humans can solve has serious implications for how humans act within biophysical systems.

Many modern scientists (as well as others) do recognize that complex systems are dynamic and rife with uncertainty and that this requires seeking long-term adaptive management approaches rather than trying to identify permanent solutions (Gunderson 1999; Gunderson and Holling 2002). Despite this understanding, even scientists often use solutionist language. This language has deep roots. Media, textbooks, and general social discourse, as Harding (2008) has written, often portray the history of science as a "narrative of achievements" that sets science apart from socio-political systems. Language that adopts a mythical, objective, third person description of scientific advances perpetuates this separation. Current popular and academic literature, including some scientific literature, too often continues to emphasize both the language and concepts of solutionism. This perpetuates both rhetoric and behavior focused on seeking the impossible: a stable, science-driven, and permanent solution to a perceived "environmental problem."

While the labels "problem" or "solution" or "environment" may seem semantic, there is significant evidence from multiple fields that these words and language more generally, do matter, because they influence how people think and because they affect social norms, behavior, and politics. Studies focused on how people communicate about science have long shown that individual words do matter in how an issue is framed and that there are distinctions in how the public perceives particular words in comparison to how experts perceive or use those words (Tannenbaum

1963; Dunbar 1995). A 2009 controversy over e-mails about climate change modeling where researchers used terms like "manipulation" and "bias" offers an excellent example of how language matters. Scientists writing about climate change studies used these terms to explain their work in conversation with each other, but a public release of the e-mails drew attention to the language they used. Media reports formulated a broad claim that scientists had fabricated data. To scientists and computer modelers these terms are benign within the realm of data management and statistical analysis; they reference standard methods of inquiry and experimentation. To the general public, however, these terms carry significantly more sinister interpretations (Somerville and Hassol 2011).

Other research demonstrates that the language used to describe diverse events affects perceptions about appropriate policy responses to those events. For example, when flooding is described as a "natural event" there is more public support for allowing rivers room to run without human interference. When flooding is described as "catastrophic" for trees and wildlife there is more public support for increasing engineered flood control measures (Cockerill 2003). In another study, experiment participants preferred different policy approaches to managing crime depending on whether crime was described metaphorically as a monster or as a virus, even when the participants could not recall the specific metaphor used. "Metaphorical frames can play a powerful role in reasoning because they implicitly instantiate a representation of the problem in a way that steers us to a particular solution" (Thibodeau and Boroditsky 2013). Language used to promote solutionism often elides a clear articulation of why the phenomena in question are perceived to be problem in the first place, and often addresses only one part of the defined problem at hand (loss or harm of human life and property, for instance) without also articulating the ways that a proposed solution might adversely affect other biophysical systems, including other human societies in the present and future.

The language used to characterize a perceived problem, therefore, reflects assumptions about the phenomena driving the problem-solution-problem dynamic. Biophysical phenomena such as earthquakes, fires, floods, landslides, and volcanoes, as well as microbial and viral lifeforms, are creative forces that have shaped the planet, and are, hence, "natural" biophysical phenomena. While these events do occur independently, human action (e.g., land use decisions) can also catalyze events or worsen the impacts when they do occur. However, labeling them "natural disasters" highlights the tension between biophysical processes and their effect on humans, which human societies wish to predict, control and/or contain. These linguistic practices deflect attention away from the social behaviors that shaped the event. Similarly, modifying the noun "problem" with the adjective "environmental" both reflects and encourages the presumption that the environment is something separate from humans, a realm that is understandable and knowable apart from the human species.

Furthermore, establishing how any particular issue rises to a level of broader social concern commonly involves defining an issue as a problem, establishing blame, suggesting solutions and invoking an appeal (Benford and Snow 2000; Davis and Lewicki 2003; Dardis 2007). In assessing how well the media cover environmental issues in particular, scholars often begin with a premise that the media should identify the problem, establish blame, and then offer solutions The perception that complex social and political problems stemming from biophysical events must have solutions is prevalent, and readers are critical of media coverage that does not offer a solution to a stated problem (Kensicki 2004; Riffe and Reimold 2008). The "message box" approach used to coach scientists on how to frame issues for the media or policy makers emphasizes specifying the problem, establishing relevance for the audience, and offering solutions to the problem (Baron 2010). This reflects the quest for certainty in thinking about problems and in considering the role for science and scientists in explaining and addressing problems in the public realm. In explaining their work, scientists are encouraged to "understand that reporters are more likely to quote you if there is no gray area in your view or research" (Hayes and Grossman 2006).

This tendency is also prevalent within academic circles. Despite recognizing that science (indeed any knowledge-seeking process) is rife with uncertainty, seeking certainty through solutionism remains prevalent in academic peer review. As academics, we have all experienced this in our own work. For example, two of us authored a manuscript on sustainable water management that proposed avoiding solution-seeking language and encouraged water managers to embrace the complexity inherent in any water system. The editor's response was to suggest retitling the manuscript to include the word solution and to conclude the piece with concrete solutions for future water management. The expectation that scholarship will define problems and present solutions exemplifies the depth of the social belief that experts should bear the responsibility of social problem-solving. Reviewers' desire that academic articles follow established patterns and conclude with concrete solutions exemplifies how the pairing of problems with solutions manifests as a pattern in our cultural knowledge production. Further, when funding organizations like MacArthur and many others call for research proposals that aim to solve particular social or biophysical issues, the very trajectory of scholarly research drifts toward solution seeking.

Because there is a self-referential relationship between defining problems and expecting solutions, once people label something as a problem, they expect that someone can solve it. This expectation often relies on entrenched cultural beliefs that science and technology provide keys to social well-being through modifying and controlling biophysical systems. Our premise is that many of these historic imperatives to control, manage, and use biophysical systems have had outcomes that are now being labeled as "environmental problems." We propose that labeling a problem as "environmental" draws attention away from the reality that these issues have deep social origins and are often predicated on a perceived separation between humans and biophysical systems. This ideological stronghold claiming that humans have the power to control biophysical process has shaped both our social institutions and the infrastructure in which we live, evidenced by massive engineering projects like dams and nuclear power plants with their concomitant management agencies.

The accepted process of defining biophysical phenomena as problems that demand solutions has serious implications, including giving humans the license to abdicate individual responsibility for decisions and actions (Uzzell 2000). Once a biophysical phenomenon or event is called an environmental problem, seeking to blame someone or some institution influences how people, including individuals, communities, and entire governments (such as the Italian government holding a handful of scientists responsible for the effects of an earthquake) subsequently frame that perceived problem. If blame is not placed somewhere, information given about the phenomena is perceived as less salient, and this may indicate that when there is no clearly identified entity to blame there is an implicit suggestion that individuals are complicit in the problem (Dardis 2007). We argue that if the accepted perception is that science and engineering can, should, and will solve these problems, then anyone who is not a scientist or engineer may perceive that they have no power to intervene, nor any culpability for *not* intervening.

When a potential risk is identified, labeled, and described as an environmental problem or a natural disaster, this allows the moving of that risk from the human-focused social realm into a perceived nonhuman biophysical realm, where only scientists and engineers hold the ability to "solve" increasingly wicked problems, reifying a separation from the politically messy relationship of humans and nonhuman systems. These practices are sustained by beliefs that emerged during the Enlightenment in Western Europe in the 1500s and came to be interpreted as clearly linking knowledge gains about biophysical systems (i.e., "nature") with a perceived ability to control those systems. Scientific or technical expertise, rather than considering collective or individual values and associated action, became the path forward. The assumption runs thus: If biophysical systems are unpredictable and uncontrollable only because humans lack complete understanding, then increased knowledge of those systems should increase humans' ability to predict and ideally control specific phenomena. The Italian seismologists have firsthand experience with the ramifications of this way of thinking.

History Matters: *Homo sapiens* and the Biophysical World

Biologically, people are *Homo sapiens* and can be categorized as primates, mammals, vertebrates, and animals, yet we tend to see ourselves as outside any biophysical system (Brown et al. 2011; Burger et al. 2012). The prevalent Western belief segregating humans from biophysical systems became culturally entrenched during the Enlightenment. Scholars from diverse disciplines have assessed the role of the Enlightenment's impact on science and society. Most relevant to our argument is the scholarship positing that ideas about using science to control "nature" (i.e., biophysical systems) played an important role in popularizing and solidifying a perceived divide between humans and "nature," and that studying such external nature offered a path to social redemption and individual Enlightenment. This created a new role for government in facilitating citizens' path to Enlightenment by generating knowledge and protecting a new type of biological human rights grounded in the "laws" of nature.

As Horkheimer and Adorno (1944) wrote in their Dialectic of Enlightenment, "human beings distance themselves from nature in order to arrange it in such a way that it can be mastered." Keller (1985) offered a more nuanced perspective, writing that Enlightenment thinking proposed, "Through science and art (that is, technology, or mechanical art), man can find the power to transform not so much the world as his relation to the world." Leiss (2007) concurred and argued that mastery of the environment was intended to be "matched by another kind of mastery, namely, self-mastery: to figure out how to control the irrational impulses of human nature, by comprehending the sources of those impulses and by extending the domain of reason in social relations." Despite this broader ideal, controlling external nature and elevating humans above the rest of the biophysical world came to dominate thought and practice, while the ideal of establishing relationships with the biophysical world was largely abandoned.

This more hierarchical association among science, technology, and societal issues also found footing in the political developments of the Enlightenment, especially visible in the colonies of the "New World": "As avid proponents of the cause of liberty, [Benjamin Franklin and Thomas Jefferson] looked to the new mechanical technologies of the era as means of achieving the virtuous and prosperous republican society that they associated with the goals of the American Revolution" (Smith 1994). Later, political leaders "shifted the emphasis away from human betterment and toward more impersonal societal ends, particularly the establishment of law and order in an unstable political economy. From the start, technological determinism proved highly compatible with the search for political order" (Smith 1994). If political order stemmed from complete control over (and exploiting resources from) the biophysical realm, the impetus for control became a driving political value, one that was relegated to the sciences and engineering disciplines with an emphasis on objective, quantifiable, and empirically produced knowledge. Jamieson (2000) argues that this has perpetuated an American avoidance of discussing moral and political differences, and instead, arguments that explicitly involve complex and competing values are conducted in "technical discourse," thus "pretending that our differences can be washed away in the solvent of scientific decision-making." This attitude that science and its technological offspring should lead to a more progressive human society continues to promulgate solutionism.

Environmental changes during the Industrial Revolution strengthened social faith in the ability of science and technology to reduce risk and improve human well-being. The instruments of science showed planets to exist beyond earth and microbes to exist within our own bodies. Applying the principles of science brought demonstrable social effects. In London in 1854, to use a popular example, John Snow mapped incidents of cholera to argue that the disease was being transmitted through the public water supply, an early example of epidemiology. In turn, practices of engineering created public works and sanitation systems that reduced the occurrence of disease in society. Such cases demonstrated how scientific study could inform collective action to benefit a population, requiring governments to care for citizens by furthering such practices.

Living in an industrialized world simultaneously widened the perceived segregation of people and biophysical systems, often called the nature-culture divide. Notably, Williams (1976) argued that people's ideas about the qualities of nature have evolved over time alongside centuries of changing human thought. Williams philosophized that the work during the Enlightenment and Romantic Era to study nature through observation required that "nature" (biophysical systems) sit in contrast with that which humans made of themselves and the world. This followed changing understandings of nature as divine or abstract and provided the foundation for understanding nature as wild places, untouched by humans. Romantic Era ideals presented nature as "out there" and needing protection from human incursion, shifting the role of humans from merely studying and observing nature, to that of stewards for nature. As stewards, people shaped the biophysical world to both satisfy their needs for not only goods but experiences as well. This shift was still firmly grounded in a belief that humans are a special species, alone on the Earth in the ability and drive to actively shape the biophysical realm.

Famously, Emerson (1849) defined nature as "essences unchanged by man" and Marsh (1864) wrote of a natural world where "man is everywhere a disturbing agent. Wherever he plants his foot, the harmonies of nature are turned to discords." While recognizing the less attractive aspects of human interactions with the biophysical world, the myth of untouched nature was juxtaposed with rapid science-driven technological advances. This instigated a social movement to delineate discreet spaces for industrial cities and wilderness parks, creating the possibility for nature to be mapped and politically bounded. These boundaries both created the need for systems to uphold the physical separation, such as park and wildlife governing agencies, and provided a mirror for society, a pristine wild space against which the need for social reforms could be measured.

Through the perceived separation of humans from the biophysical environment, nature also attained a new status as a resource for the march of industry, turning humans into consumers of nature. Both as a resource to further the acquisition of capital and as a place apart from the bustle of modernity, an external nonhuman nature became a central site for reflecting and refracting the social values of humans towards the natural world. The scientific work to know nature by its laws, which began in the Age of Reason and continues today, sustains both the pursuit of capital and the pursuit of self-knowledge and prescribes roles for government and other social institutions to ensure opportunities to pursue both.

The material qualities of the nonhuman world do not create the nature-culture dualism, but humans have created the perception of the dualism to sustain the complex and varied ways in which we use nature to "improve" society. Marsh (1860) emphasized that humans must manage nature both for the good of nature and society and in such a way that retains human dominance. Applied science seemed to offer tools for such control. Hays (1959) argued that while the conservation movement has a reputation as a "defender of spiritual values and national character," conservation "above all, was a scientific movement, and its role in history arises from the implications of science and technology in modern society." Conservationists imagined that biophysical systems would thrive by applying scientific knowledge. These efforts to control and keep separate the industrial and the wild created a new focal point for addressing environmentally relevant issues by identifying places where nature could be controlled and used for the human benefit and other places that would reflect human ideals in terms of "pure nature." Around the world, nations began to set aside lands for conservation, establishing land and ecosystem management as another role for government and creating public institutions for managing specially designated "natural" places. This philosophical approach continued well into the twentieth century, as early studies of ecology recognized interconnectedness of biological and physical systems, but excluded humans from these systems (Reuss 2005).

The desire to both protect and control, rationalized by Enlightenment thought and social institutions, is a response to an environment that not only provides all sustenance but can also be unpredictable and destructive. Biophysical processes do operate independently of human action. Earthquakes, volcanoes, floods, fires, radiation, microbial evolution, and pandemics can pose problems (i.e., risks) for human well-being. In addition to "harnessing nature" for human benefit, humans have made expansive attempts to control how, when, and where (and even whether) biophysical events manifest to reduce risks to the human enterprise. Solutionism has been rationalized and supported in part because humans have successfully controlled biophysical processes on short temporal and spatial scales. Humans have built dams and irrigated landscapes, constructed cities, grown crops in desert landscapes, and eradicated disease-causing microbes from the earth. We use fire to manage landscapes in what are labeled as "controlled burns," while dropping fire retardants on trees smoldering from lightning strikes. And humans have predicted hurricanes and tornados with enough accuracy to sound sirens that prompt citizens to retreat to higher ground or basements. This has contributed to a false, yet pervasive, sense of confidence that modern society can control risks in the long-term as well.

This belief leads to a central paradox for solution-oriented projects: Scientific work has produced more knowledge of biophysical processes, enabling new control mechanisms and resulting in fewer individuals who directly experience these processes (especially in affluent societies). Science has thereby reduced experiential understanding of biophysical phenomena (Prevot-Julliard 2015; Louv 2008). The increase in urban/suburban living further removes people from daily experiences such as seeing river levels fluctuate, observing changes in plant or insect populations or witnessing constellations and phases of the moon. Interactions with biophysical processes is so reduced for many that their only experience comes when those processes escape our efforts to control them and cause harm to health or property.

Risk perception studies show that the most persistent predictor of risk perceptions of "natural hazards" is previous experience with an event and the severity of personal consequences. Individuals directly and severely affected by a previous event often overestimate potential risk, while individuals with lower direct impacts or with no direct experience often underestimate potential risk from biophysical phenomena (Wachinger et al. 2013). Additionally, people have remarkably short memories about the impacts from biophysical events, and the further removed their experience is in time, the lower their risk perceptions become (Kellens et al. 2013; Wachinger et al. 2013). Thus, short-term control mechanisms and distancing from the biophysical world have lowered humans' experience of nature and its hazards, and therefore, their ability to assess the risk of those threats has been compromised. Furthermore, when people cannot see risk in their environment, the markers of risk management begin to stand in for knowledge of the risk itself. Thus, people know wildfire through signs posted by institutions showing "today's fire risk" or their observation of community tree thinning projects near their homes. Such acts show, first, what government is doing to mitigate risk before there is any understanding of how that risk was created.

Beyond a lack of experiential and temporal issues that shape perceptions of risk from biophysical phenomena, the language in risk studies also invokes ideals of control. The concept of a "safety chain" establishes a process where individuals or communities mitigate, prepare for, and then recover from a "natural hazard" to return to a "normal" condition (Kellens et al. 2013). This incorporates the emergency as part of the stable state of society. Protecting people's rights to life and property includes ensuring that they can quickly return to their normal practices of living following any disruption. At the scale of a population, governments must create a safety chain for enough citizens such that, even if some are harmed, collective life endures (Foucault 2007). Governments attune less to controlling the biophysical phenomenon and more to managing citizens who work for their own survival (Masco 2008), although people desire to believe the opposite.

As more people are removed from direct experience, we have subsequently created a new "normal" whereby biophysical events represent a severe deviation and disruption not just to survival but to social stability. Framed in this way, the problem of the biophysical event demands a solution designed to create a state where such phenomena (e.g., floods, earthquakes, epidemics) either no longer occur or cause no harm when they do occur. Again, the Italian case seems to offer a very real example of this growing expectation for a no risk society where scientists understand and can predict all biophysical phenomena, and hence, make risks controllable. When biophysical events upset the boundaries of human control, there is an urge to return to the previous (i.e., "normal") state as quickly as possible, to rebuild in the same floodplain or restart nuclear reactors in earthquake zones, and thereby avoid deeply contemplating the stochasticity of biophysical interruptions.

Even as human societies search for a return to normalcy on an individual or community scale, as a category of social perception, risk itself has outgrown human-oriented scales. Science cannot function as an arbiter of risks from the complex interplay of social and biophysical processes, as human effects on the planet outstrip human urges and ability to know, predict, and control the biophysical realm. Climate change presents a "problem" so large that human scales of articulating and anticipating the risks are not applicable, nor appropriate. Climate change, therefore, indicates what Beck (2006) referred to as a new kind of modernity, one where risks are incalculable, noncompensable, and delocalized. By delocalized, Beck is referring to the ways that new global risks move across spatial, temporal, and social borders. Risks from modern human society, such as climate change from carbon emissions, chemical pollutants from industrialized agricultural methods, or fallout from nuclear accidents, along with biophysical events like hurricanes, earthquakes, floods, and pandemics transcend political borders as well as human life spans, challenging the human ability to both attribute and to comprehend them. The "slow violence" (Nixon 2013) of the social and political outcomes of living with these modern risks, unfolding across generations of human existence, makes it impossible to predict with any certainty what the combined effect will be at any given time, and also impossible for science to give reliable information necessary for any perceived permanent solutions. Beck (2006) argues that due to "the complexity of the problems and the length of chains of effect, [the] assignment of causes and consequences is no longer possible." These underlying aspects of global risks trouble any notion of solving such wicked problems.

Anti-science Thinking

While solving wicked problems is outside the purview of modern science, managing risks on small timescales and with flexible goals has been more possible. This limited success, however, places the scientific disciplines in a paradoxical bind. The examples of successfully controlling events led to a belief that we can simply scale up previous temporally and geographically bound experiments for increased human benefit. Yet broader scales confound external factors, both physical and social, and experiments in laboratories and models on computers yield different results when applied to global scale concerns. Further, though science is still seen as an essential authority for containing risks from biophysical phenomena, anti-science sentiment, especially in the US, is a growing issue (Prothero 2013; Collins 2014).

We propose that popular anti-science attitudes result from linkages among the Enlightenment promise to use science to solve problems, the subsequent expectation that biophysical events can be contained and controlled, and the mid-twentieth century movement to problematize science's authority. Core to understanding anti-science attitudes is the science-based evidence that humans are not innately rational, and therefore, science's emphasis on rationality is pushing against innate human tendencies (Kahneman 2011). Further, Heath (2014) argues that if scientific research indicates humans are not rational, irrational thinking and behavior becomes acceptable, this facilitates an anti-science position.

Additionally, anti-science ideals represent an unintended consequence of the postmodern, deconstructionist agenda to refute the certainty of Enlightenment thinking. A shift in thinking of science as an objective arbiter of reality able to provide "Truth with a capital T," to recognizing science as a human endeavor influenced by social values and norms, to the radical relativist notion that any "way of knowing" is as valid as any other, has likely caused some people to reject science outright. Latour (2004), one of the architects of the deconstruction platform, argues that the anti-science agenda is a regrettable product of some of his own work and he fears the serious implications this has for the human response to biophysical phenomena. Collins (2014), a leading scholar on the relationships among science and society writes, "If we start to believe we are all scientific experts, society will change: it will be those with the power to enforce their ideas or those with the most media appeal who will make our truths, according to whatever set of interests they are pursuing." This perceived danger in scientific expertise counters the Enlightenment ideal that broad access to knowledge would bring social justice.

We propose that the anti-science position is also a reaction to a perceived broken promise that science could and would solve broad social issues and reduce or eliminate risk from unpredictable biophysical events. Solutionist thinking and language continue to suggest that solutions, with their concomitant certainty and stability, are possible. Yet science has not delivered permanent solutions: biophysical events continue to occur and this causes people to reject science because it is not infallible (Prothero 2013). Of course, perceiving science as a monolithic practice that can make claims of certainty far into the future is problematic. It is not the role, purpose, or ability of scientists to ensure such certainty (MacFarlane and Ewing 2006; Shrader-Frechette 1993).

While Enlightenment thinking promoted a false barrier between humans and our biophysical surroundings, it simultaneously prompted a more robust understanding of the planet's long and diverse history and the complexity inherent in biophysical systems, including human evolution within those systems. Science, as a way of knowing, is profoundly powerful. We argue that relinquishing the solutionism paradigm for addressing wicked problems will require more scientific work, not less. Embracing complexity will require exploring biophysical systems more deeply, while simultaneously and explicitly situating humans within those systems. A nonsolutionist approach requires rethinking social expectations of science and scientists in ways that recognize the knowledge science can generate but does not conflate that knowledge with a normative role for making, what are at root, social decisions.

As several notable cases show, the lines between being a practicing scientist and an advocate for social and political change are blurring. For instance, Amory Lovins, a physicist by training, is also director of the Rocky Mountain Institute, a think-tank for renewable energy technologies and policies, and he openly advocates for "soft energy paths" to reduce reliance on fossil fuels. Nonprofit groups like the Union of Concerned Scientists are dedicated to protecting free speech for scientists and the ability to demonstrate the validity of their research. Government-funded science may conflict with government interests, and scientists who present research that challenges these interests, are accused of "politicizing science," by which critics mean that by introducing explicit policy recommendations, particularly those at odds with orthodoxy, scientists undermine the objectivity of scientific research and applications. However, these explicitly political calls from scientists also challenge solutionist thinking by laying bare the human, and therefore, the inherently social and political complexity of wicked problems.

The Book

Writing this book began with a serendipitous reunion of the authors at a professional conference. As we filled in gaps in our knowledge about each other's work since our last meeting, we quickly discovered that although our individual research areas are diverse, we struggled with similar overarching questions. Specifically, we all recognized in our own work the complications inherent in continuing to try to segregate people and our economic, social, political systems from the reality of the biophysical world in which those human systems function. We also all recognized the power that language holds in framing any issue. We quickly realized that because we all reached a common point by taking different paths, developing along the way particular questions about solutionist thinking, we likely had ideas worth further exploring. As we framed the book content, we recognized that others were addressing parts of our argument from their own diverse directions and disciplines. This offered yet more support for our sense that the timing is right to engage more deeply with environmental realism and more specifically with the idea of resisting solutionism in language and practice.

In keeping with our premise that complexity is key, the text that follows is at times complicated by limitations of language and diverging intellectual approaches. Throughout the writing process, the authors experienced quandaries arising from cross-disciplinary co-authorship. We determined to embrace these difficulties in order to challenge traditional ways of doing scholarship, including customary forms of interdisciplinary work. Perhaps the most trying hurdle in writing has been that the four of us do not fully agree with all components of this text. We agree with the core premise but differ in the details. The established scholarly tradition in which we work makes it intellectually difficult to put one's name to ideas that one did not put forth. However, we wanted to do more than create an edited collection. Rather we engaged in the process of exploring an idea through collaborative writing, with its many accompanying conversations, revisions, and ideological experimentations. Accordingly, we do not claim full consensus but have worked to incorporate our different ideas into one document. At times our individual voices will shine through. Some examples have multiple perspectives and greater depth; others introduce an idea and offer references that readers can follow to explore at length. In sum, our purpose is not singular or goal-oriented, but we aim to explore the origins of solutionism and its manifestation in the current moment to find ways forward.

Secondarily, we struggled to write about solutionism without using solutions-based language. Because we strove to choose our words precisely, at times our language feels tortured. We recognize this and ask our readers to similarly recognize that even in writing about solutionism as a concern, we struggled to escape the limitations of language. In drafting this book, we encountered numerous examples where others also seemed to struggle. For example, several books about wicked problems do define such problems as being intractable, without definitive permanent solutions, yet use the word "solve" in their titles: *Wicked Problems: Problems Worth Solving* (Austin Center for Design); *Wicked and Wise: How to Solve the World's Toughest Problems* (Watkins and Wilbur 2015); *Wicked Solutions: A Systems Approach to Complex Problems* (Williams and Hof 2014). Reducing and revising the self-referential language of problems and solutions is foundational to creating a positive reinforcing condition, but even as there is increased attention to the problem-solution-problem cycle and the concept of wicked problems, the idea and ideal of "solutions" as feasible and desirable remains prevalent.

In challenging solutions, we are not suggesting that those engaged in making decisions do not see the immediate complexity of any environmental issue. What we suggest is that even with such acknowledgment, the focus is often on how to solve a problem without recognizing the history and future implications of defining something as a problem and subsequently seeking a solution. We suggest that despite recognizing the ratcheting structure of the problem-solution-problem cycle, there is an ingrained worldview, especially perhaps in industrialized societies, which seeks solutions and often ignores the complex interrelationships among human perception and biophysical realities. We seek to invigorate an idea that political scientist Wildavsky (1979) put forth more than three decades ago, "Instead of thinking of permanent solutions we should think of permanent problems in the sense that one problem always succeeds and replaces another. Then we might ask whether today's answers are more moral or more effective than the solutions they succeeded or which they might replace."

To explore Wildavsky's idea, we pursue two guiding questions:

> What do contemporary society's solutions-based thinking, language, and history imply or promise when applied to biophysical systems (i.e., the environment)?
>
> How can "challenging solutions" redirect thinking, language, and action toward a more sustainable future based in environmental realism?

We offer the examples of managing rivers, microbial diseases, and nuclear energy/waste to illustrate the breadth and depth of the issues instantiated in promoting "solutions" to what have been labeled as "environmental problems." We conclude by highlighting examples of linkages among language, thought, and action that suggest a positive shift away from solutionist ideals. We further draw from recent developments in science, especially macroecology, evolutionary theory, and complexity science that lend support to our thesis and point to new avenues for thinking about human interactions with the world in which we are embedded. There is not, however, any singular way forward. We offer no solution to solutionist thinking.

CHAPTER 2

River Management and Restoration: Addressing Yesterday's Solutions

Abstract *Homo sapiens* have always managed water to satisfy perceived needs and desires. Human history is also a history of the effort to contain and control rivers, and hence this history is rife with examples of the problem-solution-problem cycle. River improvement programs in the nineteenth century are connected to flood control concerns in the early twentieth century, which are subsequently related to river restoration efforts in the twenty-first century. In each era, problems have been defined and subsequent "solutions" implemented, too often with little regard for the reality of how rivers function over both short and long temporal and spatial scales.

Keywords River improvement · Flood control · Dams · Restoration · River management

Homo sapiens have always managed waterways to meet their needs and desires. Rivers offer water necessary for life, provide transportation corridors, and deliver rich soils for growing food. It is no mystery why humans have consistently settled near rivers. The long history of human efforts to control river flow, to harness that flow for diverse uses and to prevent flooding from destroying the human built environment has made rivers into what archeologist Edgeworth (2011) calls "entanglements of nature and culture." Edgeworth writes that rivers have an archeological past as

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well as a hydrologic past and their use and their management has long been "fully embedded in everyday industrial processes and domestic activities—interwoven into the very fabric of economic and cultural life."

Rivers represent possibility. Rivers capture our imaginations. Their very names—Nile, Congo, Thames, Yangtze, Mississippi—conjure diverse images and sensations. Rivers flow prominently through the nature writing genre and in books with titles like *Writing on Water* or *The Gift of Rivers*. Humans across culture and time often show a preference for landscapes and settings that include water features (Orians 1998; Ryan 1998). In a project called the Most Wanted Painting, Russian artists Vitaly Komar and Alex Melamid survey people around the world about their aesthetic preferences and use their responses to create an "ideal" painting for a particular country. All but one of their 15 paintings include a prominent water feature and the single exception is an abstract painting with a prominent swath of blue in it (Komar and Melamid 2016). It is not surprising that images of a burning Cuyahoga River helped catalyze the modern environmental movement by making widely and publicly visible the negative effects that humans can have on river ecosystems. We, *Homo sapiens*, are inextricably entangled with the rivers that sustain us and our way of life. We therefore simultaneously desire to control and to protect rivers.

In their respective historical treatises, Solomon (2010) and Fagan (2011) provide rich descriptions of the indelible role that water has played in enabling human civilization to flourish. The history of water and river management is a history of the problem-solution-problem cycle as well as a history of linkages among science, technology, and biophysical systems. *Homo sapiens* have consistently employed ingenuity and technology, from simple scoops to massive dams, to assure access to water and harness water's power to meet human needs and desires. This coupling of intellect and tools to control water contributed to the advent of agriculture, which was a milestone in the evolution of the human relationship with biophysical processes. By 4500 BCE irrigation-based agriculture was well established in Mesopotamia and Egypt. Extensive systems of dikes and canals shifted floodwaters onto crop fields. The first known large-scale dams had been constructed on the Nile by 3000 BCE. These provided both flood control and a consistent water supply to be used for irrigation. Reflecting the Malthusian-Darwinian Dynamic, as humans became a more settled species with a consistent food supply, the population expanded rapidly, requiring yet more focused attention to contain and control water.

Politically, the ability to manage water led to centralized, authoritarian states structured around the ability to produce agriculture at a large scale. As humans managed rivers, they forged a long and deep relationship among politics, economics, and social systems.

Rivers provided early forms of industrial scale energy to mill grain, operate tanneries, run sawmills, and to generally power Europe's Mechanical Revolution of the eleventh through thirteenth centuries. The need to ensure that rivers could support economic and political interests is one of several examples historian Deborah Harkness (2007) offers for how science and technology promoted national welfare in Elizabethan England. Harkness writes that an idea analogous to contemporary "Big Science" was already prevalent in the sixteenth century and was made manifest through letters patent awarded to inventors and discoverers, including one to George Cobham who offered an instrument to deepen waterways and remove built up silt and sewage that prohibited navigation. Ensuring that British harbors remained open and rivers remained navigable helped maintain an empire where the sun never set. In modern history, public policy discussions about massive engineering projects, like the St. Lawrence Seaway and the Suez and Panama Canals have continued to focus on the economic and political value of controlling waterways. Other efforts, like dam building and flood control, have added reducing risk to people and property to the value of river control measures.

Humans have impressive ingenuity and persistence in their attempts to control and contain rivers and have been quite successful over short temporal and spatial scales (e.g., controlling floods of a prescribed height on a specific river reach), justifying Edgeworth's (2011) characterization of "entangled" biophysical and cultural systems. Over longer-term scales, however, rivers are fully subject only to their own physical phenomena of flow. Hence, floods and drought remain vexing concerns for humans. A long-term quandary of river management is that human attempts to control or contain rivers have generated a ratcheting effect in catalyzing new problems. Irrigation technologies produced more food, which prompted population increases of people who expect more, cheaper, or higher quality food, increasing the need for more land and water for agriculture (Defries 2014; Solomon 2010). Draining river bottoms (wetlands, swamps) reduced water borne disease and offered rich land for agriculture, but also increased flood heights as the river's ability to absorb increased flow had been reduced. Flood control protected homes, farmland, and businesses, and therefore, more people settled in floodplains, which subsequently resulted in more damage when flooding did occur, prompting calls for greater protection, generating an increased sense of security until the river's flow again overwhelmed attempts to control it (Pinter 2005; Freitag et al. 2009).

Most pertinent to this book, these actions have had significant effects on the ecosystems, including altering flow regimes with subsequent impacts on habitats and aquatic species. In the twentieth century, the paradigm shifted from calling on science and engineering to "improve" rivers, contain floods and control flow, to calls for science and engineering to develop methods to "restore" rivers to mimic less-controlled channels and flow regimes. Of course, invoking a human action to "restore" a river to a less controlled state is still an effort at controlling how the river functions and perfectly demonstrates the intractability of wicked problems.

Flood Control

Following the historic lower Mississippi River flood in 1927, which covered 28,000 square miles, killed more than 200 people and left almost a million people homeless, there was an intense demand to solve the problem of flooding on the great river. A resolution from the American Bankers Association stated, "the control of the Mississippi River is a national problem, should be solved by the nation, and that, cost no matter what it may be, should be borne exclusively by the nation" (Barry 1997). In June 1927, 150 Congress members and state governors attended the Chicago Flood Control Conference to generate momentum for a bill to support flood control of the Mississippi River (Barry 1997). Embedded in ensuing debates about controlling this single river was a fundamental discussion about the federal government's responsibility for protecting people and property on all rivers.

Discussions about flood control echoed deliberations a century earlier about the federal role in "improving" rivers for navigation. A leading cause of steamboat accidents in the US was "the river's natural hazards, especially the snag" (Paskoff 2007). Snags (and variations "sawyers" and "planters") are uprooted trees in a river's channel. Other hazards include shoals, rapids, ice, and rocks. As river transportation gained economic import, reducing risk to boats and their cargo became a focal point for public policy. The result of these debates was federal investment in removing natural hazards from rivers, which did improve conditions for riverboat traffic. The debates also represented a naïve and overly simplified expectation of human ability to solve problems related to river systems. It reflected a thoroughly anthropocentric view as well as "a type of conception that was already becoming established in scientific, business, and increasingly, government circles. A problem, once identified, described, and appraised necessarily would yield before the determined application of machinery and manpower, both guided by a complete faith in the triumph of the instruments of progress over nature" (Paskoff 2007).

Along with improving rivers for navigation, nineteenth-century public policy promoted draining wetlands to enable more settlement and increase agriculture. By the turn of the twentieth century, draining wetlands was also seen as a public health issue to reduce the risk of diseases including malaria and yellow fever (Willott 2004). With a focus on economic progress and human health, communities embarked on "swamp" draining programs, which were highly successful in opening land and reducing disease. They also, of course, catalyzed a new suite of problems. The wetlands were habitat not only for disease-causing life-forms but also for a diverse array of plants and animals. The wholesale loss of these habitats rapidly altered the ecosystems and imperiled many species. Wetlands are often highly integrated with river systems, and they hold and slow down water during high flow events. Draining these "swamps" reduced a river's ability to handle increased flow, and consequently, flood water speed and height increased in many places.

The push for flood control in the twentieth century built on the success of nineteenth-century river management "solutions," which had solidified a belief that humans could and should employ science and technology to contain and control biophysical systems to reduce risk to property and people. The perceived need for flood control was directly related to the successes of river improvement and wetland drainage because improved navigation plus more accessible land encouraged increased economic development along rivers. Subsequently, more structures and people occupied floodplains, which were then threatened when rivers rose, an iconic example of the problem-solution-problem cycle.

Partially in response to the 1927 Mississippi River flood, the Annals of the American Academy of Political and Social Science published an issue in 1928 dedicated to Great Inland Water-Way Projects, including the Mississippi River flood control and Boulder Dam project (now Hoover Dam). In more than a dozen articles by prominent scientists, agency heads, and politicians, the issue featured arguments concerning a federal role for more intentionally and intensely managing the nation's waters. In discussing how to control flooding, a leading engineer reported that at a meeting of the American Society of Civil Engineers, "there was presented the embarrassing spectacle of engineers of national reputation and long experience proposing widely varying and conflicting solutions to this great problem. The reason for this conflict and confusion is that no one is in possession of the facts" (Morgan 1928). The general sense of his article is that once decision-makers had the "facts" the solution would become obvious. This epitomizes solutionist thinking with expectations that science and engineering can fully understand biophysical processes and subsequently control them.

In 1927, the US Chamber of Commerce appointed a Committee on Mississippi Flood Control to study the problem of flooding. This Committee reported that their focus had been on "arriving at 'a program which will insure, so far as is humanly possible, a permanent solution' of floods of the Mississippi River" (Delano 1928). Further, the report stated that "the highest engineering talent in the country" was unanimous in its presumption "that adequate control of the Mississippi River is practicable." In arguing for constructing the Boulder Dam, Davis (1928), a former head of the US Bureau of Reclamation and nephew of Colorado River explorer John Wesley Powell, wrote that shifting the Colorado River from a "natural peril to a national asset" was simply a problem of water storage. A representative of the California State Railroad Commission concluded that controlling the Colorado River would mean that Imperial Valley, "a valley made up of sturdy pioneer stock of Americans, will be freed from the ever present menace of destruction by flood" (Seavey 1928). The language and tone of these entries reflect an idealistic acceptance of reductive logic whereby narrowing the focus to some specific aspect of a biophysical system made a science-derived solution seem obvious.

While a few articles questioned whether waterway management was a federal responsibility, the prevailing attitude and language in the Annals articles reflected a sense that because river control was deemed "practicable" and permanent, but represented a large scale, cross-state endeavor, it warranted a federal investment. While none of the authors questioned the inherent solutionist position that humans could manage and control rivers, they did debate details about *how* to manage. Although they did not label it as such, both Sherman of the US Forest Service and Pinchot, a former head of the Forest Service, argued for a watershed approach to managing rivers. Pinchot (1928) strongly opposed the "levees only" policy in place at the time for flood control. He wrote, "In establishing control of any stream or any river system for flood prevention or any other purpose, every useful and available means of establishing such control, including levees, spillways, soil conservation, forest conservation, storage reservoirs, and any others, should be considered and made use of to the fullest practicable extent." Pinchot concluded that "The essential thing is to make use of the best we have in knowledge, experience, and achievement and to learn from the blunders of the past how to avoid falling into the same pit." Sherman (1928) focused on reforesting land, which "should never have been cleared" as a component of flood control measures. In hindsight, it is clear that Pinchot's "blunders" of the past were implemented as solutions to previously perceived problems. For example, some of the lands that Sherman references were cleared in the name of river improvements for navigation. Trees along rivers were felled to prevent them from becoming snags (Paskoff 2007). Cleared land often increases erosion and runoff rates, presenting greater flood risk, further contributing to the problem-solution-problem cycle.

Like Enlightenment language and intent, which lost its broader social implications in favor of reductive, science-driven "solutions," a more complex understanding of the watershed role in river function was lost as engineering-based management dominated discourse and action. This history reflects the division between the human ability to solve tame problems, and the impulse to conflate that ability with attempts to solve wicked problems. Designing and building a dam to control when and where water is available, for example, is a tame problem, and engineers long ago mastered this task. Using dams to fully and finally control a river in hopes of permanently solving human-derived problems, however, remains impossible because it ignores the biophysical reality of rivers and the problem-solution-problem cycle of wicked problems.

The siren call of certainty, stability, and normalcy and the subsequent promise of less risk prompted government agencies and private landowners to drain wetlands, build dams, levees, spillways, and other features on a large scale, all attempts to control and contain rivers throughout the world. In the short term, these structures have reduced the incidence of disease and protected millions of acres from floods as well as provided drinking water, energy, and recreation facilities to human communities. These actions, however, have simultaneously generated significant social and economic impacts, many of which were not predicted or were underestimated.

Echoing ancient history, large-scale river management efforts in the twentieth century, especially dams, fundamentally changed the global political landscape including helping some poor countries to develop more rapidly and helping communist countries to challenge western democracies (Solomon 2010). He further explains, "Dams transcended political or economic ideology. Whatever the system, dams meant prosperity, more stable societies and greater governmental legitimacy." Solomon continues, noting that between 1960 and 2000 "world hydropower output doubled, food production multiplied two and a half times, and overall economic production grew sixfold" (Solomon 2010). Postwar Japan rebuilt its economy through hydropower. India and China fed their explosive populations through dam-enabled irrigation and Soviet dam building enabled it to become a superpower. Most pertinent to this book, these river management practices have contributed to significant changes in river-based social, economic, and ecological systems around the world, which have subsequently prompted increased attention to the negative consequences of historic practices.

Restoring Rivers

As this latest revolution of the problem-solution-problem cycle turns, there is now a multibillion-dollar-a-year industry in river restoration targeted at solving "environmental problems" emanating from human attempts to control and contain rivers. Romantic sensibilities about "nature" and its "wildness" prompt positive reactions to the idea of restoring rivers to redeem ourselves. Additionally, the swell of support for restoration revives histories of river management centered on restoring economic prosperity. The idea of restoration has been variously defined and applied since the 1800s. In Britain, in 1871, the House of Commons heard appeals to "restore" rivers polluted with effluent from woolen manufacturers and authors in nineteenth-century publications promoted "restoring" rivers and their fisheries (Royal Commission on River Pollution 1871; Ffennell 1872; The Naturalist 1872).

These early calls for river restoration focused on restoring the economic value and productivity that had been lost due to poor water quality. By the late nineteenth century, coal and lead mining were known to contaminate water, which had both health and economic consequences. In fact, there was so much residual mined material in some waterways that the rivers themselves were being mined to recover this material. This generated a sub-industry that was then threatened by calls to restore the rivers (BMJ 1873) to their original, more economically productive state. By the early twentieth century, people invoked restoration as a flood control measure, specifically to remove accumulated mining waste that had modified river flow, increasing flooding in some areas (Pitkin 1956).

Interestingly, some authors suggest that the idea of ecologically based river restoration was contemporaneous with calls to fully control and contain river systems (see Sopper 1966; Riley 1998; Roni 2005 citing Tarzwell 1934). These seemingly contrasting ideas do share at their root, a belief that science can achieve a desired change, whether it be "restoring" a river to some past, idealized condition or "controlling" future conditions. As ecological concerns gained prominence in the mid-twentieth century, dominant ideas about restoring rivers changed. Contemporary usage typically implies applying science and technology to "fix" any perceived concerns with river condition. The underlying philosophy is that science-driven action can atone for past ecological sins. This powerful belief energized much of the 1970s' environmental movement. In an interview reflecting on the early days of the US Environmental Protection Agency, William Ruckelshaus, the agency's first administrator, lamented the naiveté of the time. "We thought we had technologies that could control pollutants, keeping them below threshold levels at a reasonable cost, and that the only things missing in the equation were national standards and a strong enforcement effort. All of the nation's early environmental laws reflected these assumptions, and every one of these assumptions is wrong . . . " (Lewis 1985).

The shift toward restoration continues, however, to rely on equally erroneous assumptions. As an extension and modification of previous goals to control, restoration ironically attempts to make humans invisible. Faith in restoration implicates humans as the causal agent in generating perceived negative ecological change and simultaneously perpetuates human hubris that we have the capability to contain or control biophysical processes with only narrowly prescribed human needs as the end goal (Eliot 1997). Further, restoration presupposes that humans can control rivers in a way that reflects an uncontrolled system, and thereby atone for previous control efforts that are now perceived as damaging. This hope for redemption is reflected in definitions and descriptions of restoration, which often invoke the words "original" or "historic" or "predisturbance." For example, in 1992, the US National Research Council's definition of river restoration was "reestablishment of *predisturbance* aquatic functions and related physical, chemical, and biological characteristics" (emphasis added). In 1990, the Society for Ecological Restoration defined restoration generally as "the process of intentionally altering a site to establish a *defined, indigenous, historical* ecosystem ... " (Langston 2006, emphasis added).

Assuming that society should, and expecting that it can, redress ecological change is problematic on many levels. First, the verb "to restore" is defined as looking back, looking to the past. The idea of "restoration" suggests that humans can know what a river looked like and fully know how it functioned at some point in the past. Second, restoring implies that society can and should somehow recreate a version of the river's former self (Hilderbrand et al. 2005). As Langston (2006) notes, there is an irony in using "human labour to erase the physical evidence of human labour." The nostalgic language creates a tension between a perceived need and desire to improve river conditions, and the reality that humans cannot manipulate the space-time continuum to recreate a past version of the river. This is not to suggest that addressing river quality is not a valid societal goal. The point is to accept the reality of dynamic biophysical systems and to use more accurate, less romantic language in characterizing both the river and the human effort that has helped shape that river.

As attention to the idea of restoration has evolved, so has attention to the problematic nature of the word and what it implies. In fact, there are more than 30, sometimes contradictory, published definitions of the term (Wheaton et al. 2006; Shields et al. 2003). Definitions have evolved to reflect a greater complexity, but they continue to rely on the idea that there is some ideal former state for a river to be in and that humans can create (or re-create) that desired state. As scholars have recognized the complexity inherent in the idea of restoration, their reaction has been to parse language to try to be more specific about how a particular term and its affiliated actions align. The scholarly literature now recognizes restoration, rehabilitation, preservation, naturalization, enhancement, reclamation, creation, and mitigation as parts of a larger whole focused on addressing perceived river management problems (see Shields et al. 2003).

Changing definitions reflect evolving ideas and by 2002 the Society for Ecological Restoration had modified their definition of restoration to "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed." The European River Centre defines river restoration as " ... action that restores the natural state and functioning of a river system." Much of the romantic language invoking some idealized state of origin has been eliminated from contemporary definitions, although the etymological associations remain. Despite this attention to language and its implications, contemporary texts prescribing applied methods for restoring rivers rarely include any history of the idea of restoration nor do they discuss what the concept implies (a notable exception is Riley 1998, with an excellent chapter on the history of restoration). Rather, in most texts, restoration is simply accepted as "good" and is presented as the dichotomous antidote to human-induced degradation (see as examples Petts and Calow 1996; Ostfeld and Tyson 2005; Darby and Sears 2008). The contemporary emphasis on restoration continues the long tradition of conflating tame and wicked problems by narrowing perceived problems such that solutions (i.e., restoration) do seem apparent.

The notion that through science and technology humans can restore a river in the same way they might restore a car or a painting or a building perpetuates the mythology of human dominance and the quest for certainty. Unlike a building, painting, or car, however, a river is dynamic and there is no snapshot in time that captures what it *should* be like. There is also no point of origin when a river was fully formed and brand new. With or without human intervention, the river (and associated biophysical systems) would be different today than it was yesterday, different than it was 100 years ago, different than it was 100,000 years ago. If it were feasible to recreate a past version of a river system, which past version would we choose? For instance, research shows that in New England, what had been interpreted as "natural" stream physiology was actually the result of hundreds of mills placed in waterways in the seventeenth and eighteenth centuries (Walter and Merritts 2008). Two centuries later, these rivers were "restored" to a colonial-era condition created by humans. Further, prior to the colonial era mills, American Indians modified these rivers as had beavers. Before there were humans or beavers, geomorphological processes modified these rivers–entangled systems indeed.

Dam Removal

Dam removal represents an increasingly popular river restoration technique for communities and advocacy groups. As already established, throughout history, humans utilized dams to "solve" all manner of perceived problems, from providing a stable drinking water source, to controlling floods, and to feeding an increased energy demand on an ever-expanding scale. These dams have subsequently catalyzed a new generation of problems, including displacing people, prompting a misplaced sense of security for those living or working in the floodplains, and altering ecosystem functions. This latter concern has prompted numerous individuals and groups to call for dam removal as a restoration measure.

Within a century, humans have shifted from considering dams to be a long-term solution to a variety of water management issues to recognizing that the dams generate their own set of concerns. Proposals for dam removal promise that the projects will replenish, restore, renew, and/or redeem rivers. Language about dam removal resonates with Romantic nostalgia. For example, the Sierra Club website about the Hetch Hetchy dam in California includes the subhead "time to redeem a historic mistake" and the International Rivers website offers dam removal as one of their primary "solutions" for restoring a river: "The complete dismantling of all physical barriers to stream flow is the only way to fully restore the natural flow of the river, including peak flows and seasonal flooding."

The rhetoric surrounding dam removal also commonly invokes a Romantic ideal of sublime wilderness. Individuals and organizations seeking dam removal call on agencies to "free" their selected river (e.g., Free the Rogue or Free the Snake). The largest dam removal project to date occurred in 2014 on the Elwha River in Washington State and is described on the US National Park Service web page as "A River Gone Wild" in large type, followed by the statement "The Elwha River is transitioning from its dam-bound era to a river wild and free." The nonprofit American Rivers website declares the Elwha "(Re)born to be Wild." The shift in emphasis from controlling rivers to now allowing them to be "wild" is a shift in language. These claims of "freeing" rivers, however, rarely recognize the human component of dam removal, including that the dams may no longer be serving their intended human-oriented function or may pose a safety threat. The reality is that dam removal is simply another form of river management and does not return the river to some pre-managed, "wild" condition.

Some academic and interest group literature does recognize the complexity inherent in dam removal. International Rivers acknowledges that modified dam operation, rather than complete removal, can contribute to improved river conditions. The River Alliance of Wisconsin encourages anyone thinking about removing a dam to consider the environmental, economic, engineering, and social concerns related to the dam and its potential removal. Further, they highlight the complex relationships among these cultural forces (Lindloff et al. 2000). Much of the dam removal language, however, strongly perpetuates Romantic sensibilities, solutionism ideals, and a lack of attention to the dynamic reality of any river.

The prevalence of the prefix *re*—to suggest a return to some former, preferred (i.e., "natural") state and the insistence that these rivers are now "wild" and "free"—too often dilutes the more complex reality. First, much of the discussion surrounding dams and their impacts ignores that dams are not solely human phenomena. Earthquakes, rock slides, and volcanoes can dam rivers. Fallen trees can dam streams. Beavers dam rivers. These dams also affect the surrounding ecosystems. Over time, these dams may be removed with or without human assistance, and again, the surrounding ecosystem is changed. More salient, however, is that the language used to describe removing human constructed dams ignores the reality that human action cannot remake the river into what it was before it was dammed. Further, the river would not be today what it was before damming even if it had never been dammed.

The dam removal rhetoric also frequently submerges the potential for dam removal to catalyze future problems or re-create previous problems for human society. If the dam was providing flood control, then properties in the floodplain will once again face a higher risk of flooding—as they did before the dam "solved" the flooding concern. To address such possibilities, there are significant efforts made prior to any dam removal to lessen downstream impacts, which may include installing levees or dikes to provide continued flood protection. This fundamentally challenges any notion of a "wild" river. Further, removing a single dam from a river that is dammed multiple times ignores the complexity of watershed scale functions. While human efforts to control and contain rivers routinely focus on a subset of the watershed, the river functions throughout its watershed. Removing dams upstream will potentially have unintended downstream consequences. Efforts to remove dams lower in the watershed may be less successful in meeting their goals because of remaining upstream dams. Yet the dominant message in proposing and implementing dam removal is that environmental problems can be and have been fixed or solved. These rivers, however, remain highly managed with or without dams and their biophysical processes will continue to function with or without dams.

Restoration in Practice

While some scholarly literature critiques the idea and the language of restoration, actions attempting to restore rivers to some preferred state continue to proliferate, and practitioners continue to employ language that explicitly or implicitly invokes both a Romantic ideal for rivers and a perceived scientific basis for "fixing" rivers. River restoration provides an excellent example of directing focus away from the messy social, economic, political reality of living with dynamic biophysical systems. While causes of river change/degradation are often understood, applied action is not routinely aligned to address those causes. As the European Centre for River Restoration website fully acknowledges, "The widespread decline in river habitats across Europe has resulted from river engineering activities and the alteration of rivers and their floodplains. These activities have been in response to changing landscape activities as a result of industrialisation, urbanisation and intensification of agriculture." As modern societies build a world that aims to meet their imminent needs and desires, they broadly impact land surfaces, air quality, and water.

Clearly, the causes of river degradation happen throughout a watershed; yet, most restoration activity, especially in more urban settings, occurs directly in or near the river and/or its riparian area (Bernhardt et al. 2005; Alexander and Allen 2007; Christian-Smith and Merenlender 2010). The most common restoration practices include altering channel conditions as an attempt to mimic a less controlled flow regime, sloping and vegetating stream banks, and constructing wetlands. Such efforts do not address watershed-scale phenomena, such as population growth and land use change with its concomitant stormwater runoff, which are recognized as root causes of river degradation.

Stormwater provides an excellent example of both the problem-solution-problem cycle and the misalignment between management actions and known causes of negative impacts. In the late twentieth century, stormwater management systems were typically designed for flood control, with the goal to shunt water off the land and into the nearest stream as quickly as possible (NRC 2009). Water from throughout a watershed was guided, often through pipes, directly to rivers. This caused increased stream temperatures, stream flashiness (i.e., rapidly rising flow), and in some cases increased sediment loads, all of which have negative impacts on stream quality. Current thinking in stormwater management focuses on keeping water on land to slow its flow and reduce its temperature before it enters a stream, much like the floodplains and wetlands would have done prior to being drained and paved. Because all water flows down, stormwater management presents a challenge because it originates throughout a watershed, routinely crossing political jurisdictions, but the impacts are often most intense at downstream points far removed from the source of the runoff. As already noted, while runoff is recognized as a core cause of river degradation, few restoration efforts focus on managing runoff as a restoration technique.

Floodplains are another site where knowledge and action misalign. Floodplain development continues despite the known ecological consequences and risk to people and property. Following the 1993 record-setting floods on the upper Mississippi River, floodplain development actually increased in many communities (Pinter 2005). News reports following flooding in the UK, in 2016, cited public officials encouraging continued floodplain development to address housing needs, as long as "attendant risks and the possible devastation" from living in the floodplain were made clear to potential buyers (Harvey 2016). Continued floodplain development has downstream implications in terms of contaminated run-off and flood potential, so the risks are wider than just any individual floodplain property owner. Additionally, insurance and public relief programs mean that risks are not borne only by the floodplain property owner, but also by society more broadly.

While communities and organizations spend billions of dollars to "restore" rivers, these same communities support social, political, and economic programs that continue to raise stream temperatures, alter sediment flows, and reduce aquatic habitat. In exploring the myths of the restoration paradigm, Hilderbrand and colleagues (2005) have written,

> Despite our dependence on healthy ecosystems, society has made the decision to continue life as usual until a loss of valued goods and services is realized; then, society will expect and rely on science to clean up the mess *and* make it look natural. Many government policies concerning development and extractive resource use already assume the ability to mitigate ecosystem damage through the restoration of degraded land or creation of new habitats.

The significant debate about the science employed in river restoration further problematizes contemporary river management. A general assumption bolstering the billion-dollar industry is that knowledge about biophysical conditions is employed in designing and implementing restoration projects. The evidence, however, suggests that this is not always an accurate assumption. Most restoration projects have not employed any data about stream conditions and have not assessed if or how the restoration project actually changed ecological conditions (Wheaton et al. 2006; Bernhardt et al. 2007; O'Donnell and Galat 2008). This lack of assessment also means that any negative consequences of restoration activities have not been well documented or publicized. Cockerill and Anderson (2014) conclude that the results of restoration, especially in urban areas, are often positive for the built environment (e.g., managing flooding, reducing erosional undercutting) and often improve the aesthetics of a stream, but are not providing the ecological benefits that those implementing the efforts claim. They argue that promoting these projects as ecologically beneficial creates a "false image" of how a stream functions and what a high-quality stream looks like. This has the potential to limit support for protecting high-quality streams because they are not recognized as such. It also perpetuates the idea that scientists and engineers can simply "restore" rivers once they are degraded, thereby releasing society from the responsibility for being aware of the impacts that humans have in a watershed and the need for consistent river management.

Research into public perceptions about what a high-quality stream looks like further supports the idea of false images. Studies have shown that the public perceptions about the aesthetics of a stream and the characteristics that support good water quality and/or excellent aquatic habitat do not always align. For example, thick vegetation or woody debris, which ecologists suggest contribute to high-quality streams, appear chaotic or messy to many people (Chin et al. 2008; Larned et al. 2006; Junker and Buchecker 2008). Such conditions are interpreted as representing a lack of management, which is subsequently deemed negative (Gregory and Davis 1993; Piegay et al. 2005; Chin et al. 2008; Suren 2009).

A more recent study focused specifically on public perceptions of river quality and a perceived need for restoration. River monitoring efforts demonstrated that the New River in Boone, North Carolina meets established criteria for a high-quality river. Temperatures were consistent and well within the required parameters for native trout, the banks offered significant vegetation for shade and habitat, and the macroinvertebrate populations as well as fish populations were diverse and strong (Swinson et al. 2015). Researchers then surveyed people using a greenway trail along the New River. When asked to rate the river on a scale from 1 to 10 for broad, general statements like, "general environmental condition of this section of the river" or "the 'naturalness' of this section of the river," the ratings were quite high, with the most common response being 8. When asked about specific potential water quality issues like thermal pollution, pet waste, or chemical contamination, about one-third of those surveyed responded "don't know." Despite the generally positive impression and the expressed uncertainty about specific issues, a majority of respondents agreed that the river should be restored (Cockerill 2016). These responses suggest that the public recognizes there may be issues that they cannot see. It also suggests a public acceptance and perhaps expectation that rivers are in peril and even if they cannot see or articulate a specific concern, people do think someone has a responsibility (and presumed ability) to fix them.

Contemporary restoration efforts present a multi-layered example of solutionism. Restoration is promoted as solving environmental degradation issues but is not pointed at root causes and is not rooted in science-based evidence. This is in part because funding for restoration efforts has not routinely included post-project monitoring. Determining project success or failure is based largely on perception or on whether specific restoration techniques were implemented rather than on actual data collection to demonstrate specific results (Bernhardt et al. 2007). Therefore, even if river management were NOT a wicked problem, even if there were permanent solutions available, the current approach would not facilitate a solution to end degradation and address past damage. Yet there is public support for solving indeterminate problems via restoration and a strong presumption that these efforts are scientifically supported. In the case of the New River, despite the evidence that the river was high quality, a $2.5 million restoration project was implemented, potentially further confusing public perception about what high-quality rivers look like.

Our critique of "restoration" is not to suggest that humans should not address activities that are known to negatively affect water availability, water quality, or ecological conditions. For example, attempting to remove harmful materials that were intentionally or accidentally spilled into a waterway is often a good idea. Planting riparian areas is often an excellent (and cost-effective) idea. Removing some dams is definitely warranted. But none of these actions will return the river to some previous state nor will it make a river "wild." Our point is focused on the power of language to create particular perceptions, which encourage particular actions. Our intent is to encourage more careful language to better reflect what is actually occurring. The rhetoric of restoring creates the possibility of atoning for human sins while allowing humans to continue sinning. Why worry about avoiding known harms to rivers if we can simply "solve" any problems through restoration?

The assumption that the people engaged in restoration actually know what the river needs perpetuates the idea that science can, and therefore should be able to, contain and control biophysical processes and be able to "solve" any issues that arise from human river use. At the same time, restoration efforts invoke some impossible return to a state where rivers are "free" rather than managed. The reality, of course, is that rivers are, have been, and will continue to be managed. Current actions, whether labeled as restoration, rehabilitation, or any other term, are simply the latest in a long history of management practices.

The point of this book is not simply to argue for parsing language to be more precise. It is, rather, a quest to use language that embraces complexity and subsequently influences change in social practice. This includes fully acknowledging that restoration, or any perceived "solution," is often addressing actions that in the past were the science and technology-based "solutions" (e.g., tree removal, dams, levees) applied to perceived problems of the day (e.g., irrigation, snags, flooding). Rather than "solving" any perceived problem with river conditions through restoration, we encourage terminology that reflects dynamic systems and concomitant dynamic management. We are never actually, literally, "restoring" a river. We are always continuing to manage waterways to meet human needs and desires, including a desire to have sufficient quantities of high-quality water and functioning ecosystems.

CHAPTER 3

The Human Nature of Infectious Disease

Abstract Infectious disease raises questions about humans' abilities to eliminate harm through the control of nature. People work to understand microbial life in order to manage the ways microbes mutate, adapt, and evolve, even while recognizing organisms' essential nature. Public health practices from the past and present exemplify this ongoing quest to "solve" disease. Eradicating pathogens persists as a public health objective, even as new microbes emerge in the human environment. "Superbugs" and antibiotic resistance exemplify the problem-solution-problem cycle of disease. Moving from solutions-based thinking enables new imaginings of the microbial world in which humans reside.

Keywords Microbes · Disease · Pandemics · Antibiotic resistance · Public health

In the summer of 2014, people around the world watched news reports of a viral outbreak in West Africa and calculated the risk they had of catching Ebola on the New York subway or in their Berlin apartments. In the fall of 2015, media reports began to circulate about a virus borne by a hardy tropical mosquito, which posed a particular threat to pregnant women. News of the Zika virus led to travel advisories and concerns over attending the Olympics the next summer in Brazil. Since the turn of the century, panic over epidemic disease has surged around outbreaks of "swine flu" and "bird flu," SARS and

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MERS, and diseases like West Nile Virus have crept slowly across the globe and into people's daily lives. Politically-rooted concerns that people will deliberately manipulate microbes to harm populations through bioterrorism or biological warfare amplify fears of contracting a transmissible disease. These moments when microbes surge into the public spotlight, evoke solutionist rhetoric from media, politicians, and the public. In a 2016 speech on Zika, US President Obama said, "You can't solve a fraction of a disease. Our experts know what they're doing. They just need the resources to do it" (White House 2016). Such calls for action are grounded in the belief that scientific expertise, given sufficient time and money, will create a solution.

The modern pandemic reminds citizens both that they live in a globalized, technologized world, and that their bodies are vulnerable to organisms that exist outside human control. In response to their fears, humans both try to mitigate the effects of infection upon individual bodies, and to manage how germs move through the environment. Centuries away from the Black Death of the Middle Ages, people still imagine the sweeping devastation disease might have upon human life, a manifestation of cultural fears of nature still understood through the logics of containment and control. These fears drive people to clinics for vaccines and Tamiflu, and to drugstores for facemasks and hand sanitizer. People also turn to science and its agents who work in laboratories to develop technological interventions like vaccines, or to use computers to model and predict how microbes will bring future harm. Government organizations like the Centers for Disease Control and Prevention have become retailers of disease information, a source of knowledge used by both medical professionals and people surfing the Internet in their own homes.

While humans have always lived with infectious disease, scientific study of microbes—beginning with the germ theory of disease, continuing through the vaccine and antibiotic production, and manifesting today in genomic studies of the human body's relationship with microbes—has shaped how people individually and collectively understand disease threats. Scientists' ability to see, study, and explain how pathogens infect bodies seems to hold the promise that infection can be contained and controlled, "solving" the infectious disease problem worldwide. Vaccines, along with the origination and marketing of products like Clorox and Penicillin, generated the belief that with the right knowledge and subsequent application of modern technologies, humans might be able to manage the organisms in their environment that put them at risk of contracting a disease. Thus, as soon as scientists identified microbes as a cause of disease, people called upon the science industry to solve the problem of infection, including eliminating microorganisms that threaten human life. The scientific production of microbes has enabled solutions-based thinking about human disease.

The promise that infectious disease could be eradicated through vaccines and antibiotics has not manifested and instead exemplifies how the problem-solution-problem cycle generates a series of unanticipated consequences. This case study explores the power of the promise of disease control, revealing ingrained cultural beliefs about the human relationship to biophysical systems, as well as the conviction that science can and should solve the "problems" of the human condition without having to acknowledge the underlying social and political values that also contribute to these systemic issues. Examining the contemporary and historical production of germs shows how microbes have been made as a pernicious, invisible form of nature best known through the lens of science. The techno-scientific fixes of vaccines and antibiotics fall short of achieving eradication, and "solving" one health problem generates new problems that demand new solutions, bringing disease control into the problem-solution-problem cycle. The modern antibiotic-resistant "superbug" is a material effect of this cycle.

As disease-causing microbes elide eradication via scientific fix, it becomes increasingly apparent how entwined pathogenic natures are with human behaviors. This has at least two potential consequences for human populations. First, disease eradication may not prove to be for the benefit of human life and society, nor for ecosystem health and sustainability. Evolutionary science ascribes a vital role to pathogens in promoting strength, mutation, and change. Second, recognizing complexity in people's relationship with disease opens the possibility for societies to step away from a solutionist regime of disease control and prevention in favor of practices that recognize that diseases will forever exist in our world and respond accordingly.

The danger of solutionist language and thinking about disease control is the potential for societies to rationalize increasingly militant disease responses based on a belief that the combined powers of science and social governance can control disease to the benefit of greater good. The desire for permanent solutions may overstep vital conversations about ethics, social values, and human rights. The case concludes by considering how public health actions work to govern the wicked problem of disease, demonstrating how disease must be managed, not solved, and how more nuanced understandings of microbial natures and the human relationship to nature open possibilities for more just and sustainable governance and disease management practices.

Creating the Modern Microbe: A History of Disease Control

In September 2014, an editorial in *Businessweek* proposed that the Ebola crisis could only be contained by deploying military forces. The authors painted a grim picture of Ebola in Africa:

> the situation is desperate. Hospitals have become quarantine zones for the dead and soon-to-be-dead . . . Liberia's government is incapable of managing a response; even elected officials have fled the nation. Doctors and nurses have either perished from Ebola or have left the country due to a lack of support and concern for their safety. Amid the collapse of health-care infrastructure, it is only a matter of time before total chaos descends. The number of infected people is spiraling out of control . . . The Ebola crisis is a natural disaster, like a tsunami or earthquake. But unlike natural disasters with limited global consequences, Ebola is perpetual with far-reaching implications. (Brozak and Noronha 2014)

This depiction of unending, nature-induced disaster shapes how social institutions approach and react to pandemics. The apocalyptic language used to describe the disease paves the way for pleas to solve the crisis and respond to a disaster. In 2014, the United Nations Security Council declared unanimously that Ebola was a threat to international peace and security, and the United States pledged military support to establish a "command and control center" (UN News Centre 2014). Governments instituted quarantine as part of a militant effort to contain the spread of the virus. The outbreak of Ebola evoked a global desire to *contain, command*, and *control* (3 Cs) the virus in order to mitigate a new type of global human disaster.

Achieving these 3 Cs demands broad scientific knowledge and social power. The failure to solve disease problems through scientific fixes leads to managing human behaviors in ways that propose to optimize the effects of the technological interventions. At the core of the political response to infectious disease lies a pervasive belief that the spread of germs can be contained and the risk of infection can be mitigated by intervening in the cycles of microbial life. Disease scientists primarily have worked to develop and prescribe "solutions" to disease outbreaks, including technological medical interventions that seem to overcome human political barriers and predictive modeling of disease behaviors that can be used to plan social interventions. Vaccines, antibiotics, and other drug therapies overlie the sociocultural dimensions of contagion and cultivate the idea that individuals are culpable for disease prevention using techno-scientific fixes. The consequences of the belief that microbial nature can be managed exclusively for human health extend broadly into the human social life, creating a wicked socio-scientific problem.

Today, the fear of germs permeates public debates over vaccination and public schools, global travel and airline safety, immigration and border security, and the regulation of science laboratories. In these debates, as well as in abundant social acts to control infection, people present disease as a problem for science and technology to solve. In part, this is because scientists made the modern microbe. Virus and bacteria are unseen in the environment, but science-derived technologies like the microscope render them visible. Microscopes showed the world to be covered with miniscule organisms, generating in humans a desire to understand how those microbes interact with the world around them and affect their lives in particular.

Microbes complicated our knowledge of the world, but even as scientists work to understand and explain the complexity, society demands that they simultaneously control it. The rise of the science and profession of microbiology bestowed authority upon trained individuals to explain what is seen through the lens, including how these organisms cause disease. Because people can see microbes using simple microscopic technology, they legitimize the need for knowledge and the authority of scientists to generate it. Governments and social institutions vest the scientists who peer at microbes with power to interpret the workings of this invisible world for an audience who have quite narrow concerns about the organisms, centering on their own health, comfort, and survival.

Moreover, the work of scientists binds humans to microbes in a biological system that is simultaneously human and nonhuman, and where ever-blurry line renders the differences indistinct. Microbiologists transformed the scale by which life was known and demanded that the notion of nonhuman nature expand to include microscopic organisms. They also showed that these forms of nature could be located within the human body itself, disrupting boundaries between human and nonhuman, and nature and culture. This dissolution of boundaries challenged a human political system predicated on humans as a distinct species outside of nature. Finally, this knowledge of microbes significantly changed how humans understood their own lives and the interactions that introduce death into human life. As a result, not only was the modern microbe brought into existence by science and technology, but the modern human was remade through this knowledge, particularly in terms of risk and the relationship between humans and the world around them.

In the nineteenth century, the germ theory of disease presented microbes as the cause of human illness, supplanting notions that diseases manifest individual moral failing or were contracted through miasmas or "bad air." This transformative theory located the origins of disease in living creatures that could be brought from the environment into the human body to cause harm. Managing disease was less a moral question and more a concern of how to avoid disease-bearing organisms. The germ theory of disease made it possible to mitigate disease by managing unclean spaces, and empowered people to act upon their environment to manage their individual health. By transforming a moral shortcoming into a failure to act, the germ theory reallocated the responsibility for disease control to individuals and public action.

Germ theory also delocalized disease, expanding the scale of threat to include the world broadly, even as a further scientific study showed that specialized environments enable microbes to flourish. If associating microbes with humans transformed human identities, connecting microbes to environments gave humans a new form of responsibility for managing the world around them. This management applied to individual homes as well as communities, towns, and cities.

From the moment the microscope lens rendered microbes, industries of science and technology set about eliminating the disease by sanitizing the environment. Communities drained swamps as a measure of disease control and as part of broader river management plans. Civic sanitation systems offered another technological fix, separating humans from disease-bearing waste. Tomes (1990) argued that the late-nineteenth-century cult of domesticity created the moral imperative for homemakers to maintain high standards of cleanliness, primarily by consuming goods such as ceramic toilets, water filters, and chemical disinfectants. Such consumer products and public health works seemed to bring disease solutions within the grasp of any individual who could afford to consume or community who had capital to build. Even as harmful associations between disease and the impoverished, immigrant, and "unclean" segments of society strengthened, the promise of disease-free living through consumption and cleanliness swept through society, made possible by pinpointing unseen microbes as the originators of disease.

Locating the source of infectious disease in pathogens outside the human body raised questions of how the body itself might resist infection. The proposal that humans have an "immune system" further defined the body as separate from and in opposition to its environment. Immunologists theorized that taking action upon the body itself could create immunity from disease. In the late eighteenth century, Edward Jenner, a scientist working with poxviruses (like smallpox and chicken-pox), observed that people seemed to have varying levels of resistance to disease, possibly due to prior exposure to viruses. He injected healthy humans with fluids from cowpox lesions into dairymaids' hands, and then exposed them to the smallpox virus, a disease that ravaged human society in that era. His test subjects experienced increased immunity to smallpox. This new vaccine technology promised another way to combat disease, by creating human bodies that were inhospitable environments for disease-bearing microbes. Though the earliest vaccinations transferred living matter from one body to another, concoctions created in laboratories facilitated the wide-ranging dispersal of vaccines, spreading hope that disease could be eliminated through a simple prick in the arm. The promise that the application of science and technology could solve the human problem with disease seemed evermore attainable.

Indeed, within two centuries of creating the first vaccine against small-pox, humans had eliminated from nature this disease that killed more than 300 million people in the twentieth century alone (Henderson 2009). The eradication of smallpox, however, also testifies to the role of human cultures in disease management, for though scientists had proven vaccination to be effective in increasing smallpox immunity, containing smallpox required the physical circulation of the technology along with manifold social acts to convince people to be vaccinated. Technology and scientific discovery cannot contain, command, and control, no matter how simple the solution seems. Scientists have developed vaccines for a number of deadly diseases that persist in the population, including measles, polio, whooping cough, and yellow fever.

In part, because disease eradication requires a cultural system that can broadly manage human behavior, disease persists as a wicked problem. Moreover, because microbes are living entities that strive to survive and reproduce, they continually evolve in order to stay alive. New diseases emerge as microbes adapt to survive the assault of the immune system. Like a river continually changing over time which cannot be restored to a singular past moment, the pathogens on the planet that have the potential to harm humans are constantly changing and cannot be targeted at a static moment. Efforts by scientists or technologists to solve the disease problems of the present become outdated as microbes persistently evolve to find new ways to survive on the planet and in the bodies of human hosts.

Furthermore, the social systems that mediate the distribution of vaccine technology disperse its effects unequally through society. The continued experience of polio or measles in poor communities is a problem of social origin, as vaccines have dramatically reduced the occurrence of these diseases worldwide. In the global campaign to eradicate smallpox, health workers realized that distributing vaccines around the globe not only required ratification from numerous nation-states but also social strategies that would convince people to allow foreigners with needles to act upon their healthy bodies. In public controversies over vaccination in the current moment, social systems have again made it easier to blame individuals for disease, now framed as a failure to police oneself against pathogens using the technological fixes provided by modern science.

For example, when a 2014 measles outbreak in California appeared to spread through unvaccinated populations, a UCLA professor argued the event was “100 percent connected” to popular sentiment against childhood immunizations, which had increased the percentage of unvaccinated individuals within the population, saying, “There are some pretty dumb people out there” (Nagourney and Goodnough 2015). The California Center for Infectious Diseases issued statements directly asking unvaccinated individuals to be vaccinated against measles, and county health officials authorized schools to send home students who could not verify vaccination. This governmental response placed responsibility for the health of the population upon each citizen, not only blaming unvaccinated individuals for the outbreak but vilifying their actions and insulting their intelligence. Here, broader questions about global health, economics, and demographics paled beneath debates about individual choices to use vaccinations. Even when officials acknowledge the social and political systems that shape contagion, at the moment disease erupts in a population, the public response tends to focus on individual behaviors like hand washing, public sneezing, and the use of vaccines. Solutions-based thinking connects vaccines to the promise of a disease-free society, without examining the assumptions and politics of the vaccine itself.

Throughout the nineteenth and twentieth centuries, disease science gained credibility because the study of microbial nature led to disease containment, both through sanitation and public health works and the eradication of diseases like smallpox. This science has also brought broader social effects. For example, disease intervention relies upon separation and containment, such as the use of quarantine during the 2014 *Ebola* outbreaks, and the forceful management of environments. These practices materialize a deep-seated belief that the human body separates people from each other and the world around them (Cohen 2009). Not only do we imagine the immune system as a filter to prevent harmful external natures from entering the body, but through disease, we think about interpersonal interactions in terms of risk.

The global response to contain *Ebola* attempted to manage how the virus moved between people by managing people themselves, intervening in centuries-old mourning rituals and scrutinizing traveler's bodies with temperature scanners. Such activities may be rational in the face of death, but must also be understood as the outcome of certain ways of knowing the human-microbe relationship. These actions have consequences in how humans understand their connections to each other and the world around them. To create futures where complex understandings of the human place in the world can operate, we must embrace our bodies as permeable entities that bind us to our biophysical environments and to each other.

Locating the source of disease outside the human body widened a perceived gap between humans and their environment, strengthening the cultural belief that problems can be solved by managing nonhuman environments. As a wicked problem, disease presents complexity because it is so entwined with the corporeal self. Every living body faces "a ceaseless problem of boundary maintenance" (Cohen 2009) as its immune system works to ward off invasions from the world in which it moves. New scientific knowledge, however, overturns the presumption that all microbes constitute a threat and that vaccines can create a perfect barrier against disease.

Research on the complex relations between organisms and their microbes challenges dichotomies of good and bad with new ideas about mutualism, adaptation, and co-survival of species. A century ago, the scientific germ theory of disease created microbes as a primary threat to human health and wellbeing, but scientists have since posited that microbial life contained within the human body is integral to health, and even that individuals are constituted by unique communities of microorganisms, the "microbiome" (Clemente et al. 2012; Shreiner et al. 2015). Consequently, microbes are receiving new scientific and cultural attention as bearers of human life.

Microbes in the Problem-Solution-Problem Cycle

Corporations, government agencies, scientists and medical professionals have presented antibiotics and consumer products that kill germs as science-derived solutions to infectious disease, despite growing evidence that unmoderated use of these agents creates new disease problems. The evolution of antibiotic-resistant "superbugs" is an outcome of the problem-solution-problem cycle of disease control. In the twentieth century, antibiotics provided a miracle-like cure for bacteria-caused infections and were widely used to treat disease. This "solution," however, generated new problems as microbes evolved to avoid harm from anti-microbial treatments. While antibiotics reliably kill bacteria, they also change the worldwide theater of disease, entering a cycle of problems and solutions because the actors on the stage—both human and microbial—are living organisms with the ability to adapt and change. In biophysical systems, the mutable qualities of actors eliminate the possibility for a single, large-scale solution.

Household products and pharmaceuticals with anti-microbial properties provide consumers a seemingly immediate technological fix for the problem of disease. Hand sanitizer, for example, was once used primarily in hospitals but appeared on consumer shelves in the mid-1990s. Effective marketing opened a niche for the glossy gel, and sales grew. In 2002, the CDC reported in the "Guideline for Hand Hygiene in Health-Care Settings" its scientific conclusion that instant alcohol sanitizers were "more effective" for hand antisepsis than antimicrobial soaps, and were better at killing drug-resistant pathogens than soaps and detergents. Such claims in the hands of marketers built public support for using hand sanitizers as a solution to the spread of infectious disease (Owen 2013). Sales climbed steadily for the new product before plateauing in the early twenty-first century. Sales have stayed relatively flat for years, with the notable exception of 2009 during the H1N1 "swine" flu epidemic. Because flu viruses are primarily picked up through the air (spread by coughing and sneezing), scientists questioned the effectiveness of the gel in combating flu, yet sanitizer sales still rose 175 percent during the swine flu outbreak (Fottrell 2013).

In order to be effective, anti-microbial “fixes” to disease problems must be applied in a society on a scale that cannot be matched by the distribution of consumer products. Moreover, product marketing may misrepresent the effectiveness of an antibiotic in preventing individual infection. A product like antibacterial soap may kill germs in a controlled environment, but disease exists in a complex, changing environment with countless unique biological agents. People also have unequal access to consumer products and limited understanding of how these products impact vectors of disease and human health more generally. When the US Food and Drug Administration banned several antibacterial ingredients found in over-the-counter soaps in 2016, they also called for further study of antimicrobial products focusing on how the broad use of these products by consumers, often multiple times a day, diverges from occasional exposure (USFDA 2016). Studies to assess the safety of these products to humans did not anticipate the ways they would be used in practice, and how the microbes targeted by these products would adapt.

While antibiotic technologies offer an effective method for killing pathogens, the spread of these products created new disease problems. Because biophysical systems are dynamic and evolutionary, microbes quickly evolve and adapt to survive. The overuse of antibiotics as an attempt to solve the most inconsequential health problems has fostered the evolution of antibiotic-resistant organisms. Through the process of natural selection, the microbes most resistant to antimicrobial products survive the application of antibiotics and live to replicate their genetic properties in creating the next generation of microbes.

In 2009, the World Health Organization named antibiotic resistance as “one of the three greatest threats to human health,” and the CDC estimates it to cause more than 20,000 deaths and 2 million illnesses in the United States annually (WHO 2011; CDC 2013). These adapted microbes have been named “superbugs,” evoking the evolution of an organism with exceptional abilities, while retaining the negative association with “bugs” and other undesirable creatures. The term affirms our cultural expectation that bacteria will succumb to antibiotics, identifying microbes that resist antibiotics as “super” or exceptional. We expect antibiotics to destroy microbes, and when they do not, the disease problem shifts: now, it is resistance that must be controlled.

When well-adapted “superbugs” survive a perceived fix, new scientific practices or other cultural interventions must again try to mitigate the spread of the newly mutated germ. Recognizing the rise of antibiotic resistance, health workers are reaching out to prescribers and consumers of antibiotics to limit the overuse of antibiotics. This new awareness of unintended consequences of antibiotic use has the potential to ripple into many areas of social life, not only in health and consumer systems but also through food systems, as the prolific use of antibiotics in agricultural systems is a primary influence in the evolution of “superbugs.”

In 2015, the Obama Administration announced the US “National Action Plan for Combating Antibiotic-Resistant Bacteria,” promoting nontraditional therapeutics, probiotics, and an international research agenda. The language of the press release and fact sheet accompanying the plan exemplify the enduring myth that solutions exist: “Antibiotic resistance is a global problem that requires global solutions” (White House 2015). The promise cultivated alongside Penicillin that antibiotics, vaccines, and other scientific interventions would create a disease-free world has subsided as scientists and practitioners consider complexities in the lives of microbes that were previously unknown. This political initiative reaches beyond national politics and emergency events to frame a problem global in scope. Even as a US President asserts a continued pursuit of solutions, the scientific community and public at large have gradually opened up to the possibility that a direct war on microbes may not “solve” disease problems, and indeed may cycle back to create a new equation of disease.

One indicator that the problem-solution-problem cycle has generated new ways of thinking about human-microbial life is the “hygiene hypothesis” first put forth in the late 1980s. Scientists propose that exposure to microbes in childhood is essential to the development of the body’s ability to fight infection (Strachan 1989, 2000). In a discourse eerily echoing Progressive Era class-oriented associations of disease and cleanliness, the hygiene hypothesis argues that the overuse of antibacterial agents in “developed” nations has led to higher rates of asthma and digestive disorders. The high value on cleanliness, first accessible to those who could afford it, then taken up by the government through sanitation and public health projects, effectively sanitized much of the world inhabited by the wealthy. While achieving the goal of disease suppression for a generation, this work may have unintentionally weakened immunity among the populations living in the disease-free environments they created.

The creation of a "healthy" and immunity-producing microbiome during childhood may require exposure to a diverse and broad spread of "friendly" microbes, particularly bacteria and parasites originating in dirt, water, and vegetation. The widespread use of individual and communal technologies to sanitize and "solve" the problem of disease created new problems for people living in a germ-free (or germ-lessened) world. In the last decade, scientists have explored the role of microbial exposure in immunity, spurring a social movement to increase childhood exposure to germs (Olszak et al. 2012). The first-world return to dirt exemplifies the ongoing effort of individuals to manage their own relationship to disease, intriguingly framed in a new global perspective of dirt.

The concept of a microbiome places a peculiar responsibility upon people (including parents of young children) to manage the concoction of microbes in their bodies which will, through replication of countless generations, be with them through life. In books like *Eat Dirt* and *Healthy Food, Healthy Gut, Happy Child*, medical professionals encourage parents to expose their children to dirt—specifically the microbes associated with dirt—through diet and activities, arguing not only that this practice will protect against asthma and allergies in the long run, but also that it can bring physical and behavioral changes in the short term. Managing exposure to microbes, not eliminating them, becomes the work of daily living.

Where once marketers took up antimicrobial science to sell products that sanitized the world from viruses and bacteria, now the market holds a place for products that help users feel like they are cultivating beneficial microbes within them, a marketable solution to the new problem. Spurred by "probiotic" assertions, products like yogurt grew in sales in the early twenty-first century, despite controversy over the immune-producing claims that eventually led to the ban of the term in European marketing. In 2015, probiotics were a billion-dollar industry in the United States, and the world's largest yogurt company Danone sold $2.7 billion in probiotic yogurts (Mitchell 2016). AOBiome, under the brand Mother Dirt, markets a "biome-friendly" body spray that "replac(es) essential bacteria lost by modern hygiene and lifestyles" (Mother Dirt 2016). It seems the probiotic craze is poised to repeat the pattern of the antibiotic craze a century ago, capitalizing upon a new popular awareness of the microbiome to promote the idea that individuals can control the microbes within their body through consumption and behaviors.

Meanwhile, public and private organizations, from the White House to the Bill & Melinda Gates Foundation, have increased funding for microbiome research through the National Microbiome Initiative, spending hundreds of millions of dollars to "develop approaches to reliably alter microbiomes to benefit individuals, communities, and societies" (White House 2016). This initiative particularly directs the study of the microbiome towards social gain, placing foremost the idea that science must study microbes primarily to understand how they benefit humans, an idea that assumes both human centrality in biophysical systems and the ability of humans to control microorganisms. The 3 Cs appear as reliably in discourses about managing "good" microbes as in battling "bad" ones. Aside from pandemic events like Ebola, the nuanced understandings of the human relationship with disease are growing, but the belief persists that humans can alter nature wholesale to a perceived human benefit without cycling around to further problems and desires for solutions. Defining disease control as a human problem necessitates recruiting citizens to respond. While individuals bear the primary responsibility to govern their biological and social selves to promote healthy human-microbial systems, when scaled up to the level of society, disease control becomes the work of nations and governments.

Scales and Cycles of Disease

Although disease is experienced by individuals, it is also calculated on larger scales. A disease can be calculated at the scale of a population: the number of cases of infection among otherwise healthy bodies. This number fluctuates as new infections take place and other bodies recover from illness, but even as individuals heal, the disease remains present in a population. Still, disease is never omnipresent within a population; it continually ebbs and flows geographically and temporally. Because disease exists on global, national, and communal scales, citizens ascribe responsibility to contain, command, and control to the social institutions they establish to govern collective life. Then, because liberal citizens have the right and responsibility to govern their social interactions as they relate to the risk of contracting a disease, they join in the work of disease control, becoming willing participants in upholding the social good.

In the twenty-first century, the fluidity of microbial disease compounds with the continually evolving nature of microbes and global communications systems to create a world where people can think about their individual risk of infection on a vast scale. Rapid transportation of humans and goods provides vessels that move microbes to new environments as never before. A mosquito carrying the Zika virus might cross the globe in a suitcase in an afternoon, rapidly spreading a disease that might otherwise be tamped down seasonally, even temporarily entering into habitats where the vector insect cannot long survive. The speed with which people and goods can move today creates a sense of risk that often seems immediate even among those who do not move. This global social system exposes disease as much more than contact with a germ; an outbreak is created through human interactions that cannot be eliminated, at the scale of the individual and up to the global.

While microbes have always moved around the world, knowing microbes as agents of a disease has also changed how microbes are positioned on the globe. Desired microbes, such as those used in vaccines or probiotics, are distributed through global laboratory systems or manufactured en masse, while others, such as smallpox, are eradicated. Critics point to the role of laboratory scientists in creating new antibiotic-resistant microbes, sometimes a result of their very work to study antibiotic resistance. People also manipulate the qualities of microbes, both to increase health and knowledge and to cause harm and spread death, primarily for social purposes derived from human values. From the time of those first glances of microbes beneath the microscope eyepiece, people have engineered microbes for particular social objectives, including the use of microbes in weapons of war. In the modern world, healthy bodies are continually at risk, not only from the somewhat-predictable movements of disease through the population (such as the annual flu cycle), but also from the unpredictable behavior of humans attempting to bend germs to their bidding to inflict harm and terror. A microbial disease is a wicked problem because the mutating and evolving nature of microbes presents citizens with an unending number of threats.

Through human-caused and microbe-originating evolution, germs contain the ability to perpetually harm human life. Techno-scientific approaches, even when coupled with social-cultural approaches fail to eradicate disease, and recent studies of the microbiome and bacterial resistance cast doubt upon the desirability of environments cleansed of microbes. Ever-growing knowledge of the ecological function of disease raises the possibilities that microbes, even disease-causing viruses, can be "good," fulfilling a vital ecological role. For example, studies of the role of viruses in gene function show that mutualistic viruses were the key to the domestication of bell peppers and the cold tolerance of rice (Roossinck 2015; Xu et al. 2008). Annihilating these viruses, deliberately or not, might severely impact the ability of these crops to survive. Centuries after their existence was known, the role of viruses and bacteria in broad ecosystem health is only beginning to be studied, and will likely challenge the very notion of disease and its negative associations.

Even the perfect management of microbes, however, would operate through human social systems. In a world where a body is continually at risk of contracting an infectious disease, both sick and healthy bodies must be managed in order to contain infection. The technologies that destroy microbial life create effects within populations because they operate through social acts and political systems. Vaccines and antibiotics entered society via newly created public health systems which gave governments, as a mediator between individuals, nations, and the world, responsibility for creating healthy environments. Bioterrorism and pandemic preparedness activities have further affirmed the government's role in managing human behavior to minimize disease risk. To contain the spread of disease from so many quarters—food, air, travel, and even terrorism—governments require that citizens be aware of their behavior on a daily basis. Thus, the search for solutions to disease problems leads to assigning public institutions with authority over people's health and bodies. Recognizing these outcomes, as discussed in the concluding section of this case, becomes more possible when breaking out of the cyclical search for solutions and scrutinizing the motives that underlie disease governance.

Public Health and the Consequences of Containment

Disease transforms society through the shared experience of risk and the human desire to mitigate harm. Bennett (2010) argues for thinking of publics as "human-nonhuman collectives that are provoked into existence by shared experience of harm." A public cohering around shared vulnerability to disease may then create a government, or assign responsibility to the existing government, to manage that risk. People who govern have a range of disease responses available to them, ranging from allocating research funding to the scientific search for cures, to managing human bodies and biophysical systems to contain and control disease transmission. Most governments respond in manifold ways.

The rise of public health more than a century ago established the prevention of disease as the work of government. Scientists create knowledge about how microbes can be contained, but governments work to ensure that the population participates in prescribed behaviors to fight disease. This governance can be local, national, and/or international in scale, but notably is always intimate, focused on the individual body and on the interpersonal behaviors that make us human and affirm our cultural relations. Sneezing and shaking hands become suspect in a world covered with germs; if we wish to protect ourselves from disease, we must moderate those behaviors.

One form of infectious disease management has been to focus on how a disease is transmitted daily by human behaviors. For example, in the 1980s, a Chinese public health advertisement posed and answered a question: "Where should you spit? In your handkerchief! Tissue paper! The spittoon!" Similarly, a modern Australian ad reminds citizens in rhyme, "The spread of flu is up to you. Flu doesn't spread itself, people spread it." Such campaigns recognize that techno-scientific interventions alone cannot contain a disease, for people must continually regulate their own behavior to protect the population. This language taps into communal values and individual citizenship to motivate people to perform certain behaviors. In turn, citizens bestow a degree of trust upon their governments to identify and promote best practices.

Health promotion campaigns turn disease control into a psychological exercise in redirecting human behavior, relying upon individuals to police themselves against new social mores. These work in tandem with governmental interventions to manage environments, such as water and sanitation systems. Governments also have broad authoritative powers available, such as the enforcement of quarantine or mandatory vaccination programs. Infectious disease challenges us to consider the extent to which we wish for governments to intervene in personal liberties to create a healthy population.

Foucault (2007) theorized a changing relationship between people and disease based upon the new conceptualizations of a population, a collection of beings defined by common biological and pathological characteristics and sharing governance. A population attains security by maintaining a "normal" condition, and the liberal state functions when all citizens work to attain that normalcy. An outbreak of disease threatens the "normal" health of the population, and must, therefore, be mitigated to maintain the security of the population. For this liberal government to function, the state must define normal for its population and then govern deviance. Citizens must assume the responsibility to moderate their own behaviors that relate to the risk of contracting a disease. In turn, the public health system can operate as a tool of the security state, working to *contain*, *command*, and *control* disease within the population to control deviance and secure precious human life. Because there is no solution, subjects and governments continually negotiate the risks and costs of interventions to the individual and population, often in heated debates over ethics, rights, and responsibilities.

In the modern United States, this debate is exemplified in contestations over government-imposed requirements for childhood vaccinations and parents' claims for the right to decide whether their children should be vaccinated. An infectious disease like measles cannot thrive in a population where most bodies have been vaccinated against diseases, allowing a small percentage of citizens to remain healthy even when unvaccinated. However, as the aforementioned 2014 outbreak of measles in California demonstrated, lower rates of vaccination render all unvaccinated bodies vulnerable. When a critical number of citizens refuse vaccination because of a perceived risk to themselves individually, they create a security risk for the population, which must be addressed by government, and then public officials plead for individuals to be vaccinated for the collective good. When public health posters and politicians from the pulpit cry, "It's up to you!" they employ a language that locates the problem and a perceived permanent solution with individuals. The educational message lacks the nuances and complexity that scientists see in human-microbe interactions, establishing instead, the expectation that disease can be contained by socially responsible behavior (and conversely implying that irresponsible behavior is part of a disease problem).

At the core of the debate, then, are human rights to govern our own bodies that must be separated from the scientific knowledge of how to kill microbes. What, for example, should governments require of individuals by rule of law in order to secure a community—or demand of a community in order to secure the nation? These questions can only be addressed through public debate and cultural politics. Scientists cannot determine the ethics of disease control practices, but may provide some insight into how science-based knowledge and subsequent technologies might be applied to control a disease.

During the crisis response of the Ebola virus in 2014, a full quarantine of healthy bodies was called for by nation states, exercising authoritarian rule to maintain the health of the nation. There is a long history of using quarantine to contain the disease, but it is a history tainted by racial injustice and government acts that correlate health, cleanliness, and fitness with skin color and social class (Stern 1999). A court declared a 1900 plague quarantine in San Francisco to be racist in closing nonwhite businesses and in roping off Chinatown but allowing white residents to leave. While quarantine was never enacted, a 1985 poll by the Los Angeles Times found that the majority of the 2,308 survey respondents favored quarantine of AIDS patients. A decision to use quarantine during epidemics masks but cannot separate associations between disease and impurity under a call for health security. When governments impose on human rights in the name of health security they often shirk vital ethical discussions and broader social discourses that would expose injustices and systemic discrimination in these acts. Neutral, nonsocial responses to disease are not possible.

The apparent urgency created by pandemic disease serves a particular social function in affirming the role of the security state to respond to, and even "solve," disease problems. Consider the words of President Obama at the CDC, reported in *USA Today* during the 2014 Ebola events. The newspaper quotes the president saying "the solution is within grasp," even as he described a downward spiral of events in West Africa. Scientific knowledge, coupled with a rapid, militant response, offered the apparent "solution": "The world knows how to fight this disease. It's not a mystery. We know the science. We know how to prevent it from spreading. We know how to care for those who contract it. We know that if we take the proper steps, we can save lives. But we have to act fast. We can't dawdle on this one" (Korte 2014). Scientific and public health knowledge promised to contain Ebola and end the crisis, but that knowledge demanded swift application, in this case, deploying US troops to Africa. The US President promises a solution in words that assure the public that scientists have done their part, now the rest is up to the citizens.

Obama's language calls people to action—caring for victims, taking proper steps, and acting fast without dawdling. By this articulation, the promise of a scientific solution seems to be achievable if the public cooperates. In 2014, as nations debated closing their borders to global travelers, the politics of disease control met the limits of scientific knowledge. Governments shifted blame from science to citizens. Displacing culpability away from scientists and onto human subjects may change the framing of infectious disease as a problem, but does not make it solvable. As a wicked problem, the Ebola crisis could not be solved, though social decisions made on multiple scales of government and in individual lives could manage its immediate social effects. Even eradication of a disease like Ebola does not break free of the problem-solution-problem cycle.

Despite centuries of work in microbiology, people are still learning how complex their relations with microbes are, recognizing that managing disease brings unintended consequences to human and ecosystem health and vitality.

By ceasing the fruitless quest to solve disease problems and opening new discourses that do not rely on solutions-based language, everyday politics of disease can more fully center on the individual and collective rights and values inscribed in public health. Questions concerning how societies will use the knowledge generated through the scientific study of microbes to address disease outbreaks of all sorts must be discussed prior to emergency events, such that the political response can be brought in accordance with social ideals that emerge during public debate, cultural politics, and careful evaluation of our ethical values.

Conclusions

Even as the hopefulness of a swift, global conquest of disease fades in the modern era, the successes of applying science and technology to managing infectious disease are apparent. Ebola, H1N1, and SARS faded from the population. Sanitation increases health and vaccines save lives. Smallpox virus exists only in secured biological laboratories. With lowered disease stressors, however, populations continue to grow and move. As humans gather into tighter urban spaces but also travel increasingly longer distances on a regular basis, they create new paradigms of contagion and risk. Germs are adapting to survive in these new environments, becoming the germs of the future. These microbes have their own evolutionary impetus to grow and change, and their endurance may be inextricable from human survival. Microbes are being remade for another generation.

In society's search for a "solution" to the human struggle with diseases, people have created new microbial realities, and new cultural ideas and political systems are taking shape around the "superbugs" and engineered microbes of the twenty-first century. These politics demand a security apparatus that governs the environments where microbes and humans live together. Because infectious disease management blossomed around the impossible static goal of eliminating disease, it has created microbial environments (which are all environments) as places awaiting a seemingly endless series of technological fixes paired with calls for specific behaviors. By continuing to manage diseases as a problem of nature to be solved, primarily through species eradication, we have waged a scientific and political fight for knowledge of how to destroy germs.

The goal to create a society that does not fear disease is admirable, but work to overcome the fear must accompany any fight to eradicate organisms that may sustain human life in the present and future. Recognizing disease as a social condition and an unending condition of nature, not a problem awaiting a singular solution, opens the possibility of addressing both the cultural conditions and biological processes that create and spread disease. Living with our social "microbiome" means we can recognize germs as an inextricable part of our social institutions, just as we know they permeate biophysical systems.

CHAPTER 4

The Unpredictable Materiality of Radioactive Waste

Abstract This chapter examines the materiality of nuclear waste as a wicked problem that has had many proposed "solutions," none of which can comprehensively address an issue that will remain toxic and dangerous to ecosystems for millions of years. This is evident in both nuclear disasters like the Fukushima Daiichi nuclear plant explosion and meltdown, and the intractable issue of nuclear waste disposal in the US. In both cases, the biophysical properties of nuclear waste confound any singular solution. Instead, nuclear-dependent societies need to think about nuclear waste as an object of perpetual management for humankind rather than a problem that can be "solved" by geologic disposal based on political expediency.

Keywords Nuclear · Nuclear waste · Radioactivity · Fukushima · Nuclear energy

The production of nuclear energy and nuclear weapons has greatly affected the geopolitical relationships of nation-states post-World War II. While nuclear energy as a method of producing electricity is waning in some nuclear states, interest in nuclear energy production is growing in other developing nations. One of the main reasons is for energy security, but another major reason is the rationale of "clean energy" production, which pro-nuclear supporters position as a means of "solving" climate change, and addressing global energy poverty (Porter 2013; Hansen et al. 2015;

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Sovacool and Valentine 2010). Proposing that nuclear energy can “save” humanity from a changing climate depends on seeing climate change as stemming solely from energy production and carbon emissions. Nuclear energy is being posited as a solution for addressing the increasingly obvious effects of climate change brought on by rampant fossil fuel use, as well as the need to produce more sustainable energy to support the economies of industrialized societies and modernize developing societies.

The idea that nuclear power can solve energy access issues for entire nations has roots dating to the advent of the nuclear age in the aftermath of World War II, when nuclear energy was idealized by the federal government as a national energy source that would be “too cheap to meter” (Wellock 2016), and the production of nuclear energy was linked to a quickly modernizing American landscape that needed plentiful access to reliable energy sources to keep growing. The notion that nuclear energy can “solve” these deeply complex social and political issues emerged after the shocking and awe-inspiring destructive capabilities of nuclear weapons was unveiled on the world in Japan in 1945 (Boyer 1985; Weart 1988), leading to the development and implementation of nuclear energy systems in order to convince the public (both domestically and internationally) that there were legitimate peaceful uses of atomic technology. This urge to redeem nuclear technologies in the eyes of the public still resonates today, as nuclear “[s]olutionists lurch in fits and starts from one extreme position to another, from one answer to the next, failing to understand that the problems we have created are as complex as the societies we live in” (Benedict 2013). The production of nuclear power engenders new problems that society is ill-equipped to deal with under the rubric of a temporally and geographically fixed solutionist paradigm.

Nuclear energy production on a national scale is rationalized as a solution for two major political concerns: national security and economic development (Jasanoff and Kim 2009). While these two concepts are linked, recognizing why and how different nations access these rationales is a critical aspect of understanding how the solutionist approach has politically evolved and fed into the promulgation of nuclear energy. It also shows how a solutionist approach commits nation-states to nuclear energy production, even as the production of nuclear energy erodes public trust, upends environmental security, and creates intergenerational justice concerns in relation to radioactive waste management. This chapter complicates these two paradigms of energy security and modernization by viewing nuclear energy and its attendant by-products as an example of what Hughes (2009) called a “sociotechnical system,” where the social and political values of a society shape and drive the production of a technical system, which also shapes the society in which it is embedded. Nuclear systems are most dangerous when they are viewed solely as technological systems that can solve complex social and political issues. This view is troubled by the issue of nuclear waste, a persistent emblem of the ways that a solution for one perceived problem (energy production) leads to a far more complex social and political issue (nuclear waste disposal).

The concept of a sociotechnical system underscores the social and political aspects of nuclear energy production and its waste. A sociotechnical system has “both a cause and an effect; it can shape or be shaped by society. As they grow larger and more complex, systems tend to be more shaping of society and less shaped by it” (Hughes 2009). The nuclear fuel cycle, which includes uranium mining, nuclear power production, and radioactive waste streams, is an inherently sociotechnical system, embedded with values from the Cold War era. It is shaped by what Cowan (1990) has called “technological lock-in.” As an example of this principle, nuclear states like the US chose the light-water reactors used most commonly today because of their ability to also produce plutonium and highly enriched uranium for nuclear weapons. The Atomic Energy Commission (AEC) dismissed other designs that would not have produced materials for weapons. Countries that wanted nuclear energy capabilities and assistance from the US received light water reactors that would need more security controls (Sovacool and Valentine 2010; Cowan 1990). The issue of nuclear waste was also an after-thought for nuclear engineers until the 1980s, as it was assumed that an easily engineered solution for what was viewed as a technical problem would be found before waste became a systemic risk to the environment and human populations. Furthermore, political concerns regarding nuclear weapons production and management vastly overshadowed any discussion of comprehensively managing nuclear waste streams.

A similar pattern of developing nuclear energy without considering the entire nuclear fuel cycle is evident in other nuclear states. The examples, however, of Japan’s ongoing crisis surrounding the 2011 nuclear power plant meltdown in Fukushima and the US’s seemingly intractable issue with nuclear waste run counter to the notion that nuclear energy can “solve” deeply political issues of security and development. Treating energy systems as tame problems with straightforward, often technical solutions, rather than as wicked problems, inevitably leads to more thorny issues of governance and management, as well as concerns over public values and intergenerational justice, which, for nations with democratic systems of governance, are matters of politics, not engineering.

Viewing nuclear energy as a solution for energy security and development ignores other important considerations, including where nuclear energy will be produced, how the fuel cycle will be managed from cradle to the grave (and beyond), who is at risk from and who will have access to the electricity produced, and how future generations will bear the burden of risks from radioactive waste produced today. While these questions pertain to any kind of energy production, from coal to solar, nuclear power presents inherent complications related to these questions. Specifically, nuclear energy is a large-scale form of energy production that requires massive state investment, management, oversight, and commitment over decades, as well as safeguards for radioactive waste products. Overlooking the back-end is inherent to the nuclear fuel cycle because conflicting values over how and where to store nuclear waste are often considerations that are omitted in prevailing paradigms, which have historically been high-level conversations held by political elites who assumed that scientists and engineers would find solutions in a timely fashion. Nuclear systems were decided upon by elites using the rationales of developing domestic energy supplies to power growing economies, and in some cases, of nuclear weapons development for national security interests. The backend of the fuel cycle has taken a back-seat to the national imperative of producing nuclear energy for security and modernization, which are seen as more pressing concerns than the storage and perpetual management of nuclear waste.

Ultimately, every approach put forth for permanently "solving" nuclear waste has been contested. This is partially because the reliance on technical solutions ignores the ways that the nuclear fuel cycle is a deeply political and social issue, one that draws into question the entire legacy of nuclear projects including public accountability, transparency in communicating with the public, and management over the entire nuclear fuel cycle. The difficulty of addressing these questions over the long time periods that nuclear waste is hazardous to humans and other species is further complicated by a lack of trust between the publics who will potentially host repository sites and the federal agencies charged with siting and safeguarding those sites. The concept of a permanent solution based on geological repositories is seductive because it seems to circumvent questions of why we produced the waste with no plan in the first place and also appears to close off any discussion of how a society's values toward nuclear waste may change in time. However, because some radioactive waste products remain radioactive for millennia, considering intergenerational concerns of future peoples is an ethical and moral aspect of nuclear waste management that technological discussions about geologic repositories avoid. The technical, social, and ethical complexity inherent in nuclear energy production and its subsequent waste present a classic wicked problem. There are no permanent, singular solutions to address nuclear waste, but rather it will require consistent and persistent management over centuries, which includes acknowledging conflicting value systems, recognizing political and social concerns, and engaging with different public factions.

From Atoms for Peace to Atoms of Uncertainty

The history of nuclear power in Japan is an integral part of this story. The modern nuclear age began with the detonations of atomic bombs dropped by the US on Hiroshima on August 6, and Nagasaki on August 9, 1945. The nuclear age ramped up in the 1950s as more nations gained technological expertise and access to nuclear materials to create both bombs and energy. Internationally, US President Eisenhower was also developing and garnering support for a program called Project Plowshares, and delivered his "Atoms for Peace" speech in 1953, anticipating a near future in which the US would not have singular control over nuclear technologies. Under the Atoms for Peace program, the globe would be divided into "supplier" states and "user" states (Atoms for Peace speech; Schlesinger 2007). Supplier states, such as the US, the UK, and France, would control sensitive materials and supply engineering and regulatory expertise, while user states would have the benefit of locally produced nuclear energy, without access to the ability to make enriched uranium that would potentially lead to weaponization.

Japan, the only nation to have endured atomic attacks during World War II, was one of the first countries in 1956 that the US supplied with nuclear power capabilities (Jasanoff and Kim 2009). The US saw this effort as a means of creating an ally in the Eastern hemisphere against the growing threat of the Soviet Union, while Japan sought a method of creating more domestic energy supply despite their experience with the destructive capabilities of nuclear weapons. As a nation with no fossil fuel resources domestically available, nuclear energy seemed a pragmatic means of securing a dependable national energy source (Pickett 2002). In early 2011, Japan had 50 nuclear reactors in the country, producing 30 percent of the electricity needs of this highly industrialized nation. Six of these reactors were located at the Fukushima Daiichi site, in the Fukushima prefecture about 300 km north of Tokyo.

The current situation in Fukushima vividly demonstrates the complex social and political issues with one of the key aspects of nuclear energy production: radioactive waste management. The Fukushima case is an example of cascading events that stem from a geologic event and subsequent technological failure. At its roots, it is a human-generated disaster producing unpredictable streams of radioactive waste that are proving to be uncontainable over vast geographies, ecosystems, and time scales. The waste created at Fukushima, as well as the site itself, will need to be managed for hundreds, if not thousands of years, a problem that endures after the immediate issue of containing the unpredictable flows of radioactive waste. Therefore, the growth of nuclear energy can be seen as a catalyst for an additional suite of problems manifested on a geographical and temporal scale that defies the possibility of any solution.

The 2011 Fukushima catastrophe started with an earthquake and tsunami that engulfed the northeast coast of Japan and subsequently created power outages and a loss-of-coolant accident at the Fukushima Daiichi nuclear plant. The radioactive debris and fluids produced by the reactor core meltdowns at three of the plant's reactors defied any comprehensive manner of containment and storage. The radiation emitting from the reactors prompted the evacuation of a 40-km area around the plant on March 13th, and in 2016 more than 100,000 people remained displaced because of radioactive contamination concerns. Removing the fuel inside reactors 1–3 may take an additional 30–80 years (McCurry 2016). Unpredictable radiation-leaks continue to plague the Fukushima site, and the state of the cores from the three stricken reactors is unknown, as the conditions inside the reactors are too radioactive for remote-controlled robots to function (Yamaguchi 2013).

As water from rainfall and storms moves through the site, radiation also moves through the landscape. Japanese authorities have been attempting to contain the contaminated water in huge tanks throughout the plant, many of which are overflowing and leaking, spreading more radioactive contamination. The uncontrolled movement of water has created tons of radioactive soil requiring treatment and disposal at other remote sites, which will, in turn, create more radioactive "sacrifice zones." Vegetation growing in contaminated soils, as well as wildlife that consumes these plants, presents an additional waste stream that affects local ecological processes. With so many ways for radiation to move through the environment, coupled with accidental emissions from leaking tanks, trying to create fixed boundaries for the disaster at Fukushima is increasingly complicated, defying solutionist efforts to contain the risks from radiation.

A key element of trying to contain the material effects of the disaster is characterizing the radiation issues at Fukushima, and five years after the initial event there is no comprehensive management plan for the site because none is possible. This is evident in the continuing issue of cooling the reactors, which uses water from the ocean that subsequently becomes contaminated with radiation. The fluids are then stored in water tanks around the reactors, which are now filled to capacity. Additionally, leaks have been discovered in the area around some of the tanks, leading to concern about the remaining tanks. Plant managers admitted that the tanks continue to leak about 150 tons of liquid every day (Demetriou 2016). There is no way to solve the problem of the leaking tanks in light of the amount of water that is moving through the plant, but to prevent water from leaching into surrounding soils and waterways, the Japanese government proposed constructing a 100-m tall ice wall around the plant. The hope is that the partially submerged wall freezes water and liquids in order to prevent other fluids from migrating and mixing with the radioactive materials in the plant (Yamaguchi 2013a).

The ice wall concept manifests more solutionist thinking. The problem of how to contain the threat of radiation moving through ground and water was couched in technical terms (although such containment notably will have no effect on airborne radiation). The relatively forthright technology of an ice wall has been used before on smaller scales, but the concept raises a host of additional questions, including how the ice wall is constructed and maintained. The Japanese government pledged $500 million dollars to build the ice wall and to treat contaminated water from Fukushima. The ice wall is a proposed “solution” that seems to settle a particular problem—the spread of radioactive liquid through the environment—but actually raises more questions about how quickly it could be built, how it will be maintained, for how long, and how it will be reliably powered (Fackler 2016). These technical questions, however, are incidental to the main conversation promoted by the state, which is to assure the populace that the situation is under control and nuclear power production is safe. The ice wall is a gamble, but the only other option for dealing with the thousands of gallons of water being poured over the reactors and for the groundwater moving through the site is to dump the water into the ocean under the assumption that ocean currents will dilute and spread any radiation, rendering it harmless. But this also potentially creates yet another dangerous and risky situation that exposes the limits of control and predictability for radionuclides in Fukushima.

No one can predict how effective the wall would be at actually freezing the soil and liquids to a temperature that would contain the radioactive threat (Dechert 2014). However, the main architect of the wall has noted that it would not be watertight and that groundwater would continue to flow up and around the barrier, becoming contaminated and seeping around gaps in the wall (Kagayama and Yamaguchi 2016). When the ice wall was partially completed and operational in March 2016, its impact was underwhelming, with more than 300 tons of water still flowing to the ocean. Representatives from the Tokyo Electric Power Company (TEPCO) admitted that they could not stop the flow of irradiated water from the site (Otake 2016). Even if the ice wall were completely effective, it would still only be a temporary measure at containing radioactive contamination and would not address the radiation already in the biophysical systems outside the perimeter of the wall.

The ice wall is emblematic of a technical solution for a tame problem (containing radioactive water), but it is also an act to address a much more complex issue, which is the erosion of trust in the central government of Japan, as well as the regulatory apparatuses that are supposed to govern nuclear energy production. The ice wall was meant to contain the movement of radiation physically in the environment around the plant. But it was also meant to contain psychologically the uncertainty in the minds of the Japanese and global public, to demonstrate that the situation is under control and that normalcy is possible. The ideals of normalcy and control are critical values for convincing the public that the government and TEPCO are ready and able to restart the nation's other reactors, which were all taken off-line after the earthquake. These containment projects are inextricably linked in the Japanese system of governance, and the erosion of trust only deepened when the ice wall failed to keep radioactive liquids sequestered from the surrounding environment.

Bold claims by government leaders add to uncertain conditions, even as they are intended to stem the tide of mistrust. In 2013, Japanese President Shinzo Abe promised that, at least in relation to the effects of Fukushima on Tokyo, "there has not been, is not now and will not be any health problems whatsoever…Furthermore, the government has already decided a program to make sure there is absolutely no problem, and we have already started" (Lies 2013). But even after ice walls and more storage tanks are constructed, Japan must still find a means of decommissioning the site, which is further complicated by the fact that Japan has never decommissioned any of its reactors and has no plans for long-term storage of radioactive waste products. Now that the issue is pressing, the Japanese government is finding it impossible to site a location due to systemic mistrust between the public and the governmental agencies responsible for nuclear management. In attempting to site a repository, the Japanese government has further upset a population that is increasingly distrustful of any action proposed by TEPCO or the federal government. Underscoring this issue is the historic and continual seismic activity in the region, which could derail any plans of geologic storage in the future (Aldrich et al. 2015). There is no program for decommissioning or managing the Fukushima site, and much of the work that needs to be done at the site is highly experimental in scope and scale, making claims of certainty highly suspect.

Recently, Japanese officials have decided to try a more consent-based approach, mirroring attempts in the US for siting waste in a more democratic fashion (Blue Ribbon Commission 2011). The search for consent underscores the need to see nuclear waste disposal not as simply identifying a permanent solution for nuclear waste based on technological parameters or ideal geologies, but rather understanding arguments over nuclear waste as a complex and ongoing social process involving the interplay of public trust, scientific expertise, and national regulatory bodies aimed at perpetually managing social and environmental risks from radioactive wastes. However, even with this acknowledgment, a permanent repository does not address the deep mistrust by the Japanese public of officials in charge of the nuclear fuel cycle, nor can it address the inherent risks of nuclear energy going wrong or the management of waste over unfathomable amounts of time.

Despite public opposition, re-elected (and pro-nuclear) President Abe has ordered the restart of some nuclear plants, citing economic necessity, as national investments into renewable energies have yet to pay off in terms of producing energy at the scale that Japan's highly industrialized society requires. Energy conservation and energy imports have alleviated the need for nuclear in the short term, but the government has determined that Japan must turn on their reactors in order to be economically competitive and meet climate goals on carbon emissions, which coal imports only exacerbate (Koyama 2013). Prime Minister Abe is also hawkish on Japan's political security in the face of growing aggression from China, making energy security a priority for his administration (Krauss 2016), but local politics complicate this national strategy. For instance, as the first plant in Sendai came back online, the newly elected governor of the Kagoshima prefect, who ran on a platform of nuclear reform, requested that they be shut off for more inspections, which the local utility rejected (World Nuclear News 2016). This mismatch of public expectations and values with current energy system needs and realities exacerbates the lack of trust between the public and the government.

The aftermath of the Fukushima disaster demonstrates that problems with nuclear energy, waste, and accidents that produce new nuclear conditions are not solely discussions about energy production; they involve much more complex questions over how "the natural world is constituted, contested and defined within institutional practices, environmental discourses and forms of expertise" (Irwin 2001). These constitutions, contestations, and definitions change as different groups, both nationally and internationally, assert their expertise, or rush to assure their constituencies that nuclear energy is still safe. The sociotechnical nature of unpredictable nuclear waste streams highlights the inherent limitations of promoting nuclear energy production as a solution for energy needs. Rather, there is no singular solution for energy demand and production—nuclear or otherwise. Energy demand is a highly social and political issue that each nation-state is negotiating on several different levels of governance, from the local to the international.

Efforts to build nuclear energy systems in developing nations are often tied to security and industry needs but are stymied by local resistance fueled by a lack of trust in centralized governments. In industrialized nations with high energy needs like Japan, Fukushima is evidence of the complex political and physical infrastructures necessary to govern nuclear systems, including the development and implementation of systems of emergency planning, communication between utilities, government, and the public, and oversight of nuclear systems from cradle to grave and beyond. Ironically, these infrastructures are needed to prevent nuclear disasters, but also when the disaster has occurred; as Fukushima demonstrates, the risk of something going wrong with nuclear energy production may be small based on historical antecedents, but the consequences are severe, environmentally, technologically, and politically. Presently, there is little trust in the oversight of nuclear facilities for the Japanese public because of the collusion between government agencies and utilities operating plants.

The continuing catastrophe of Fukushima shows the limits of solutionist thinking in relation to nuclear energy production—a sociotechnological system whose worst-case scenario is simply outside the bounds of human ability to plan for or manage. It highlights the sociotechnical nature of nuclear energy and radioactive waste management in a highly industrialized society. Without more emphasis on the reality that all energy production operates through consistent management and on the political and social values driving nuclear energy production, reducing nuclear energy and nuclear waste to technical parameters will always result in an erosion of public trust in an energy system.

Struggles with Nuclear Waste in the US

Fukushima is an instructional example of a worst-case scenario in relation to producing unpredictable and unmanageable nuclear waste in an emergency situation. However, the issue of spent nuclear fuel produced by reactors over the past 70 years and into the present remains a persistent concern for nuclear nations. Nuclear waste did not become an issue for scientific scrutiny until the 1950s when the pressures of an active wartime situation ceased and scientists and engineers started to think more seriously about the end of the nuclear fuel cycle. All that needed to be done was identify the appropriate medium, locate that medium in a place that was unpopulated and unproductive, and the solution would be found.

After World War II, the US continued to develop larger, more powerful, and more sophisticated nuclear weaponry, enmeshing all corners of the country into a massive nuclear project for weapons production and management. During the ensuing decades, the US and the Soviet Union were locked in a struggle for nuclear supremacy. While competing ideologies over geopolitical influence were the main cause of friction between these two nation-states (or at least as nuclear weapons arsenals became the physical manifestation of deep ideological divides), nuclear energy was also quickly becoming a focal point for state attention. In the US, the federal government underwrote a large-scale nuclear energy program, funding research in atomic engineering and science to propel "the peaceful atom" into the national mindset (Jasanoff and Kim 2009) and to influence the

American public to view nuclear energy as a force of democratic good that would ensure national freedom alongside the arsenal of nuclear weapons that would ensure national security.

The previous section discussed US President Eisenhower's internationally focused program called "Atoms for Peace" and its effect on Japan. Domestically in the 1950s, Eisenhower was also promoting the Plowshares Program, a program focused on finding peaceful applications for nuclear weapons in the US and abroad, that took its name from the Biblical passage Isaiah 2: 1–4: "They shall beat their swords into plowshares, and their spears into pruning hooks; nation shall not lift up a sword against nation, neither shall they learn war any more." In the US, Project Plowshares took the form of nuclear detonations to stimulate oil and natural gas production, and to dig canals and train tunnels (Kirsch 2005). These large earth-moving and energy-producing projects failed, due to concerns over economic infeasibility and environmental contamination, but nuclear energy caught on in the form of reactors that could produce electricity to power America's growing economy and populations.

Eisenhower also established the Atomic Energy Commission, a federal body charged with overseeing the safety of the American nuclear energy project, as well as promoting the growth of the industry, which was heavily subsidized by the federal government. With the opening of the first nuclear power plant at Shippingport, Pennsylvania in 1957, the US began producing energy to supply domestic electricity needs, and nuclear weapons to cement national security. Meanwhile, waste from both these streams, weapons and energy, was piling up across the US.

During the Cold War, the priority for the US was to produce enough nuclear bombs to ensure the security of the state through nuclear deterrence. This objective trumped any kind of planning for dealing with waste. Scientists assumed that the problem of nuclear waste would have a straightforward technical solution, and geologic storage was seen as the most effective and pragmatic solution (National Research Council 1957). It was not until 1957 that the National Research Council issued a report entitled "The Disposal of Radioactive Waste on Land," where a committee of scientists recommended deep geologic disposal as the best method for ensuring that radioactive waste stay sequestered from human societies. Since then, geologic repositories have been the major focus of the federal government, although radioactive waste was also dumped in the ocean and radioactive waste produced at Los Alamos National Laboratories was disposed of by burying it in unlined dirt trenches (Makhijani et al. 1998) and dumped in canyons near the lab (Kosek 2006), creating new risks from the movement of radionuclides through ecosystems, including the risk of forest fires that could burn plants that absorbed radioactive elements and then spread them through the air. People did not plan for these new streams of radiation, and they understood little about how radiation would move through ecosystems.

The advent of nuclear power production to redeem the destructive atom into the peaceful atom brought about huge federal investments into nuclear power but little funding for research into managing the backend of the nuclear fuel cycle, as the development of nuclear weapons and energy were the sole focus of the US government during the Cold War. Now that more attention is paid to nuclear waste management, the geologic solution forecasted in the 1950s is not forthcoming. The next section of this chapter examines the nuclear fuel cycle in more depth and uses the US as a case study to explore why identifying solutions for nuclear waste streams is actually impossible, as the future is inherently uncertain. Because of its long history with nuclear technologies and systemic difficulty with addressing nuclear waste issues, the US is an exemplary site for understanding why nuclear waste defies permanent solutions. The problem is actually about conflicting public values surrounding the production history and future storage of nuclear waste.

The Nuclear Fuel Cycle and the Production of Waste

Each step of the nuclear fuel cycle, from uranium mining to enriching uranium, to the spent nuclear fuel rods, produces radioactive waste, and each step blends the political with the technical and environmental in an effort to completely harness and control the power of the atom. The US deploys a once-through fuel cycle for nuclear waste (Strandberg and Andren 2012). In this system, there are five general steps in the nuclear fuel cycle, and each step produces radioactive by-products First, the uranium, the basic ore for nuclear plants, is mined from the Earth's crust. Ore is brought to the Earth's surface, through underground mining, open-pit mining, or in situ leach mining. From the 1950s to 1970s, uranium mines operated throughout the desert Southwest in the US (Amundson 2002), especially on the Navajo Nation (Eichstaedt 1994; Brugge et al. 2006). The toxic legacy of unremediated mines and uranium mine tailings piles across the Navajo Nation and the Four Corners area has left a host of health and environmental issues, including contaminated earth and water systems. Due to risks of water contamination, some mine and mill tailings on the banks of the Colorado River near Moab, Utah are being moved 30 miles north to Crescent Junction, Utah to be buried away from currently active and existing water systems. At current funding and operation levels, the process will take until 2025 to be completed (DOE 2016a).

The next step is uranium conversion and enrichment: At this stage, uranium is converted into a gaseous form called uranium hexafluoride. This conversion allows the enrichment plant to separate enriched uranium-235, which will be used for nuclear fuel, from uranium-238, which can be processed into plutonium. One of the by-products of this process is used or depleted uranium hexafluoride, which is highly toxic, especially if it comes into contact with water. Currently, it is kept in casks on-site at uranium deconversion plants. The third step is fuel fabrication: it compresses enriched uranium into pellets, bakes them, and then puts them in metal casings inside fuel rods. The next major step occurs when the fuel rods are emplaced in the reactor, and a chain reaction is started to begin producing heat from the rods. Boiling water under pressure creates steam to turn turbines, which in turn create electricity.

Finally, the spent nuclear fuel (SNF) is removed from the reactor every 18–36 months, and for the first five years after its removal, it is stored in fuel ponds to absorb radiation. After five years, the SNF is cool enough to be moved off-site to another repository. This last stage, or backend of the nuclear fuel cycle, has become an intractable issue for the US. The goal of creating a permanent geologic repository for nuclear waste disposal also clearly demonstrates how the "solution" of nuclear energy was implemented on a national and international scale without a similar acknowledgement or recognition that nuclear waste would also present serious and long-term social "problems," such as the undermining of democratic processes to site a repository. It also illuminates the wicked problem of why we continue to produce waste, knowing that we have no place to "dispose" of the waste and no process or plan to do so, 60 years after the first plant began operating in the US.

Holistic examination of the social, political, economic, and larger environmental concerns surrounding nuclear waste reveals the error of viewing nuclear power as a permanent or singular solution to energy production or climate change concerns. Further, the inherent unpredictability of physical events (e.g., earthquakes and radiation migration) compounds the complexity inherent in considering nuclear energy and its concomitant waste.

Geologic containment as a permanent solution for nuclear waste is based on assumptions of static geographies and environments, as well as temporally bound human values (Macfarlane and Ewing 2006). Finding permanent geological repositories for both conventional and unpredictable radioactive waste streams is a fraught exercise because the federal government has ordered that it must secure the consent of present generations and also consider the safety of future generations. Managing the entire nuclear fuel cycle requires plans for perpetual management, acknowledging unknown complexities, such as the stochasticity of geologic environments over thousands of years, changing human values, and how accidents may factor into nuclear waste management.

Eternal Isolation

While the National Academy of Sciences recommended a geologic repository for nuclear waste in 1957, actually finding an appropriate site for a repository for nuclear waste in the US has demonstrated that this is not a simple technical issue. The few attempts undertaken, such as research into the salt deposits underneath Lyons, Kansas, were unsuccessful in locating a repository due to public resistance and a growing mistrust of federal information (McCutcheon 2002).

In order to address the issue of waste building up at nuclear reactor sites, the US Congress passed the Nuclear Waste Policy Act (NWPA) in 1982, a federal commitment to select and construct two central repositories for waste produced during commercial nuclear energy production. Under this Act, one site would be in the Western half of the US, while the other would be in the East. It also recommended the study of several sites across the US. But in 1987, Congress passed an amendment to the NWPA, mandating only one repository would be sought, and it should be in the West. Attention quickly focused on the area of Yucca Mountain, in the state of Nevada. Yucca Mountain was seen as an appropriate location for three main reasons: (1) it is exceptionally arid, precluding agricultural development; (2) it was a sparsely populated area, with a large portion of the state under the aegis of the federal government, including military bases, Yucca Mountain, and the Nevada Test Site where nuclear testing had been conducted throughout the 1960s; and (3) Nevada was viewed as a relatively weak state, politically, where there would be little resistance to a repository.

However, the siting of waste at Yucca Mountain has proved to be politically and culturally divisive and is an example of how different values shape perceptions of how the landscape of the US should be used. Concerns about Yucca Mountain involve environmental, political, and cultural issues. While the site was deemed appropriate by the DOE based on scientific characterizations, long-term ecological concerns involve environmental stability, the movement of water through the site, and the seismology and volcanology of the site. Politically, the Nevada public, represented by long-time Senator Harry Reid, rejected the NWPA, contesting the notion that they would fall in line with a top-down decision mandated by Congress to the state, setting up a battle between federal interests and state interests. An additional concern that was not integrated into site selection is the fact that Yucca Mountain is of long-held cultural and spiritual significance to three Native American tribes who were forced out of the area, and who are strenuously decrying the desecration of the Mountain as a repository for nuclear waste (Endres 2009). The emergence of these concerns led to the Yucca site to be mired in controversy for almost 30 years, and currently there is no activity at the site for nuclear waste. Politically for the moment at least, the idea of using Yucca Mountain as a means of permanently addressing the nuclear waste issue in the US is dead.

Presently, there are two other major geological formations being explored by the DOE for potentially holding SNF. In 1957, the National Research Council recommended deep salt beds as a potential medium (National Research Council 1957), and the Waste Isolation Pilot Plant (WIPP) in New Mexico has utilized a Permian salt bed since it began operations in 1999. However, WIPP is only licensed to hold nuclear waste produced by the Department of Defense and has not been approved for spent nuclear fuel. It is also currently closed due to an accident on February 14, 2014 involving a miscommunication about the material meant to absorb liquids that may form around the canisters stored 2000 feet below the earth's surface. Normally, the canisters are coated on top with an inorganic material that will absorb liquid without reacting to the material of the canister. The substance normally used is conventional clay-based cat litter. Unfortunately, the instructions for storage requested an "organic" (instead of "inorganic") resulting in the wrong kind of litter being used and allowing the canister to leak radioactive fluid and airborne emissions (Savannah River National Laboratory 2015). Remote monitors one mile away from the site detected the radiation and several employees had detectable radiation in their urine or blood streams, although at nonharmful levels.

WIPP re-opened in January 2017. However, public trust has eroded, due to promises of absolute safety officials made before the accident. This calls into question how “permanent” a repository can be, when miscommunications are an inherent part of human existence, both now and presumably in the future. A repository may minimize some risks in the present, but it can never eliminate them entirely due to human errors always being a factor. Human intrusion is acknowledged as the main risk to the site, though biophysical conditions persist as a major concern. WIPP demonstrates that trying to contain the risks from radioactive waste over a 10,000-year period is indeed a wicked problem with no solution, as geologic repositories are actually an attempt to contain radiation as well as control human behavior. If humans cannot do either in the present over a few decades (or in the case of WIPP, 15 years), it is difficult to imagine this working over several millennia.

The second option under discussion in the US is borehole storage. The DOE is trying to explore the concept of drilling narrow boreholes about three miles deep into the Earth’s crust and then placing tubes of certain kinds of nuclear waste in those boreholes permanently. This method has been described as cost effective and easy (Conca 2015), but the DOE has already met public resistance with this method. In 2015, the DOE proposed a field test site in North Dakota, coming to an agreement with its contractor to drill two experimental boreholes. However, the DOE did not communicate with the local officials and residents in the area, who found out about the proposed project through local media after the agreement between the DOE and its contractors had already been finalized. County commissioners decided to reject the project, declining to allow the DOE to use the land for these experimental sites, though the DOE assured local residents that no nuclear waste would actually be emplaced in these sites, which were located on state-owned lands. The DOE had expected to break ground in fall 2016 but instead have canceled the project due to public dissent. The County Commissioners cited their lack of trust in the DOE to not pursue nuclear waste storage should the experiments work. The fact that no local public representative had been considered in conversations between the DOE, a local university partner, and the contractor, and the negotiation of state lands without local input further depleted the trust that the public would need to consent to the project (Voosen 2016).

This situation demonstrates the gulf between the social and the technical aspects of nuclear waste. The DOE and its partners viewed the issue as one requiring scientific research, technological assessment, and engineering geology. Since no actual waste would go into the boreholes for this project, the DOE thought it did not need to engage the public for what was considered an experiment with no risk of radioactive contamination. The public was haunted by the perceived risks of becoming a nuclear waste site like several other de facto waste sites across the country that are still waiting for DOE to address their waste (Donovan 2016). They also lack trust in the public process, especially if experiments can be done in their locale without their knowledge or consent. However, the DOE did not view borehole disposal as part of that larger context, instead seeing this as a discrete activity that might be yet another possible solution for part of the nuclear waste storage issue facing the US—one the department thought would be "less-objectionable and cheaper" (Cornwall 2016) than Yucca Mountain.

For the public in Pearce County, North Dakota, this project was part of a larger national pattern of the DOE ignoring local concerns and desires for communication and recognition as a stakeholder from the beginning of projects, rather than an ancillary party that is only brought in after decisions are made at higher levels. Understanding nuclear waste repository siting as a process for building trust between the federal and local levels of governance would be one avenue for healing this lack of trust, rather than viewing them as simple engineering projects. The public is distrustful of nuclear waste repositories because of a lack of trust in the governance of these projects, which is underscored by the DOE's lack of communication with local residents. The erosion of trust from the post-World War II era to a new nuclear age (post-Cold War) in federal agencies requires a shift from thinking of geologic disposal as a "solution" for nuclear waste to recognizing nuclear waste management (rather than disposal) as a political process that will need to address a lack of trust between the public and federal agencies.

Each strategy for nuclear waste is predicated on the belief that eternal isolation is possible and desirable, and that these are the most effective methods at our disposal today to ensure that nuclear waste will not affect human environments in the perpetual future. When the public, including elected local officials, disagrees with the rationales from scientists and federal agencies like the DOE, these complaints and concerns are often dismissed as irrational or "just politics," yet they are also a reflection that the realm of politics is where democratic nation-states make more just societies. Deep geologic repositories can be seen as an attempt to preempt any further conversation about managing nuclear waste, as they close off discussions over whether a nation should be producing more waste if there is no truly secure place to store it. They contribute to a pervasive belief that "our differences can be washed away in the solvent of scientific decision-making" (Jamieson 2000).

Conclusions: The Future of Nuclear Waste

The state of Nevada continues to stand firmly against Yucca Mountain, and the DOE has decided, after almost 40 years, to pursue a different process for siting a repository (though it is still yoked legally to the NWPA of 1982). Called Consent-Based Siting (CBS), this process involves not only public meetings around the US but also small focus groups in non-nuclear communities to gain more insight into the public values toward nuclear waste (DOE 2016b). American efforts to deal with nuclear waste ultimately tells us more about the values of our current society than about the values we presume that future societies will have, and our current value system dictates that there must be solutions to defined problems. In order to overturn this presumption, the public consent process is a critical piece of this conversation. Yet it is often delimited to educating and informing the public with little time for input from the public, and little back and forth between government representatives and the public. The CBS process aims to create dialogues between technical experts and the public, and garner more insights and inputs into ideas for a better process. While this is a laudable goal for the DOE, the end goal is still a permanent geologic repository, not an exploration of public values regarding the more entrenched value of solutionism, and whether a strategy that is more adaptable and flexible can be found.

Another consideration that is politically difficult to grapple with is that of intergenerational justice. Storing nuclear waste underground does not address the ethical and moral rationales of why certain populations in the mid-twentieth century are committed to an energy production system that has dangerous by-products that will become the responsibility of future generations. It is fundamentally illogical to assume that energy systems that made sense to societies in the twentieth century will make sense for all future societies, especially considering the known history of energy transitions. Framing nuclear energy production in a historical context, the energy we produced over this period will leave a legacy that is toxic to humans and other species for millennia. Viewed this way, the practice of producing energy through nuclear fission becomes fraught with ethical and moral concerns about intergenerational justice and the kinds of burdens that our needs in the present displace onto future generations. Geologic repositories necessitate the sacrifice of specific places and spaces as off-limits for incredible expanses of time, without those future communities, societies, and ecologies benefiting from any of the energy that was produced to power our present lifestyles.

The future is an inherently speculative place and one that becomes increasingly uncertain as temporal frames become longer. We may be able to predict where some biophysical events will happen, such as earthquakes, but trying to determine when, is beyond the scope of human ability, as evinced by the Tohoku earthquake that instigated the Fukushima disaster. Trying to predict the state of a nation 100 years in the future is impossible, but we assume it will look remarkably like our own time, perhaps with more advanced technology. But over 1,000 or 10,000 years, it is unpredictable where humans will live, how they will conduct their lives and arrange their societies, and how they will govern themselves. Therefore, once a "solution" is settled upon by any nation, it may be complicated by intergenerational concerns. How will future societies understand the nuclear waste management cycle that very few people understand today? Will they need to understand it? Even marking a site is an ethical consideration: Is it better to mark the site and attempt to explain the dangers of radioactive waste to future generations thousands of years in the future, who may not be American, may not speak languages that are currently extant on Earth today, and may not even be human? Or is it more ethical to not mark the site, to not draw attention to this hazardous substance?

In 1993, different groups of academics and scientists were asked to imagine potential scenarios and methods for marking nuclear waste sites, with the understanding that human intrusion was the greatest risk to the integrity of these sites. The report speculated that communicating the risks of radioactive waste to future generations would be an incredibly complex task. The messages have to clearly communicate a particular message, a eulogy for the nuclear age: "This place is a message . . . and part of a system of messages . . . pay attention to it! Sending this message was important to us. We considered ourselves to be a powerful culture . . . this place is not a place of honor . . . no highly esteemed deed is commemorated here . . . nothing valued is here . . . what is here was dangerous and repulsive to us. This message is a warning about danger" (Trauth et al. 1993).

Because the future is speculative, we cannot speak in certainties, but only possibilities. While it may be possible that radioactivity will sit quiescently hundreds of meters under the Earth's surface for perpetuity, it is also possible that generations over the next millennia, who have no cultural connection to our societies, will seek out or stumble across our nuclear waste sites and question our way of living. They may look out at the global landscape, from the former "US" to the island that was once a country called "Japan," and wonder why we hid so many toxic things underground—from salt mines a mile underground to caverns carefully carved out of deep rock—and wonder at this legacy. Perhaps it will be something they seek out and are harmed by, or perhaps they will understand our messages and see these sites as cursed places to avoid. Or, perhaps future beings will need the materials and see these sites as a resource. Regardless of future scenarios, we must acknowledge that we will have powerfully changed the subterranean landscape as a legacy for future generations, and while these repositories may hold the longest legacy of humanity, they offer no solutions.

CHAPTER 5

Integrating Science and Society for Environmental Realism

Abstract Recent developments spanning numerous fields—including ecology, evolutionary science, psychology, sustainability, technology studies, and economics—further demonstrate the problematic nature of a solutionist paradigm and offer compelling evidence of ways forward that accept the deep interconnections between human and biophysical systems. However, consistent with the book's driving premise that environmental realism with its inherent complexity must be acknowledged, there is no singular conclusion to this work. Although the developments discussed offer reason for optimism, they also highlight the continual effort that will be required at multiple organizational levels to shape a positive trajectory for humanity.

Keywords Solutionism · Wicked problems · Evolutionary psychology · Sociobiology · Anthropocene · Environmental justice · Indigenous knowledge · Sustainability · Adaptive management · Human ecology

In many ways, the promise of the Enlightenment has been realized, as science has become a powerful force to help humans understand how biophysical and social processes function. This knowledge made it possible to manage rivers, microbes, and the nuclear fuel cycle on brief temporal and small geographical scales. But success in deciphering how systems work furthered a belief that humans are separate from these systems, and

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also created a false sense of security and a social expectation that science can provide certainty. Therefore, when people declare problems, they expect science and engineering to offer solutions to lower any perceived risk from biophysical systems. In fact, the idea of risk comes from the very ability to evaluate the world in terms of "normal" and "acceptable variation," tools provided by science. But there are processes in the world that human action cannot stop on any temporal or geographic scale, such as rainfall, earthquakes, the movement of radiation, and evolutionary adaptations. Rather, the human problems manifesting from our interactions with biophysical phenomena must be explored as the complex interplay of processes with multiple origins and paths. The biophysical phenomena do not generate risk; the cultural perception of the relationship between the phenomena and human well-being generates a sense of risk.

Science-derived knowledge can help humans understand how or why particular biophysical phenomena work, but uncertainty is always present in these explanations. Gaining knowledge of the world through scientific inquiry produces a sense of satisfaction among those who seek it. However, despite systematic study since the Enlightenment, it remains the ultimate expression of hubris to think humans can fully understand and subsequently control biophysical phenomena. Science cannot provide simple, finite solutions to what are complex political, cultural, and social concerns. Any deep comprehension of any large-scale concern requires close collaboration between disciplines and domains of knowledge (Beck 2006). Even with a robust comprehension of some biophysical system, applying the term "should," as in what action "should" humans take, moves the issue into the realm of values and perception. Once in this realm, the only resolutions to articulated problems are social and political at their core; they are not technological or scientific.

Explaining how or why a biophysical phenomenon exists does not inherently provide guidance on whether and how that knowledge should be applied. Bronowski (1956) observed half a century ago, "There is no more threatening and no more degrading doctrine than the fancy that somehow we may shelve the responsibility for making the decisions of our society by passing it to a few scientists armored with a special magic." As highlighted in this book, examples abound illustrating that despite Bronowski's warning, human societies persist in looking to science and scientists to respond to any perceived risk from biophysical phenomena. As our species expands exponentially in population, consumption, and impact, humans are entering an age where the problem/solution dichotomy is more dangerous than helpful.

Because science is embedded in sociopolitical systems, and when paired with technology offers powerful tools for society to use in deciding what should be done, the imperfect knowledge that science generates is integrated with sociopolitical ideas and desires. The case studies in this book illustrate how science has been used as a means to "settle" complex social and political arguments over how the world should look, without explicitly acknowledging and recognizing the ways that values are at the heart of these issues. We argue that reframing how scientifically produced knowledge is utilized is a critical component of challenging the problem-solution-problem cycle. Our approach has been overtly interdisciplinary in trying to better understand the origins and impacts of solutionism thinking from diverse perspectives. This includes taking seriously the role of evolution, considered broadly, in understanding and resisting solutionist ideas and in moving toward environmental realism.

Fundamentals of Human Ecology and Evolution

Reframing a social understanding of science and thinking about environmental realism includes recognizing human evolution as fundamental to our current behavior. Scientists have shown how basic ecological and evolutionary principles demonstrate the danger of expecting that science-derived innovations offer the key to humanity's challenges (Nekola et al. 2013a). As discussed in the introduction, two interacting ecological and evolutionary forces, together referred to as the Malthusian-Darwinian Dynamic (MDD), influence all populations. Put simply, the MDD is shorthand for the innate tendency of populations to keep growing, innovating as necessary along the way. A defining characteristic of the Malthusian-Darwinian Dynamic is that, following innovation, an intrinsic tendency to expand in population size and consumption until facing even stronger limits leads to the requirement for new innovation to address challenges associated with the new limits. Consequently, science and its technological innovations (an aspect of the Darwinian dynamic) cannot alone ensure long-term sustainability, and living systems (including humans) are continually facing problem-solution-problem cycles.

As multiple authors in economics and ecology have pointed out, the monumental task of shifting societal structures and behaviors toward more sustainable modes necessitates understanding the ecological and evolutionary context of the human system (Burger et al. 2012; Gowdy and Krall 2013; Martin et al. 2016; Nekola et al. 2013a; Waring 2010). A crucial component of any strategy to address biophysical limits or culturally defined "environmental problems" will require attaining a deeper understanding of complex biophysical processes to better align human population growth and resource consumption, for example, with the limits of a finite Earth. Moving toward a more sustainable mode will also require carefully evaluating how problems are labeled and characterized.

The Malthusian and Darwinian components of the MDD can be derived from the fundamental metabolic evolutionary ecology of organisms. The tendency for populations to increase their size and resource consumption until they reach resource limits constitutes the Malthusian component of the MDD. This tendency is a well-established principle that applies to all living organisms, including humans (Nekola et al. 2013a). Organisms evolved by being successful at reproduction, and so when sufficient resources are available, organisms aim to reproduce at rates that exceed mortality rates. This principle of populations as it applies to humans was first laid out by Malthus in 1798 and then was subsequently integrated into the sciences of ecology, population biology, and evolutionary biology. Interestingly, thinking of people in terms of populations also shaped social systems and underlies critical cultural theory and the social sciences (Foucault 2007).

All living systems, including individuals and social groups, have metabolisms—they acquire, transform, and allocate resources to maintain their structures, to grow and reproduce. By increasing their metabolisms, living systems can maintain more complex structures, increasing their resource stores to prepare for times of starvation, and grow and reproduce more quickly. Consequently, when resources are available, living systems have the tendency to increase their metabolism, as well as their population size, both of which lead to an increase in population-level resource consumption. However, population growth can continue only as long as sufficient resources are available and biophysical conditions remain favorable. As numbers increase, sooner or later, limits and feedbacks cause birth rates to decrease and death rates to increase, ultimately leading to an end of population growth. Living systems can continue to increase their metabolisms and population sizes by coming up with innovations, whether genetically based (e.g., morphological changes) or cultural (e.g., innovations in technology, learned behavior, and language), that push back environmental constraints such as food or water shortages.

The tendency to innovate and adapt through biological and/or cultural evolution to circumvent biophysical limits constitutes the Darwinian component of the MDD. This tendency is, of course, named after Charles Darwin, who first published the theory of evolution by natural selection in living systems (Darwin 1859), which has become a foundation of biology and medical science. Today, evolutionary biologists and social scientists are making important advances to further develop and refine evolutionary theory, expand its purview, and clarify how general principles of selection shape the evolution of the traits of organisms and groups, including cultural traits, technology, behavior, and social structure (Mesoudi et al. 2006; Danchin and Wagner 2010; Gowdy and Krall 2013; Nowak 2006).

The Malthusian dynamic pushes a population to increase until it reaches its biophysical limits; the Darwinian dynamic pushes back against these limits by incorporating new traits and technologies that enhance survival and reproduction, increasing the metabolism of individuals and populations. But, as noted in our introduction, although the MDD can lead to cycles of growth, resource shortages, environmental limits, and subsequent innovations, it does not guarantee that a population can innovate or adapt (i.e., "solve the problem") in time to avert negative consequences of resource shortages. Such consequences include increased background mortality rates, devastating epidemics, widespread famine, and debilitating warfare leading to severe reductions in quality of life, the extirpation of populations and the collapse of civilizations. The MDD (or any scientific principle) does not and cannot guarantee the timeliness of innovations, nor does it address complex issues of scale.

The key to MDD is birth and death rates. Most theories of the demographic transition (the typically observed reduction in fertility rates with economic development) suggest that increased consumption and costs of living and raising children in more economically developed countries is a driver of the demographic transition (Burger et al. 2011; Moses and Brown 2003). Thus, unless fertility policies are implemented or some new sociocultural movement for lowering fertility arises, increased global consumption will be required to reduce fertility rates to replacement levels. Analyses suggest there are insufficient energy resources to engender a global-scale demographic transition (DeLong et al. 2010). This means without fertility policies or cultural incentives to have fewer children, countries with high birth rates are likely to continue to experience high birth rates, which both stems from and causes elevated mortality rates from deficiencies in healthcare (starvation, epidemics) and war. These effects are prominent, for example, in many regions of Africa and the Middle East.

Putting all these considerations together, it becomes clear that the problem-solution-problem cycle of the MDD is not solely the result of biophysical forces but also engages deep cultural values. Technologies such as birth control pills and intrauterine devices have been available since the 1960s, but birth rates are still closely linked to health care to prevent infant deaths, emphasis on male heirs to carry the family name and property, religious values, and access to nutritious and sufficient food and clean water, as well as to opportunities to thrive socially and economically. On the other hand, reining in a population's resource consumption through technologies focused on efficiency is also not a "solution" for many reasons, including entrenched beliefs in the right to consume resources and complex webs of consumption, where goods can be cheaply imported and waste cheaply exported without examining biophysical consequences of growth.

Examples of the MDD: Ultrasociality, Agriculture, and Jevons Paradox

Numerous historical and contemporary examples highlight how the problem-solution-problem cycle arises from the MDD. One example critical to understanding *Homo sapiens* is the evolution of human's ultrasociality and adoption of agriculture. These two key innovations, which have been crucial to our remarkable success as a species, are also potent drivers of biophysical changes that threaten the future of industrial civilization (Gowdy and Krall 2013).

The evolution of *Homo sapiens'* powerful brain over the course of around 2.5 million years (Schoenemann 2006), culminating around 200,000 to 50,000 years ago, provided our species with the ability to carry out complex cooperative interactions with kin and non-kin (Sherwood et al. 2008). Enhanced memory was key to this ability, as the ability to remember favors and sleights enables the tit-for-tat nature of long-term cooperation. Along with concomitant changes in our neurological system that foster social behavior (Chiao and Blizinsky 2010), this ability has made possible the evolution of traits that underpin human's ultrasociality—complex language, culture, technology, and social structure. The subsequent development of agriculture starting roughly 12,000 years ago altered society's interaction with its biophysical environment, as well as how humans relate to each other (Gowdy and Krall 2013).

Agricultural societies entered a pattern of more-intensive resource exploitation, overshoot, and collapse (Tainter 1990), and maintaining the necessary complex infrastructure became increasingly challenging (Wickham 1984). The average quality of life, human health, and individual autonomy declined substantially (Cohen and Crane-Kramer 2007; Manning 2004). Agriculture encouraged people to live more closely together and in proximity to their domesticated animals, contributing to increased disease spread between people as well as disease spread between domesticated animals and people (Defries 2014). Additionally, the shift to grain-based diets contributed to much greater levels of tooth decay and to individual nutritional deficiencies (Defries 2014).

The transition to agriculture not only affected individuals but also catalyzed several differentiating aspects of the human organization, especially around divisions of labor and economic markets. Gowdy and Krall (2013) argue that the group as an adaptive unit came "to constitute a wholly different gestalt driven by the imperative to produce [agricultural] surplus." Individual well-being diminished in exchange for the numerical and material success of the group. The roots of capitalism emerged from the beliefs and social norms established in these early ultrasocial agricultural societies (Gowdy and Krall 2013). Capitalism exploits MDD tendencies to increase consumption, pushing individuals, local economies, corporations, and nations to focus on increasing production and consumption. As societies structure their politics and economies toward economic growth, they increase spatial scales of operations, often at the expense of the wellbeing of some individuals, communities, or nations and the overall sustainability of the human species.

Following the innovations of ultrasociality and agriculture (reflecting the Darwinian dynamic), societies grew rapidly in population and metabolism (the Malthusian dynamic). *Homo sapiens* are once again pushing against biophysical limits, including depleted agricultural soils, water shortages, and diminishing stocks of minerals and fossil fuels that are necessary for current human endeavors (Burger et al. 2012; Ehrlich and Ehrlich 2013; Graedel et al. 2015; Rockström et al. 2009; Schramski et al. 2015). Agriculture's alteration of social organization has fueled a capitalistic force that further undermines modern civilization's ability to adapt to its current predicament of global-scale resource shortages. The evolutionary ecology of human agriculture is a broad scale example of the problem-solution-problem cycle (Defries 2014); the work to solve the perceived problems of human societies has generated wicked problems that humans live with today.

There are also numerous contemporary examples of the problem-solution-problem cycle emanating from the MDD. In the case studies presented in Chapters 2–4, we showed how innovations focused on "solving" human-focused needs in river management, disease eradication, and nuclear energy production have led to a host of new problems requiring innovations of increasing complexity on ever-growing scales. In each one of these case studies, scientific and technological innovations (the Darwinian dynamic) aim to facilitate the numerical, geographic, and material spread of populations by circumventing biophysical constraints—managing flooding that prevents safe human settlement in flood zones, epidemiological and medical measures to reduce mortality rates from infectious diseases, containing radioactive waste to mitigate mortality and security risks of increasing nuclear energy production. In each case, subsequent increases in population size and consumption push against these biophysical limits, unexpected additional biophysical forces ("problems") emerge, and innovations of increasing complexity, scope, and expense are required to further circumvent the limits. The Jevons paradox (Alcott 2005; Polimeni 2012; Polimeni and Polimeni 2006; Sorrell 2009; York 2006) also exemplifies the manifestation of the Malthusian-Darwinian Dynamic.

Often when technological advances increase the efficiency of use of a resource, an economy's rate of consumption of that resource rises due to increasing demand rather than falling as might be expected. This phenomenon is called the Jevons paradox, based on Jevons' proposition that improvements in coal engine efficiency in England in the 1800s would lead to an increase in demand for coal rather than the expected decrease in consumption (Jevons 1865). Jevons' hypothesis was empirically supported. Although debate continues about the pervasiveness of the Jevons paradox, researchers have found strong evidence for the paradox in a variety of systems (Polimeni and Polimeni 2006; Saunders 1992; Sorrell 2009). One example is that as automobile fuel efficiency rose in the US between 1984 and 2001 average and total fuel consumption actually increased. An analysis suggests that increased demand for heavier vehicles (e.g., SUVs, light trucks) offset the fuel savings of the more efficient engines (York 2006). Researchers have also shown the paradox at work in water management, as efforts to reduce irrigation through conservation sometimes contribute to farmers using more water overall (Gomez and Perez-Blanco 2014; Ward and Pulido-Valazquez 2008).

Perhaps more importantly, because of the global-scale interconnectedness of modern economies, the Jevons paradox manifests at large scales (Garrett 2014; 2013). As Garrett (2014) demonstrates, "If technological changes allow global energy productivity or energy efficiency to increase, then civilization will grow faster into the resources that sustain it. This grows the economy, but it also means that energy consumption and CO_2 emissions accelerate." This global-scale manifestation of problem-solution-problem cycles resulting from the Malthusian-Darwinian Dynamic highlights the ultimate irrationality of solutionism. It further underscores the need to consider the MDD in planning humanity's future and the need for increased collaboration between economists, biologists, planetary scientists, physicists, and social scientists on these cross-scale phenomena intersecting ecology, evolution, and sociopolitical dynamics.

Complexity and the Dynamics of Innovation

Advances in scientific understanding of biophysical systems throughout the twentieth and twenty-first centuries should unequivocally dispel faith in material innovations as "solutions" for complex biophysical phenomena and narrowly defined anthropocentric goals. Nonlinear science, chaos theory, complexity science, and biological theory highlight the stochasticity inherent in complex systems, including human systems (Colbeck and Renner 2012; Svozil 1993; Wolfram 2002). More specifically, the ability of an individual to come up with an innovation ("solution") to address a particular problem is unpredictable, requiring trial and error and the imprecise navigation of complex factors. There is no certainty that individuals will innovate and adapt in time to address even well-understood and imminent human concerns in the present. In some cases, uncertainty at the societal level may be reduced because more minds focus on a problem. However, the properties of societies are not simple accumulations of their components and the nonlinear aggregation of individual-level uncertainties can amplify, rather than reduce, societal-level uncertainty in the timeliness of innovations.

Consequently, many contingencies and interactions between diverse levels and components of society, of which people may not even be aware, can hinder the innovation process, decreasing the probability that a society comes up with an innovation in the requisite timeframe. For example, funding priorities of corporations and government agencies direct a large number of inventions and scientific advances. The bottom-line of corporations is monetary growth. The priorities of government agencies reflect a combination of the current research fads dominating disciplines, the idiosyncrasies of funding program officers, and politicians angling for the greatest popular and corporate support.

The scientific community follows a messy and convoluted path of advancing knowledge, which reflects the sociopolitical interactions between scientists, individual career choices, and funding source priorities. Some scientists prioritize research questions that can be readily and quickly packaged into many publications ("publish or perish"). For a variety of reasons, funding agency program officers prioritize certain research questions over others. Because there is no magic formula for determining what the "best" or "most appropriate" research topics should be at any point in time, research is subject to the vagaries of human interest and behavior. Like many of the topics that might be studied, there is uncertainty in the decision-making process for determining what to study, who should study it, and how to study it. Yet what does get funded and therefore studied becomes the knowledge base from which any perceived "solutions" must be drawn. This further problematizes the idea of relying on science to find a singular solution because while our knowledge base is expansive, it is also always limited.

In sum, the fundamental stochasticity and complexity of social systems and the conflicting interests among different units and levels of society (individuals, corporations, governments etc.) means there is no assurance that humans can produce timely innovations (i.e., perceived solutions) to any complex problem. Extra effort may tip the scales, but it is not a panacea. As we argue, seeking such innovation should not be the focus. Rather, human societies need to grapple and literally live with the complexity and the need for continuous, wise attention to many associated wicked problems. Unfortunately, current popular and academic literature, including much scientific literature, too often continues to emphasize both the language and concepts of solutionism.

Ways Forward

We offer no simple, linear prescription for a singular "way forward" to address the issues we have raised throughout this book. For any particular concern with biophysical phenomena, there will be uncertainty and subsequent debate about what to do. We have presented evidence from diverse scholars representing a broad array of disciplines and experience. The conclusions drawn in the works we cite do not align toward any singular way forward regarding how to manage rivers, disease, radioactive waste, or any other concern. We do understand the complexity inherent in each illustration and recognize that it is this fundamental complexity that contributes to differing views. Accepting complexity and subsequent uncertainty is key to embracing environmental realism and reducing or eliminating a focus on solutions as feasible or desirable for wicked problems.

Where the evidence we have presented does point, and where our four interests align, is in recognizing the reality of wicked problems and the positive feedback loops between calling something a problem and implementing a solution, which often creates new problems. Further, we recognize that there are positive feedback loops between what we think and what we do. Therefore, a shift in how we think is directly linked to shifts in what we do. Thinking in a less solutionist way—and this includes avoiding solutionist language—will open possibilities for acting in a less solution-driven manner. Subsequently, establishing programs and projects that operate without an expectation of a singular solution reinforces the reality of the uncontrollable conditions of the biophysical systems in which we exist. It propels us to recognize and reflect on how we engage with those systems. It also reinforces the nebulous nature of the human-driven social systems operating in concert with biophysical systems.

While there is no singular way forward, we have identified numerous sites where scholars, media, and others are moving toward more complex ways of thinking and acting to push beyond the problem-solution-problem cycle. This book epitomizes synergy in action. We are not alone in thinking about the issues or ideas we have raised. As the numerous citations throughout the book indicate, various pieces of our argument are present elsewhere. We are, however, pulling these threads together in a unique way to make a broader, more comprehensive and interdisciplinary case against solutionist approaches as key to embracing environmental realism. This begins with language and hopefully results in actions that reflect a more nuanced and respectful understanding of the inherent complexities of human interactions with biophysical phenomena. Our intent here is not to provide a detailed assessment of any of the examples we present, but simply to offer the reader an idea of the types of efforts we see as pointing toward environmental realism. The works we cite offer much more detailed information about these ways forward.

New Ways of Thinking

As documented in this book, the ratcheting nature of the problem-solution-problem cycle is being recognized not just among scholars, but also in popular media (Defries 2014; Solomon 2010). This bodes well for beginning to think differently about how we socially and collectively choose to articulate problems and about the expected relationships between problems and solutions. More specific to the prevalence of solutionism, previous authors have established well the idea that technology is not a singular solution to perceived environmental issues (Morozov 2013; Huesemann and Huesemann 2011; Fox 1995). Yet, even in refuting the ideas of technological solutions, authors continue to insist that there *are* solutions but they are just not technical. This demonstrates how pervasive solutionist thinking is, and as Maxwell (1991) explained, how difficult it is to recognize that thinking in terms of solutions at all is part of the problem. While raising attention to the problem-solution-problem cycle is key to moving forward, as we note in our introduction, the reality of the problem-solution-problem cycle begs the question of what constitutes a solution.

More promising for a nonsolutionist approach to future interactions with biophysical systems is growing attention in nonscholarly media to the wicked problem concept. The key examples include journalists and bloggers emphasizing wicked or "super" wicked problems in discussing climate change (Revkin 2011; Reidy 2013; Walsh 2015). Stressing that many of society's perceived environmental problems are wicked, and hence intractable, is a trend that offers a promising path for creating a shift toward a more complex understanding of our place within biophysical systems and a letting go of the urge to find solutions for wicked problems.

This increasing attention to the problem-solution-cycle and wicked problems comes with subsequent positive changes in language. While language remains an issue in our case study topics of river management and restoration, disease preparedness, and nuclear waste management, these studies also provide evidence of shifting perspectives. The definitions of restoration in the scholarly literature are much more nuanced in 2017 than they were 20 years ago. The idealistic utopian language about the nuclear power of the 1950s has been complicated by the realizations that nuclear technologies, together with their waste products, require acknowledging negative effects and recognizing that pluralistic approaches to decision-making processes are necessary in democratic societies. Both scholars and public health officials recognize the complex, social underpinnings of infectious disease, integrating social expertise with microbial science under a banner of disease preparedness that focuses on minimizing, but not eliminating risk from disease infection, and that values some disease exposure as essential to human health. At the 2016 annual meeting of the National Association of Environmental Professionals, several posters and presentations focused on language and its importance in thinking about environmental concerns. There were very few uses of the word "solutions" throughout the meeting but instead significant attention to complexity, flexibility, and adaptability as core to practicing environmental management. There was a general sense of acknowledging unintended consequences and accepting uncertainty as an explicit part of any environmental professional's work, and further, that this complex reality must be made manifest when communicating about environmental work.

These changes in language and the subsequent thinking about problems align well with shifts in thinking about science as a way of knowing and as a valuable tool for living within biophysical systems. The shift from portraying science as speaking from "on high" with revelations about how the world works (and how it should work) to a much more complex understanding of what science can and cannot offer, reflects environmental realism and is a positive way forward. The emerging field of *psychology of science* explores how science advances knowledge, as well as how scientists think and how all humans can and do think like scientists (Feist 2006). Deepening this body of knowledge may contribute to shifting attitudes away from expecting science and subsequently scientists to solve issues emanating from biophysical systems. This emerging field may help to inculcate a broader acceptance that science can explain how and why particular phenomena occur but that scientists cannot always predict these phenomena or provide definitive answers to the question of "what should we do?"

Academic, agency, and mainstream literature increasingly attends to the need to address the perceived human/nature divide. Daily headlines hammer against the barriers that supposedly separate *Homo sapiens* from other species. As examples, research demonstrates that species ranging from prairie dogs to dolphins have complex forms of communication akin to language (Slobodchikoff et al. 2009; Ryabov 2016) and other animals adopt and transmit behaviors creating different "cultures" (Balter 2013). Individuals in many species are self-aware (Bekoff 2013), and even non-domesticated animals can differentiate and remember individual humans (Lee et al. 2016; Marzluff et al. 2012). As the culturally defined bright lines between *Homo sapiens* and other species blur, this has significant implications for changing how people think about our place within biophysical systems.

Anthropocene

The debate over a proposal to establish a new geologic epoch called the Anthropocene highlights continued tension about the human place and role within biophysical systems. Whether the fact that there is a debate is a positive way forward or whether this is simply reinforcing a perceived segregation of humans from earth history is an open question. The debate sits at the intersection of long-established ideas in geologic nomenclature and a desire to make a political statement about human impacts on biophysical systems. Those in support of the Anthropocene designation suggest that humans have so thoroughly harnessed and disrupted biophysical processes that we are now a "global geophysical force" (Steffen et al. 2007). An editorial in the journal Nature (2011) stated, "Humans may yet ensure that these early years of the Anthropocene are a geological glitch and not just a prelude to a far more severe disruption. But the first step is to recognize as the term Anthropocene invites us to do, that we are in the driver's seat." The implication here is parallel to arguments about river restoration: because humans have been unintentionally altering the Earth's climate, humans should be actively trying to return the climate to a previous preindustrial level.

Those opposed to an official geologic designation argue that the human presence has been far too short to provide a lasting record, which would be required to meet the International Commission on Stratigraphy's criteria to establish an epoch (Finney and Edwards 2016; Walker et al. 2015). As evidence, the opposition documents other large-scale disruptions that have occurred in the planet's history (e.g., a shift to an oxygen-rich atmosphere) that have not warranted serving as geologic boundaries.

There is an assumption in proposing an Anthropocene that a prehuman planet was somehow "stable," and hence, our actions have been uniquely "disruptive." The Holocene, in which modern human civilization evolved, has been quite stable and all the evidence points to humans as a driving force in changing the climate system and various ecosystems. The Holocene, however, is little more than the blink of an eye in the planet's history. For much of the rest of Earth's history massive volcanoes, earthquakes, glaciers, floods, and diverse life-forms shaped and reshaped the planet's biophysical systems. The idea that biophysical stability is or should be the "norm" does not reflect the deep time of the planet's history. An assumption that we can intentionally manage or control the planet's stability is problematic because it continues to enforce the idea that

Homo sapiens are somehow outside the biophysical systems. The Anthropocene idea simultaneously reflects multiple perspectives. One is a fear that the planet may not continue to support modern civilization and another is that we can control biophysical systems such that the planet can continue to support us. Both reflect hubris, the first, in that, human activity will leave a significant long-term signature in the planet's geologic record, and the second, in that, we are capable of directing planetary activity.

Finney and Edwards (2016) conclude that the idea of the Anthropocene is far more about politics than about science. Indeed, the term has permeated both academic and popular media invoking the interconnectedness among humans and biophysical systems with calls for action to address planetary-scale phenomena like climate change. The emergence of the term and its rapid adoption in a nongeologic sense, along with the subsequent debate about its role as a geologic delineation reflect the complexity we argue is needed to realize a more realistic approach to thinking about the environment and a human future.

Sustainability

As a modern ecological concept, the idea of sustainability has compelled different ways of thinking about and acting toward biophysical limits and the role of humans in the biophysical world. The Brundtland Commission, in its 1987 report, *Our Common Future*, defined sustainable development thusly: "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." The report went on to warn that "in the end, sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with the future as well as present needs" (United Nations 1987). The goal of sustainable development was a reaction to intensified globalized production and its concomitant resource extraction and development. It remains a powerful concept that challenges the short temporal frames in which resource development usually operates.

Almost 30 years later, the broader concept of sustainability has become normalized, and the term is ubiquitous. It has resonated with the global public, as more industries attempt to make products more "green" to entice environmentally aware consumers and as government bodies create policies that attempt to control resource extraction and development to show their sensitivity to environmental degradation and recognition of the needs of future generations. "Ensure environmental sustainability" is goal #7 of the Millennium Development Goals put forth by the United Nations, who have established a need to "integrate the principles of sustainable development into country policies and programs and reverse the loss of environmental resources" (United Nations Millennium Project 2002).

However, its very ubiquity also makes the concept of sustainability an increasingly vague term. *Sustainability science* is focused on exploring the complex relationships between humans and the biophysical world, as well as how to make that relationship more cognizant of the limits and effects of human attempts to predict and control biophysical events (Miller and Richter 2014), but translating that information into credible policy and social goals has been elusive. The Brundtland report is evidence of the trend to see sustainability as a human goal, not one that explicitly takes into account the needs or rights of other species to exist. Sustainability has been co-opted by many different actors, as evidenced by claims of "green capitalism" or "environmentally aware products" that make claims of being more sustainably produced or more biodegradable than traditional products. Yet there is little accountability for these claims, which still rationalize and justify resource consumption. There is also little recognition of global supply chains, where countries with the strictest environmental regulations still regularly displace their waste onto countries with fewer restrictions on waste disposal and little protection for laborers (Hossay 2006). Sustainable practices have influenced the supply chains and consumer demands of goods produced for human societies, but whether that has actually affected the biophysical systems on different geographical and physical scales for other species has yet to be determined.

Sustainability itself has morphed into different terms, the most relevant of which is resiliency. In a world now facing the effects of human-induced climate change, weather events and climate patterns are predicted to increase in intensity and occurrence (Jentsch et al. 2007). Resiliency relies on shifting focus from sustainable development of resources, to preparing communities for enduring and recovering from biophysical events, including new climatic patterns. Making communities more resilient to the effects of long-term drought, floods, wildfires, and earthquakes allows for specific plans to develop on a small scale driven by the needs and concerns of communities most directly affected and who are most intimately aware of their local ecological conditions (Flint 2010). A focus on community resiliency redirects sustainability efforts toward managing the effects of biophysical phenomena on a localized scale rather than a focus on resource consumption and productivity. We argue that such an approach is a way forward, as it requires understanding and adapting to biophysical phenomena rather than trying to contain or control those phenomena.

Environmental Justice

Scholars, interest groups, and members of the general public have recognized several different approaches to making human interactions with the planet more sustainable. We touch on just two of these that seem to have strong potential for getting past the problem/solution dichotomy: environmental justice and indigenous knowledge systems. These approaches widen the field of sustainability to encompass and stress different social and cultural values, understandings of biophysical systems, and alternative methodologies for adapting to and living with a changing planet. They shift the focus of conversation from science to values. For instance, environmental justice is deeply influenced by concerns from communities of color. While the movement originated in the Southern states of the US, where black communities were targeted for toxic chemical dumps (McGurty 1997), native and indigenous communities are also rife with examples of environmental injustices.

Environmental justice stresses three major frameworks for creating more just relationships between communities and social groups, as well as with biophysical systems. The first is distributive justice, which examines the distribution of goods and resources in a society. A disturbing pattern emerges in this field of inquiry, where poor communities of color are statistically far more likely to shoulder the burdens of environmental degradation without any social, political, or economic gains, compared to wealthier and white communities. The second framework is recognition justice, which looks to understand and recognize historic and structural inequities relating to race, class, and gender, especially how historical power imbalances and a lack of recognition of those power asymmetries affects how vulnerable communities access the political process of resource and risks allocation. Finally, participatory justice calls for more fair and equitable access to legal recognition, as well as information that affects community health, well-being, and ultimately, resiliency (Schlosberg 2007). Taken together, environmental justice frameworks call for examining the distribution of benefits and burdens in society by questioning how existing patterns became established, what values inform those patterns, and how to challenge negative patterns to avoid repeating them.

Another approach that emerges from concerns over contamination and historical inequities is a focus on indigenous knowledge. Placing an emphasis on an approach that is "holistic in outlook and adaptive in nature" (Berkes et al. 2000), indigenous knowledge focuses on the ways that communities have managed changes over centuries, placing an emphasis on temporal spans that are not recognized in modern capitalist economic systems. It also challenges the ways that an emphasis on modern technoscientific expertise and increasingly global capitalist structures move decision-making power away from local communities, and coupled with centuries of forceful colonization of peoples and lands, serves to erase indigenous connections to place, as well as localized forms of knowledge about biophysical systems.

To counter this, indigenous innovations in science and technology emphasize "cultural autonomy, remembrance and retrieval, self-determination, and community-based values linked with the maintenance, preservation, restoration, and revitalization of Indigenous knowledge systems that merge episteme with place and cultural practice" (Huaman 2015). The diversity and heterogeneity of indigenous communities across the globe renders this approach a powerful antidote to the homogenizing effects of economic globalization, and also allows for a plurality of methods and approaches that emphasize adaptive management (AM) based on localized knowledge of the biophysical world, to counter Enlightenment approaches that emphasize permanent, standardized fixes for "environmental problems." It can also serve as a means to begin to recognize and redress the deep inequities of colonization, resource extraction, and toxic facility and waste siting on indigenous communities. As an example, Pope Francis' Papal Encyclical explicitly linked together poverty and environmental degradation, especially for indigenous communities and the global poor, describing how "Many intensive forms of environmental exploitation and degradation not only exhaust the resources which provide local communities with their livelihood, but also undo the social structures which, for a long time, shaped cultural identity and their sense of the meaning of life and community" (Laudato Si 2015). In this Encyclical, the Pope ties together the importance of environmental justice and recognizes indigenous knowledge for sustainability, resiliency, durability, and justice as values that should be central to understanding the roots of environmental concerns humans have and how humans need to care about places and communities.

We describe these approaches to underscore that there are fields of inquiry that are already engaging with management principles that are not based on identifying singular solutions. However, it's worth noting that even these approaches are still invested in solutionist language, where sustainability scientists search for a "solutions-oriented research agenda" (Miller et al. 2014). Further, it is important to recognize, however, that solutionism and the problem-solution-problem cycle are not unique to modern societies. As the Malthusian-Darwinian Dynamic shows, the problem-solution-problem cycle is an intrinsic feature of evolving populations. Thus, sustainability, conservation, and environmental management fields should focus on developing balanced, principled frameworks that avoid overly vilifying modern/Western societies and romanticizing indigenous populations at the expense of pervasive characteristics of human behavior, thinking, and social dynamics—those which evolutionary psychologists, behavioral ecologists, evolutionary ecologists (Burger et al. 2011; Hamilton et al. 2012; Moses and Brown 2003), and evolutionary economists (Gowdy and Krall 2013; Van Den Bergh and Gowdy 2009; Waring 2010) are making steps toward more fully understanding.

Adaptive Management

The increased attention to how we think about ourselves and biophysical phenomena is reflected in changes in how humans interact with those phenomena. AM is perhaps the most specific and common form this action is taking in modern ecology and governance, linking scientific experimentation to policymaking, and biophysical systems to human political systems. Recognizing that no ecological system—let alone any cultural and social system—will remain the same for the 30+ year life of a management plan, AM attempts to bring flexibility and timeliness to institutional management, along with dynamic public engagement. Rather than attempting permanent solutions for ecological concerns, AM allows for changes in biophysical systems and cultural value systems (including a shift from a value of permanent solutions).

Holling (1978) first presented AM as a framework for handling complex natural resource issues. It took decades for the idea to cohere and be adopted into practice, but by the late 1990s, Johnson (1999) found

65 papers using “adaptive management” in their abstract or key words published in one year. US agencies under the directive of President Clinton began formally considered Holling’s and Walters’ (1986) theorizations when the Forest Ecosystem Management Assessment Team (FEMAT) explored possibilities of AM in response to heated forest management controversies in the Pacific Northwest. The FEMAT group explored how the key principles of AM, including how to assess management successes and modify approaches based on new information, could be put into practice within the federal land system.

While definitions vary widely, at its core, AM works to link management decisions to scientific experiment while allowing for “informal learning from management mistakes” (Van Cleve et al. 2004). In its most rigorous conception, AM mimics the scientific method by treating management applications as hypotheses, experimenting upon them, and evaluating their results. At its weakest, AM has come to be thought of as shorthand for “making it up as we go.” Pertinent to this book, both the positive and negative perceptions of AM recognize that the approach rejects the idea of a singular, permanent solution, and instead puts an emphasis on patience, ecological interactions with humans as part of ecological systems, and flexibility in approach and action.

Arguably, humans have always informally tested hypotheses in order to “learn from surprise” and build knowledge to inform future decisions about resource management (McLain and Lee 1996). Learning (especially from mistakes) is key, as much in management as in science. Thus, learning might formally shape policymaking practices as it does in science, linking knowledge to action.

Although AM policies typically focus on managing biophysical systems, and institutions continue to see the world according to their own norms, which are largely technical and scientific (Miller 1999), AM in practice pays notable attention to sociopolitical dimensions. Recognizing that “natural resource management problems are social in origin and any potential solutions are framed in a social context” (Stankey et al. 2006), AM openly entangles with social elements of decision-making. The work to involve stakeholders in decision-making, while not always successful, reflects AM’s commitment to legitimating many forms of knowledge from diverse sources. In principle, AM is open to traditional ecological knowledge and embraces experiential learning in the scientific realm and beyond. For AM to work, Agee

(1999) contended that it must operate in the sociopolitical world and "reduce or define," but not eliminate, the uncertainty brought by the social dimension.

In addition to its goal to attend to sociopolitical dimensions, AM acknowledges the changing nature of all systems and anticipates that surprises will come in any management process and particularly in multi-year or multi-decade plans. These surprises must be acknowledged as normal events when working in chaotic circumstances and not viewed as the result of incompetence in the methodological design or implementation (Schelhas et al. 2001). By acknowledging mistakes, managers see setbacks more as learning opportunities that are critical to informing and designing future actions, and build better understanding of the complex system. AM institutes a system of learning and adapting that resource managers can apply to management challenges. This is "learning by doing," and the key to ensuring that uncertainty, by itself, is not an appropriate rationale for not acting (MacKay et al. 2003).

In a survey of adaptive approaches to water management, MacKay et al. (2003) metaphorically describe sustainable water use as a never-ending journey. Their characterization of the "problem" illustrates how AM approaches resist solutionism, embracing a future ripe with infinite management decisions:

> We cannot stop managing once we have reached a comfortable position. New challenges and changes will face us all the time, as the political, social, economic and ecological environments around us change. We, in this generation, are tackling only the first mountain in a range: once we reach the top of this peak, we will see more mountains for the future. Even if we wished to, we could not hand over a fully achieved goal to the next generation, for them to sit back and reap the benefits. The best we can hand over is a sound process for climbing mountains, and the tools to climb the mountains that lie ahead.

At its best, AM accounts for larger, dynamic systems that evolve over time and the social reality of decision making grounded in science but influenced by changing social norms.

Perhaps the most famous application of AM strategies is the Glen Canyon Adaptive Management Program and the high-flow experimental releases of water on the Colorado River below Glen Canyon Dam. In recognizing that the dam has altered river ecology, the management plan allows managers to experiment with water releases from the dam to simulate seasonal and annual flooding that existed prior to the dam. Since 1996, managers have experimented with four high-flow releases of water. These high-energy water pulses move river sediments downstream, forming sandbars where vegetation can root and river runners can roost, and creating habitats for native fish to spawn. Through long-term research and using monitoring stations along the river, scientists gather data before, during, and after the water release. With this data, a Federal Advisory Committee consisting of diverse stakeholder groups recommends further management actions to benefit downstream resources.

Although a new 20-year plan began public review in 2016, some argue that the Glen Canyon Adaptive Management Plan has failed to sufficiently attend to the collaborative process. "Despite the establishment of a multi-stakeholder forum, the creation of a scientific data center and the provision of considerable resources, the AMP has not helped stakeholders increase their understanding of the riverine ecosystem or make useful, broadly supported, recommendations regarding its long-term management" (Susskind 2012). Such reflections on the AM process draw attention to persistent divides, or perceived divides, between experts and the lay public, by proposing that holding knowledge qualifies stakeholders to participate in planning. Echoing Enlightenment ideals about the responsibility to pursue knowledge using the privileged tools of science, these ideas affirm the primacy of scientifically derived knowledge in environmental decision-making, alongside an assumption that good scientific information will automatically generate consensus and clear ways forward. In these collaborative planning teams, stakeholders may have expectations that cannot be realized. Scientists, in particular, may be expected to provide more direction to policy than their methods and timeframe allow, and "science does not naturally provide clear policy solutions" (Van Cleve et al. 2004). Varying definitions of uncertainty among scientists and policymakers can also impede collaboration, for policymakers perceive uncertainty as risk, which must be avoided at all costs.

Despite its commitment to management over solutions, AM still centers on identifying a singular problem. "Failure to ensure effective problem identification and subsequent action often leads to: stating the problem so it cannot be solved, solving the wrong problem, solving a solution, (and) trying to get agreement on the solution before there is agreement on the problem" (Clark et al. 1999). Diverging from the endless mountain chain vision, AM in practice still centers on the search for solutions, if temporary, adaptive solutions. Stankey et al. (2005) see within AM processes an "inappropriate attention to symptoms and solutions, . . . challenging because it is ultimately a social undertaking involving a variety of perspectives and experiences (that) must transcend its limitations as a scientific endeavor."

Evolutionary Approaches

Various scholars and practitioners have put forth a multitude of ideas for engendering more sustainable thought and action by employing evidence of how human cognition and behavior evolved. Recent scholarship supporting the idea of working with evolved human tendencies rather than fighting against them reflects yet another positive way forward. Some specific ideas include emphasizing benefits to kin when promoting conservation; using people who look alike to promote specific conservation measures in particular groups; emphasizing individual reputation within large groups, such as "naming and shaming" campaigns to get individuals or corporations to change behavior; encouraging competition for pro-environmental behavior; encouraging high status markers for people who engage in positive behavior; depicting women preferring men who engage in pro-environmental behavior; and creating visible links between behavior and immediate environmental consequences (Mysterud and Penn 2007; Griskevicius et al. 2012; Vugt et al. 2014). Accepting that there are evolutionary bases for human cognition and behavior is one necessary step toward addressing many of the issues identified in this book. Subsequently, exploring more deeply how knowledge about our evolutionary history might be applied to promote new ways of thinking and acting is a promising way forward.

In addition to thinking about individual behavior, there is value in accepting and exploring evolution-based social practices. Because the MDD is likely relevant to the evolution of cooperation, understanding the MDD may offer important insight into developing governance strategies and policies that encourage social norms that favor more sustainable, resilient, or adaptive actions (Gowdy and Krall 2013; Nekola et al. 2013a; Waring 2010). The evolution of such behaviors and norms will play an integral role in the trajectory of human history (Ehrlich 2009; Kinzig et al. 2013; Nekola et al. 2013a, 2013b).

Challenging behavior that drives the problem-solution-problem cycle requires shifts in perspectives and values. As Martin et al. (2016)

eloquently point out there is an alternative to a “fatalist acceptance of the incompatibility of our desires, and of the values and representations that shape them, with the limits of the biosphere.” A first step toward changing behavior is accepting that environmentally conscious behaviors can have direct positive impacts on individual well-being. Although choosing daily lifestyles that reduce resource consumption is often considered self-deprivation or a symbol of poverty, this view rests on a failure to recognize that such shifts can be an opportunity to improve the quality of life. For example, for most people, shifting from car to bicycle for short trips is viewed as self-deprivation. However, individuals who have made the change in their lives report gains in freedom, pleasure, and health (Garrard et al. 2012). As Martin et al. (2016) wrote, the challenge is “achieving greater ability to juxtapose desires, values, and representations with limits imposed by reality to adjust each of them through technological and environmental sobriety and literacy.”

The hurdles toward incorporating environmental ethics and more sustainable or adaptive behaviors, however, are manifold. Due to the MDD, organisms, including humans, are inclined toward resource exploitation, overconsumption, nepotism, and population growth, as the fields of evolutionary and social psychology increasingly show (Griskevicius et al. 2012; Vugt et al. 2014). Furthermore, the “anesthetic effect of modern comfort may result in psychological weakening preventing a decisive shift from the current ‘age of plunder’ toward an ‘age of respect’ that accepts a world governed by biophysical limits” (Martin et al. 2016). While our evolutionary history can help explain the MDD dynamic, it also offers insight into how to promote desirable social traits to help reduce the culture/nature divide and promote a more sustainable future for *Homo sapiens*. For example, consumption patterns have changed in a very short timescale. The socioeconomic changes associated with World War II demonstrate this. Enormous changes in production and consumption occurred in the US during the war, as Americans accepted gasoline, sugar, and meat rationing (Ehrlich 2010). An important priority for sustainability science should thus be to understand how to replicate such dramatic behavioral changes, but in response to biophysical limits rather than warfare.

Many ideas related to *Homo sapiens* evolution are controversial, and of course, understanding is continually being refined. One factor that may inform discomfort with evolution as driving contemporary behavior is that it challenges deeply embedded desires to see humans as exceptional and outside biophysical reality. Evolutionary roots of nonhuman animal behavior are fully accepted, but it is controversial to think about human behavior in that same way. Further, it is acceptable to think about human evolution below the neck as a given, but somehow it is not as relevant when thinking about our big brains. Wilson encountered this in 1975 when he first published his landmark book on sociobiology, which described the evolutionary roots of social behavior among diverse species. His ideas about nonhuman animal behavior were lauded. Thirty of the 575 pages, however, included humans as social animals and this "ignited the most tumultuous academic controversy of the 1970s, one that spilled out of biology and into the social sciences and humanities" (Wilson 2000). Indeed, much of the debate over the concept was found in fears about its political ramifications, including potentially providing support for eugenics and social Darwinism (Jumonville 2002). While ignoring the potential political ramifications of any science finding is naïve, ignoring the reality of evolution represents a significant barrier to developing realistic ways to implement resilient, adaptive approaches. Continued and increased attention to understanding human evolution and recognizing the role that evolutionary processes have played and continue to play in human thought and behavior is key to environmental realism. Such research includes trying to better understand why solutionism is so appealing and how to push against or productively coopt that appeal.

Despite the above controversies, evolutionary scientists are making important headway in understanding how selection dynamics can operate simultaneously on multiple levels of organization in both genetic and cultural/political systems (e.g., Bonner 1980; Boyd and Richerson 1988; Calcott and Sterelny 2011; Feldman and Laland 1996; Michod 2000; Nowak 2006; Turchin 2010; Waring et al. 2015). This work indicates that sociopolitical movements and economic transformations favoring sustainability and resilience will have to manage extremes of the individualism-collectivism continuum across all scales and levels of sociopolitical and economic organization, from families, neighborhoods, and local businesses to cities, nations, and international alliances and corporations.

In all living systems, there is always tension between the predilections and dynamics of evolutionary units at lower levels of organization (e.g., an individual human or an animal cell) and the proclivities of the higher-level units of organization (such as a town, corporation, or organism composed of a collection of living cells). Too much emphasis on either extreme—individualism or collectivism, lower-level units or higher-level units—increases sociopolitical instability and reduces resilience. Overemphasis at the individual level enhances inertia of existing sociopolitical structures and consequently the resistance to changes potentially conducive to long-term sustainability. Extreme individualism undermines cohesive forces maintaining organization above the level of the individual unit and inhibits implementing long-term actions that have (or appear to have) negative short-term consequences to the individual's way of living. Overemphasis on collectivism at a particular higher-level unit, at the expense of lower and other higher levels, leads to increased conflict between the multiple entities existing at the particular level, such as fighting between nations due to national pride and territoriality. And, it sensitizes the unit to the idiosyncrasies and vagaries of the actors and norms shaping it, even when such vagaries are detrimental.

Given the global reality of the human economy, efforts toward sustaining the modern human enterprise will require addressing global-scale units of organization that aim to manage and reduce the impact of humans on biophysical systems. Coalitions between nations can play an important role. Yet the success of such coalitions depends on the ability of national leaders to weigh the concerns of the coalition over national political concerns. This is a difficult task given the diversity of cultures, ethnic/national pride, and political complexities of implementing actions in democracies. In contrast to seeking coalitions between nations, global-scale social movements, streamlined by communication and networking technologies of social media, may help circumvent national and ethnic concerns, helping bridge levels of organization between concerns of individuals and global sustainability. However, because of the intrinsic tensions between different evolutionary levels of organization, sustaining an industrial way of life will require adaptive, multi-tiered approaches that integrate forces across all levels of human organization, from individual humans to global coalitions and social movements.

More Science

The idea of "embracing complexity" or "accepting uncertainty" could be interpreted as rejecting science or as a call to simply accept what is. But we argue that "embracing complexity" actually calls for MORE science, for a stronger and deeper understanding of humans and of the biophysical systems in which we live. We argue that more attention to traditional scientific studies of biophysical systems are necessary as is more attention to concepts like MDD. We cannot ignore the science of humans and our history, which is by definition intertwined with the biophysical systems in which *Homo sapiens* evolved. Linking our evolutionary history with our attempts to understand biophysical systems offers a powerful way forward. As one example, LiDAR and other imaging technology are being used to show how river channels have migrated over time, to see what land cover has looked like through time, and to find ruins of previous human civilizations. Because humans have evolved to rely heavily on sight, we tend to believe what we see. Therefore, these visualizations can help people better understand that biophysical systems, including the human role in those systems, are complex and dynamic and always have been.

A call for more scientific studies, however, is not a call for more solutions. It reflects a need for more science coupled with an acceptance that the more we know about the world, the more complex it will become for us. Additionally, multiple fields in the humanities and social sciences have long wrestled with complexity and uncertainty. This work and the diverse perspectives it developed should not be dropped—they are essential to maintain a diverse, resilient knowledge portfolio. However, we suggest that more effort should be placed toward a consilience of these diverse schools of thought and stronger integration with the sciences, particularly evolutionary and ecological sciences. Scientists, especially academics, need to more fully incorporate tools and perspectives from the humanities and social sciences into education, funding decisions, and research, and nonscientist scholars similarly should put more effort into incorporating scientific approaches and evolutionary understanding into their research and pedagogy. While there will always be a need for individuals who specialize and drill deeply into a narrow subject, society also needs scholars who see a larger picture and can understand and communicate where various research threads intersect.

Concluding Remarks

There is no neat, clear, and singular conclusion to this book. To offer such a thing would be counterproductive to our entire premise and would not accurately reflect our individual perceptions. Our work together models what we propose as a way forward in addressing perceived concerns with biophysical phenomena. We did not endeavor to reach consensus on each and every point or example, and rather than reaching some culminating singular conclusion we each drafted a short synopsis of our individual "take away message" and then pulled some common threads from those remarks. These synopses are not in any particular order.

Synopsis 1 Discoursing and Analyzing Desired Futures of Humanity

Crucial to the development of a sustainability science grounded in environmental realism is engaging in open and deliberate discourse on the desired futures for humanity. Such discourse must ultimately wrestle with questions of how many people we wish to have on the planet, the geographical distribution of people, and the amount consumed by each individual. These discussions must be civil and patiently but persistently conducted. Thought experiments of extreme visions for the future of humanity provide a tool for confronting the values and assumptions underpinning perspectives and scenarios of sustainability. One extreme vision is sustainably maximizing global population size (while providing "reasonable" health for every individual), in which case per capita consumption must be drastically reduced and regulated. Another extreme is maximizing the materiality and consumptive choices of every individual, in which case population size needs to be reduced. Neither scenario is necessarily ethically or environmentally favorable over the other and most individuals surely favor a scenario falling somewhere between such extremes. Individual happiness, fulfillment, or reduced sadness are considered by many more important than material/monetary wealth, and these emotional states are not related to each other and wealth in a simple, straightforward way (Borrero et al. 2013; Guillen-Royo and Kasser 2015; Kushlev et al. 2015; Oishi and Kesebir 2015). Yet happiness and satisfaction can be elusive goals, with paths to happiness or fulfillment being multifarious, idiosyncratic, and culturally dependent.

Underlying all scenarios for humanity are assumptions regarding the ways by which reproduction will be regulated by society or indirectly through ecological feedbacks. Although freedom of reproduction is considered an "inalienable right" by many groups, with many individuals reporting increased happiness or fulfillment resulting from reproduction, it is subjected to regulation by states, including democratic ones (e.g., antiabortion laws), and is based, like all rights, on the values and interests of its people (Quigley 2010). It is not evident that fertility rates (regionally and globally) will decline sufficiently on their own (due to phenomena such as the demographic transition; (e.g., DeLong et al. 2010)) before populations grow to unwieldy sizes even more susceptible to calamities, such as civil war, epidemics of starvation or nutrient deficiencies, and megacities of refugees from rising sea levels who are provided with limited government support due to overtaxed governments. And, for resource-limited populations, high fertility rates lead to high mortality rates or displaced populations that also require ethical considerations. So, the treatment of reproductive rights plays a fundamental role in future scenarios for humanity.

In order to move forward with discourse and policy-making, it is important to recognize and analyze the challenges toward implementing any one of these scenarios other than the status quo. Individual preferences vary dramatically both within and across states. Although increased homogenization of preferences within states (whether "naturally" or through government policies) can facilitate decision-making, it cannot provide a singular viable approach, as the potential sustainability of industrial societies is fundamentally a linked, global phenomenon (given the interconnectedness of industrial economies and global scale of human impacts). Furthermore, there will always be differences in preferences among and within nations, and these preferences can be directly conflicting, instigating war and undermining efforts toward global sustainability. Thus, the global approach has to represent an amalgamation of diverse local and regional approaches implemented by communities and nations. The amalgamations that reduce conflict and increase resource efficiency and societal stability are preferable. But, as in other complex and multi-dimensional optimization problems, there is no singular optimal combination of scenarios (or variables) and the global amalgamation of scenarios will have to continually shift dynamically as cultures, physical geography, and resources evolve. Humanity will continually have to adaptively and multilaterally regulate conflict, metabolism, and growth in order to persist as a global civilization.

Synopsis 2 Embracing the Geological and Biophysical Big Picture

The relative temporal span of human existence on this planet is brief, from a geological perspective. We live short lives, but those lives are made meaningful by relationships—with other humans, other species, and with the biophysical properties of the Earth that supports all of us. Understanding the interconnectedness of ecological webs underpinning the survival of all species on the planet, and repositioning humans within that web instead of outside of it, is a long-term educational, cultural, and political project, not one solved with the application of science and technology predicated on a superior understanding and absolute control of biophysical processes. Climate change is a symptom of a commitment to the rampant use of resources and misrecognition of what environmental resources are really worth. We are only beginning to understand the changes that humans have wrought in relation to climate change; now we must collectively manage those changes simultaneously.

We have opportunities today to re-make and re-forge our relationship with the Earth, to look at how diverse and disparate communities have lived on the planet, and to challenge the assumption that there are solutions to problems that arise from living on a dynamic planet with a growing population. As human numbers have swelled, the pressure on the planet to provide resources to support humans has also increased to rates never before seen in human history. This can be seen as a sign of success for a species, to quell disease and control the biophysical world to such an extent that billions of people can occupy the planet. But this growth is unsustainable, and also its fruits are uneven. In a world organized into individual nation-states, the wealthiest countries can displace environmental burdens onto the politically weakest states, extracting goods and resources to increase their wealth while increasing global inequality and climate debt between the global North and South. Political instability and resource scarcity are not problems to be "solved," but rather rooted in relationships between human societies and with the biophysical world that need to be re-evaluated.

Taking other perspectives into account, and learning and recognizing relationships that different cultures have had with the biophysical world, would illuminate new paths and directions that could lead to more sustainable and less exploitative relationships. Instead of denigrating other cultures' approaches to working with and managing the biophysical world, Western cultures born of the Enlightenment need to recognize that even though scientific advancements allowed for the rapid growth of humans, they cannot sustain that growth in a socially or environmentally responsible way. The hubris of the Enlightenment tradition, in which the natural world is completely knowable, predictable, and controllable, has resulted in significant shifts to climatic patterns that cannot be prevented, but only managed, through mitigation, adaptation, and a recognition of the patterns of consumption that resulted in such global change. Science has a powerful and influential role to play in this new chapter of human history, but scientists cannot solve problems that are rooted in our complex relationship within the biophysical world, and must begin by challenging the language we use to distance ourselves from that world.

Synopsis 3 Deep Time Is the Reality

Earth has existed for 4.5 billion years. Life has existed on the planet for 4 billion years. Most life-forms that have ever existed are now extinct. The Earth and life, in some form, will exist until the sun collapses in 5 billion years, more or less.

These are some bare essentials of environmental realism.

More realism: *Homo sapiens* are not special. The animal that became genus *Homo* evolved roughly 2.5 million years ago, making the human tenure on Earth thus far quite short. Someday humans, like all life-forms, will become extinct.

In evolutionary terms, humans are highly adaptive and have been reproductively successful, as demonstrated by our 7+ billion individuals living in a diverse array of ecosystems. Like all species, *Homo sapiens* modify their environment to acquire resources that ensure survival and reproductive success. Self and community preservation have strong evolutionary drivers, and hence efforts to reduce risk from biophysical systems have a long history. Science as a way to comprehend biophysical systems has provided a powerful tool for reducing risk. The "solutions" identified to reduce risks to individuals and communities have catalyzed a diverse array of contemporary "environmental problems."

This book envisions a reality that neither demonizes nor canonizes *Homo sapiens.* A key message is the need to think about language and subsequent action that better reflects environmental realism. For example, the idea that humans can or need to "save the planet" is nonsensical. Humans are causing a significantly large-scale change to some biophysical systems, but such change is not new to the planet. In fact, previous widespread change (e.g., water, oxygen) provided conditions conducive to human (and other species) evolution. Microbes and fungi have also catalyzed widespread changes for biophysical systems (e.g., plague, pox, influenza, potato blight, Dutch elm disease). Thinking that the human-caused change is in some way more unique geologically than these other events is arrogant and makes the idea of declaring a geologic era the Anthropocene quite troubling. In fact, several geologists and this author, recently coined the term Hubriscene as a more apt description of the arguments being put forth to support creating an official (artificial) span of geologic time.

Most pertinent, thinking in terms of "solving" human-caused local or global scale change does not reflect environmental reality. If we want to not think in solutionist ways, we need to not use solutionist language. This book is a call to consider the complexity inherent in biophysical systems and the enduring power of language to frame relationships among human and biophysical systems. Learning as much as possible about biophysical systems, the human role in those systems, and how those systems impact human civilization is a productive way forward. Addressing any specific concern, such as CO_2 levels, water availability, or habitat loss, requires accepting that biophysical systems are dynamic. This means accepting change as normal and communicating in a way that enforces this knowledge. Within dynamic conditions, thinking in terms of flexibility, resilience, and adaptation is more realistic than "solving." Adapting means accepting the evolutionary roots of human cognition and behavior and working with that knowledge. Adapting may mean reducing individual rights, including a perceived right to reproduce or to have access to resources. As Worster (1994) has observed, long lasting societies made and stringently enforced lots of rules about their behavior with each other and their relationship with biophysical systems. Environmental realism means reducing individual freedom if the goal is to ensure a long planetary tenure for *Homo sapiens.*

Synopsis 4 Toward Overturning the Solutionism Entrenched in Institutions

I write this summary perspective after working more than a decade in a federal agency, work that provoked my curiosity about how management operations could grow in scope and impact by avoiding solutionist thinking, reshaping the socio-biological qualities of landscapes. The mission statements of the agencies that manage public lands in the US reverberate words like "preserve unimpaired," "conserve," and "sustain," indicating a broad public charge to manage landscapes that are unchanged over time and which will exist in the future in ways that provide similar benefit to human life as they do in the present.

At the same time, my colleagues in this employment had a notable capacity to think about change in terms of evolutionary and human processes, and to use the biophysical world alongside our human history to illustrate dynamic processes at play over time and space. Many people spoke daily of the inherent change within systems of geology, human history, and evolution, but they simultaneously cultivated an ideological connection to preservation, conservation, and restoration. Recognizing the impossibility of preserving ecosystems influenced by pollution, climate change, and population growth and with limited budgets, land managers feel the impossibility of "solving" even as they address numerous aspects of their work as problems to be solved.

Beyond the culture of a workplace, fiscal pressures fuel the public and private work to create solutions. When government employees spend taxpayer money on a project, the citizenry holds them accountable for that work by demanding measurable results. Federal budgets renewed on an annual basis shorten the scope of many projects which must prove their worth within a year in order to attain another year of funding. When private foundations grant money for a project, they require reports that delineate solutions-oriented outcomes achieved through the funding. Managers who "solve problems" are promoted and given bonuses, perhaps in spite of consequences generated by their solutions. Even organizations like TED Talks perpetuate the idea that success is measured in problem-solving, and solutions can be distributed through quick 10-minute speeches. The structures of workplaces sustain solutionist thinking by requiring measurable results and linking those results to salary, budget, and employability. In order to empower employees to devote time to complex issues, these institutional structures must bend toward new assessments of success and time usage.

Finally, as one example of the power of public institutions to bring changes through new language, the director of one US land management agency has directed employees to use language about climate change whenever they engage with the public. Not only does this directive ensure that citizens who interact with these places are thinking about changing climates, but the directive pervades the culture of the workplace. During staff meetings, employees ask how certain initiatives relate to climate change. Individuals working in natural resource management can converse with facilities managers in a shared language. I propose that through similar social and institutional commitment to speak precisely about management actions, avoiding solutionist language, broader shifts in public thinking about the work of landscape managers can begin to take hold. Language matters because it is the tool through which we build shared understandings of ideas and converse about our human values and individual perspectives on the world in which we live.

An Ending. . . .

Our individual synopses highlight some significant differences in our perspectives. They also highlight much common ground. Accepting *both* the commonalities and the differences is key, so we do not attempt to reconcile the differences or privilege what we find in common. Sharing the messiness of our perspectives reflects a core point of agreement among us, which is that we need to consistently accept that there are multiple perspectives, multiple ideas, and multiple paths forward.

Throughout this book, our contention has been that the nexus of perceiving humans as separate from biophysical systems and the subsequent faith in human ability to contain and control biophysical processes is at the root of the conviction that society faces diverse "environmental problems." Thus, although these cognitive and philosophical characteristics of modern societies were integral to *Homo sapiens* remarkable population and material expansion, achieving sustainability or resilience for modern societies will require transforming this misleading worldview into one that emphasizes the reality of social, cultural, and political systems as fully integrated with biophysical systems.

Such a transformation will require intensified research about *Homo sapiens* and our evolutionary history as well as about the biophysical systems in which we live. Environmental realism suggests that we should resist the urge to try to create permanent solutions, which fail to recognize the complexity and stochasticity inherent in biophysical systems. We should recognize that acting for the sake of acting is not necessarily positive, that not taking "big" action does not mean we are doing nothing, and that sometimes waiting to see what happens is okay. It is likely a good idea to leave flexibility for future generations. One step toward making such a transformation is accepting and relying upon the linkages connecting what we think, what we say, and what, on wise reflection, we do.

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