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Anthropocene World / Anthropocene Waters

A Historical Examination of Ideas and Agency

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When I was in high school in the first half of the 1960s, I was fascinated by science fiction. The concept of terraforming was one of the key themes in the science fiction that I read. In the fantastic and fanciful worlds created by science fiction writers, human beings employed science and technology and energy to refashion (or terraform) the hostile environments of alien planets to support human life. The word *terraform* first appeared in print in July 1942. A writer named Jack Williamson employed it in an article titled "Collision Orbit," published in a magazine called *Astounding Science Fiction*. In the early 1950s, the great trio of science fiction writers, Robert Heinlein, Arthur C. Clarke, and Isaac Asimov, adopted and used *terraform* in a way that influenced popular culture (Heinlein 1950; Clarke 1951; Asimov 1952; Fogg 1995). By the early twenty-first century, a descriptive term coined by a science fiction writer and published in a science fiction pulp magazine in 1942 would be superseded by a concept generated by one of the world's leading atmospheric scientists—a concept that would highlight the dominant role played by human beings in fundamentally transforming (or terraforming) the environment of our own planet Earth.

Use of the word *terraform* by leading science fiction writers in the 1950s corresponded with a widespread faith in science and technology and cheap, abundant fossil fuel and natural resources to solve pressing social problems and improve the quality of life here on earth. Large, American-made automobiles powered by gas-guzzling internal combustion engines represented a material symbol of the good life that resources and energy and industrial production could provide.[1] Seemingly amazing products of organic chemistry offered technical fixes for pressing issues that had long plagued human populations. Petroleum-based synthetic organic pesticides promised to rid humanity of the scourge of insects that spread disease and ruined crops; combined with synthetic organic fertilizers and herbicides these new compounds held out the potential for a green revolution that would allow fewer farmers to feed ever more people. Chlorofluorocarbons used as refrigerants made in-home refrigerators much safer and facilitated the routine use of air-conditioning, which in turn enhanced comfort levels for tens of millions worldwide.[2] More food and better public health contributed to a rising global population.

Fast forward to the early 1970s—on December 7, 1972, just past the peak of the popular, ecology-based environmental movement, *Apollo 17* sent back the classic "Blue Marble" photo, showing the earth wrapped in its envelope of atmosphere hanging in the black vastness of space.[3] As we tentatively moved out into space, one of the most inspiring outcomes was to look back and gain a new angle of vision on our own earth. At approximately the same time, the research of atmospheric scientists undertaken in the late 1960s and the first half of the 1970s eventually contributed to a significant, new way of seeing our "Blue Marble." Life-sustaining atmospheric systems proved vulnerable to consequences of human action, including but not limited to burning fossil fuel in internal combustion engines and the widespread use of artificial fertilizer and chlorofluorocarbons.

Paul Crutzen earned his PhD with highest distinction in 1968 at the Meteorology Institute, Stockholm University, writing a dissertation titled, "Determination of Parameters Appearing in the 'Dry' and the 'Wet' Photochemical Theories for Ozone in the Stratosphere." In 1970, Crutzen published an important article in which he referenced earlier research reporting that nitrous oxide (N_2O) likely produced naturally by bacteria in the soil could influence the levels of nitrogen oxides (NO and NO_2) in the stratosphere. Building on those findings, Crutzen observed that "the NO and NO_2 concentrations have a direct controlling effect on the ozone distributions in a large part of the stratosphere, and consequently on the atmospheric ozone production rates" (Crutzen 1970, 320). Crutzen's findings were poised to become one of two important streams of research that established links between human agency and a relatively small but crucial layer of ozone high in the stratosphere that protected people and most other life on earth from the potentially harmful impact of the sun's ultraviolet rays. Ultimately, that research would not only transform scientific understanding of atmospheric systems, but also held the potential to revolutionize the ways in which human beings understand their relationship with the earth's environment.

In subsequent publications, Crutzen postulated that anthropogenic emissions from increasing use of artificial fertilizer and high-flying supersonic aircraft might add to the levels of nitrogen oxides in the stratosphere, and augmented levels of nitrogen oxides could deplete the earth's crucial ozone layer. "It has been indicated during recent years," Crutzen argued in 1974, "that important reductions in atmospheric ozone may be caused by a number of human activities such as stratospheric aviation, increased use of nitrates as fertilizers and the use of chlorofluoromethanes (mostly known under the name 'freons')" (Crutzen 1974, 201; see also Crutzen and Ehhalt 1977). Crutzen's research highlighted connections between single-purpose technologies that may have fulfilled their primary purposes very well and unintended or unanticipated consequences that produced adverse impacts on the stratospheric ozone layer. Reflecting on his choice of a research topic, Crutzen explained, "I wanted to do pure science related to natural processes and therefore I picked stratospheric ozone as my subject, without the slightest anticipation of what lay ahead" ("Paul J. Crutzen—Biographical" 1995).

In the early 1970s, another, related stream of atmospheric research emerged that called attention to the harmful effects of a common and widely used refrigerant on stratospheric ozone. Chlorofluorocarbons (CFCs), which are synthetic organic compounds composed of carbon, fluorine, and chlorine, were first synthesized in the United States in the late 1920s as a safe alternative to chemicals then widely used as coolants in refrigerators. After World War II, CFCs (usually sold under the trade name Freon) came into widespread, worldwide use as propellants in aerosol containers, coolants in air conditioners and refrigerators, and solvents (Elkins 1999).

In 1974, Crutzen read a draft research report on the potential adverse impact of chlorofluoromethanes (marketed as Freon 31) on the ozone layer coauthored by Frank S. Rowland, a chemistry professor at the University of California, Irvine, and Mario J. Molina, a Mexican national working with Rowland as his postdoctoral associate (European Space Agency n.d.). The research by Roland and Molina revealed that Freon, which was stable and inert in the lower atmosphere, broke down in the stratosphere and released chlorine, which destroyed ozone. Crutzen responded to their research by examining a closely related compound and developing a model of the ozone depletion that could result from continued use of chlorofluorocarbons. His research yielded a sobering prediction: "up to 40% of ozone would be depleted at the 1974 rate" (European Space Agency n.d.).

Research published in 1985 by three scientists working for British Arctic Survey Stations revealed seasonal drops in stratospheric ozone above Antarctica likely caused by the action of chlorine associated with CFCs. The scientists themselves demonstrated an abundance of professional caution as their investigations moved forward, one of them arguing in 1987 that "the evidence implicating total chlorine, and hence the CFCs, remains circumstantial. It should, nevertheless, be heeded until more direct evidence can be obtained" (Farman 1987, 644; see also Farman, Gardiner, and Shanklin 1985). Their discovery of what quickly became known as the "ozone hole" added to accumulating evidence of a negative connection between widespread use of CFCs and ozone depletion.

The findings of Crutzen, Rowland, and Molina, as well as scientists associated with the British Arctic Survey Stations, contributed directly to the Protocol on Substances that Deplete the Ozone Layer, signed in Montreal, Canada, in September 1987 and "entered into force" on January 1, 1989. When combined with several subsequent adjustments between March 1991 and May 2008, the Montreal Protocol led to strict worldwide controls on CFCs and other ozone-depleting compounds (UNEP Ozone Secretariat 2016; Elkins 1999). In 1995, Crutzen, Rowland, and Molina shared the Nobel Prize in chemistry for their findings on ozone depletion. Their scholarship helped focus scientific attention on the powerful and significant impact of human activities on earth systems. It also turned out to be one of the few successful worldwide responses to the environmental consequences of human actions to take place in the late twentieth century.

At least in the case of CFCs and the "ozone hole," cutting-edge scientific research also caught the attention of a broad international public and officials of the forty-six nations that signed the Montreal Protocol (UNEP Ozone Secretariat 2016). Looking ahead to other international and worldwide environmental problems, such as access to and distribution of freshwater and climate change, "fixing" the ozone hole proved to be deceptively simple. Complex and complicated atmospheric science could be boiled down to a relatively easy-to-understand, near-term, and direct cause-and-effect problem: CFCs and related compounds were destroying the essential ozone layer, which in turn would have a significant, measurable, and detrimental impact on the health of human beings worldwide. And the solution was a relatively "simple" technical fix that did not require people to effect any significant changes in values and expectations or to accept alterations in lifestyle or standard of living. Political leaders who lined up behind the Montreal Protocol and elimination of CFCs did so knowing that they faced a very low risk of backlash from their constituents. All that was required was to substitute a new chemical refrigerant for Freon without any corresponding need to cut back on air-conditioning or anything else.

Fast forward again, to the early twenty-first century. Between 1800 and 2011, the earth's population increased from 0.98 billion to 6.9 billion, with the most rapid increases taking place in the past century. In 1950, when Robert Heinlein and Arthur C. Clarke and Isaac Asimov wrote about terraforming distant planets, the world's population stood at 2.52 billion. In 2013, the world supported more than 7 billion inhabitants. A pronounced trend toward urbanization has accompanied explosive population growth. In 1950, 29.4 percent of the world's population resided in cities. By 2011, the percentage of the world's population living in cities had risen to 52.1—with a clear developmental trend being concentration in ever larger cities (U.N., Department of Economic and Social Affairs, Population Division 2012, 4–6). Rapid population growth and urbanization pose serious challenges for access to safe, clean freshwater and for disposal of waste- and storm water runoff.

Population growth and urbanization in the past century were facilitated by a dramatic shift from solar energy to fossil fuel and a massive increase in the use of energy. Climate change stands at the head of the list of the unintended and unanticipated consequences of burning all of that fossil fuel in the atmosphere—illustrated at least in part by a rapid rise in atmospheric carbon dioxide (Intergovernmental Panel on Climate Change 2013b, 2). Growth patterns of population, energy use, and carbon dioxide reveal two important and interrelated historical trends: (1) the pace of change accelerated rapidly in the past one hundred years; and (2) most of the key variables that illustrate and reflect changes in earth systems follow an exponential growth pattern. It is worth noting that the long, slow period of "approach" to the "elbow" of an exponential curve represents an important part of the historical/developmental trend of the variable in question.

In 2000, Crutzen coined the term "Anthropocene" to describe a new geological epoch in which human action had become the primary driver of environmental change. According to Fred Pearce writing in *With Speed and Violence: Why Scientists Fear Tipping Points in Climate Change* (2008), Crutzen told him:

> I was at a conference where someone said something about the Holocene, the long period of relatively stable climate since the end of the last ice age. . . . I suddenly thought that this was wrong. The world has changed too much. So I said: "No, we are in the Anthropocene." I just made up the word on the spur of the moment. Everyone was shocked. But it seems to have stuck. (Pearce 2008, 44)

Crutzen's towering scientific reputation bolstered by his Nobel Prize instantly conferred a high level of authority and credibility on his declaration of the Anthropocene. It is not at all surprising that the term and its initial use originated with scientists who addressed their research to human impacts on global atmospheric systems, including climate change. After all, the Anthropocene refers to new sets of circumstances where the results of human actions impact global environmental conditions and actually produce a stratigraphic record. The term "Anthropocene" rapidly and informally entered the scientific literature, used to emphasize the dominant role of human activity in shaping the global environment (Zalasiewicz et al. 2008 ; Andersson, Mackenzie, and Lerman 2005; Crossland et al. 2006; Steffen et al. 2004; Syvitski et al. 2005). Through the lens of the Anthropocene, the boundaries between natural and human history blur; understanding the present-day environment requires paying as much attention to human agency over time as it does to the evolutionary trajectory of natural processes.

Species extinction represents a global phenomenon that has left distinct fossil evidence that can be identified in the stratigraphic record. In the past 540 million years, the earth has experienced five periods of mass extinction when at least 75 percent of the estimated species comprising earth's biota disappeared. While it is likely that each of the "Big Five" extinctions was precipitated by different causes, they all had at least two things in common. First, we know about these episodes of mass extinction by studying fossil evidence originally deposited in layers of sedimentary rock. The fossil record in effect serves as the "database" or the "archive" that documents the evolution of life on earth. Second, mass extinctions one through five took place in the complete absence of human agency.

Within the past few decades, scientists have begun arguing that earth may be entering a sixth period of mass extinction—driven directly by the actions of people.[4] Some of the new information, and especially that aimed at public audiences, declares that this sixth mass extinction is already under way. In the fall of 2014, National Public Television in the United States broadcast a documentary film titled *From Billions to None: The Passenger Pigeons' Flight to Extinction* (Mrazek 2014), which follows the naturalist Joel Greenberg, author of *A Feathered River Across the Sky: The Passenger Pigeon's Flight to Extinction* (2014). At the time of European contact passenger pigeons in North America may have numbered 3 billion to 5 billion. On September 1, 1914, the last known passenger pigeon died alone in the Cincinnati Zoological Garden. At a pivotal point in *From Billions to None,* David E. Blockstein, senior scientist at the National Council for Science and the Environment, makes the following observation about extinction:

> The driving force is now humanity; changing the forces of nature. And, one of the consequences of the way that we are driving everything on the planet is that we are driving so many of the other species—our fellow inhabitants of spaceship earth—we are driving them to extinction. And, the rate is unprecedented. There have been mass extinctions in historical times, but essentially we are like the asteroid that killed the dinosaurs and the impact that we have is as swift and as overarching as that asteroid that killed the dinosaurs. (Mrazek 2014)

The asteroid that killed the dinosaurs offers a compelling metaphor for human influence on earth systems, while the reference to "spaceship earth" calls up images of the "Blue Marble," now profoundly and directly threatened by the actions of its own human inhabitants. At the same time, Blockstein's comparison of humanity to an extinction-producing asteroid lacks the precision and evidence-based caution that usually characterizes professional, scientific publication.

A measured and professionally cautious article titled "Has the Earth's Sixth Mass Extinction Already Arrived?," published in *Nature* by Anthony D. Barnosky et al. in March 2011, takes on the question posed in the title of the article. Barnosky and his coauthors begin by noting that of the approximately 4 billion species that have evolved on earth in the past 3.5 billion years, about 99 percent have gone extinct. In the history of life on earth extinction is common, but under ordinary circumstances "speciation" balances loss. The article mentions the five periods of mass extinction evidenced in the fossil record and then turns to the question of a sixth episode caused by human action. Barnosky et al. explain the possibility of such a sixth mass extinction in the following anthropogenic terms:

> Increasingly, scientists are recognizing modern extinctions of species and populations. Documented numbers are likely to be serious under-estimates, because most species have not yet been formally described. Such observations suggest that humans are now causing the sixth mass extinction, through co-opting resources, fragmenting

> habitats, introducing non-native species, spreading pathogens, killing species directly, and changing global climate. (Barnosky et al. 2011, 51)

The authors go on to explain that mass extinction, "in the conservative paleontological sense, is when extinction rates accelerate relative to origination rates such that over 75% of species disappear within a geologically short interval—typically less than 2 million years, in some cases much less." They conclude that recent historical extinction rates are both dramatic and serious, but they do not yet rise to the paleontological definition of mass extinction. They also warn that loss of species in the "critically endangered" category "would propel the world to a state of mass extinction that has previously been seen only five times in about 540 million years." Further loss of species categorized as "endangered" and "vulnerable" could bring on a sixth mass extinction in a few centuries. Understanding the difference between the present extinction-related situation and where we could be in a few generations "reveals the urgency of relieving the pressures that are pushing today's species towards extinction" (Barnosky et al. 2011, 56; see also De Vos et al. 2015; World Wildlife Fund 2014, esp. chap. 1; Monastersky 2014). Thus Barnosky and colleagues argue that while the world has not yet entered a sixth period of mass extinction, we are traveling toward a tipping point—only this time human actions can either push life on earth over the edge or effect a change of course to avert the looming disaster.

Construction of dams across rivers and streams offers an additional example of environmental change that holds the potential to alter the sedimentary and eventually the stratigraphic record. According to a recent article by Katherine J. Skalak et al. titled "Large Dams and Alluvial Rivers in the Anthropocene," "one of the greatest modifications of the fluvial landscape in the Anthropocene is the construction of dams." Worldwide, the inventory of dams stands at about 800,000. All of these dams have "increased the mean residence time of river waters from 16 to 47 days and has increased the volume of standing water more than 700 percent." Construction of dams worldwide accelerated markedly starting in the 1950s and peaked in 1968. "Large Dams and Alluvial Rivers in the Anthropocene" focuses on the Garrison and Oahe dams on the main stem of the Missouri River in North and South Dakota, examining the interactive and combined effect of dams constructed in sequence on the main stem of a major river corridor (Skalak et al. 2013).

Nationwide, the U.S. Army Corps of Engineers reports a total of 87,359 dams; slightly more than half of which were constructed between 1950 and 1980, with a precipitous decline thereafter. While the majority of the dams in the United States are low-head, earth-filled, and privately owned, most of the major rivers in the Nation have been dammed for purposes ranging from navigation and hydroelectric power to flood control, irrigation, and recreation. Indiana has 927 dams, most privately owned, earthen, recreational structures heavily concentrated in the southern half of the state. Alongside their intended benefits, dams individually produce significant changes in riparian habitat, to include converting free-flow to slack water, accelerated evaporation, erosion and deposition of sediment, water temperature, turbidity, and the mix and distribution of species. Meanwhile, the cumulative, anthropogenic impact of hundreds of dams in Indiana, tens of thousands of dams in the United States, and hundreds of thousands of dams worldwide is both significant and lightly studied.

It remains unclear whether or not the Anthropocene will officially replace the Holocene as the latest geological epoch, and simultaneously, there is on-going debate about the starting point of the Anthropocene. In a paper published in *Nature* in 2002, Crutzen argued that "the Anthropocene could be said to have started in the late eighteenth century, when analyses of air trapped in polar ice showed the beginning of growing global concentrations of carbon dioxide and methane (Crutzen 2002, 23). Writing in 2008, a distinguished group of scientists representing the Stratigraphy Commission of the Geological Society of London agreed with Crutzen on the general subject of the transition from the Holocene to the Anthropocene. They proposed and then discarded "the global spread of radioactive isotopes created by the atomic bomb tests of the 1960s" as a beginning point for the Anthropocene. These authors then concluded that for now it might be enough to pick a date, such as 1800. This, they argued, "would allow (for the present and near future) simple and unambiguous correlation of the stratigraphical and historical records and give consistent utility and meaning to this as yet informal (but increasingly used) term" (Zalasiewicz et al. 2008).

Building on that foundation invites examination of three points about the Anthropocene as it relates to the historical human interaction with rivers and with world environmental systems more generally. First, in thinking about the explanatory power that the Anthropocene has for clarifying the relationship between people and the environment, it is important to remember that ideas have a history. One of the most distinguished environmental historians practicing today is Donald Worster, who wrote the definitive study of the history of ecology, *Nature's Economy: A History of Ecological Ideas* (1977). In chapter 10, which engages the history of the science of ecology, Wooster opens with the following sentence: "In the beginning was the Word." He uses this biblical reference to highlight the fact that Ernst Haeckel coined the word *ecology*—originally *Oecologie*—from two Greek roots meaning "house" or "household" and "the study of." Worster goes on to say that "long before there was a word there was an evolving point of view, and the word came well after—not before the fact." Haeckel himself recognized his intellectual debt to this "evolving point of view" when he described the term he created as "the body of knowledge concerning the economy of nature[;] . . . the study of those complex interrelationships referred to by Darwin as the condition of the struggle for existence" (Worster 1977, 191–92).

So it is with Anthropocene. As it takes on meaning, it is important to study and understand the evolving points of view that gave rise to the word. The concept of the Anthropocene did not come out of nowhere. The reason that it caught on so quickly was because it brought into focus ideas and perspectives that had already begun to emerge in a number of disciplines. For well over a century scholars have wrestled with the idea and the significance of human beings transforming the natural world.

George Perkins Marsh—lawyer, diplomat, and conservationist—published a seminal work, *Man and Nature; or Physical Geography as Modified by Human Action,* in 1864. His preface articulates a perspective that embraces the entire earth and the central role of human agency. While his point of view was out of step with mainstream thinking of his own time, it retains remarkable resonance in the present. Marsh explained in his preface:

> The object of the present volume is: to indicate the character and, approximately, the extent of the changes produced by human action in the physical conditions of the globe we inhabit; to point out the dangers of impudence and the necessity of caution in all operations which, on a large scale, interfere with the spontaneous arrangements of the organic or the inorganic world; to suggest the possibility and the importance of the restoration of disturbed harmonies and the material improvement of waste and exhausted regions; and, incidentally, to illustrate the doctrine, that man is, in both kind and degree, a power of higher order than any of the other forms of animated life, which, like him are nourished at the table of bounteous nature. (Marsh 1864, iii)

Man and Nature contains major chapters on plants and animals (what he calls "Vegetable and Animal Species"), woods, waters, and sands.

Several twentieth-century scholars highlighted the role of people in transforming the natural world. The geographer Gilbert White defended an extraordinarily influential dissertation titled "Human Adjustment to Floods: A Geographical Approach to the Flood Problem in the United States" in 1942. White examined the interaction between human agency and flooding, explaining, "Floods are 'acts of God,' but flood losses are largely acts of man. Human encroachment upon the flood plains of rivers accounts for the high annual toll of flood losses" (White 1942, 2).[5] The marine biologist and popular writer Rachel Carson observed in *Silent Spring* (1962) that "only within the moment of time represented by the present century has one species—man—acquired significant power to alter the nature of this world. During the past quarter century this power has not only increased to one of disturbing magnitude but it has changed in character" (5–6). The French-born American microbiologist René Dubois published *The Wooing of Earth: New Perspectives on Man's Use of Nature* (1980), in which he included a chapter titled "Humanization of the Earth" (Dubos 1980). The historian Richard White (1966) published a brilliant and provocative history of the Columbia River in 1995, in which he characterized the river and its drainage as an "organic machine"—an interconnected and interdependent system composed of natural and artificial elements. White's Columbia River is as much a human-created, "cyborg-like" machine as it is a natural system.

Particularly insightful in terms of framing the relationship between people and nature is the definition of material culture developed by the archaeologist James Deetz: "that segment of man's physical environment purposely transformed by him according to culturally dictated plans" (quoted in Schlereth 1989, 294). Although Deetz definition rarely broke free of use by social scientists and humanists, its nuanced treatment of the role of human culture in making and remaking the environment is nearly as sophisticated in its explanatory power as the Anthropocene. Viewed through the definitional lens provided by Deetz, the global environment and its component parts including rivers are as much human artifacts as they are natural systems. They are, in fact, physical manifestations of human beings acting over time on the values and attitudes that form the bedrock of culture.

The second point about the Anthropocene is that it highlights the role of human agency and human culture in reshaping the natural world. It removes what has increasingly become an artificial dividing line between the natural and the cultural environment and between natural and human history. The American Fisheries Society recognized this perspective when it published *Historical Changes in Large River Fish Assemblages of the Americas* in 2005. The society's description of the volume reads as follows:

> Dramatic changes have occurred in the functioning of larger rivers because of social values and policies, land use, in channel causes, and alien species. These changes have resulted in the reduction in range and abundance of many native fish species. This book describes the historical changes observed in the fish assemblages of 27 large rivers in North, Central, and South America. (Rinne 2005)

By noting the important links between values and policies and "dramatic changes in the functioning of larger rivers," the American Fisheries Society recognized the essential role played by culture in transforming large floodplain rivers—and by extension the broader humanized environment.

The environmental history of the Great Lakes in the early 1970s provides a useful example of the interplay between science, policy, and culture. Richard Nixon was president (1969–74) during the height of the environmental movement that rested on a popular understanding of the science of ecology. The Nixon presidential papers make it clear beyond a shadow of doubt that Richard Nixon was no environmentalist; yet he signed several pieces of landmark federal environmental legislation, including the National Environmental Policy Act (1970), the Clean Air Act (1970), and significant amendments to the Water Quality Act (1972). He also created the Environmental Protection Agency (EPA) by executive order in 1970 and appointed William Ruckelshaus as its first administrator.

It is worth noting that passage of the National Environmental Policy Act, the Clean Water Act, and President's Nixon's Executive Order Creating the Environmental

Protection Agency were all pushed along by public outcry when the badly polluted Cuyahoga River caught fire in June 1969. The Cuyahoga is a tributary of Lake Erie near Cleveland, Ohio. A month later, in July 1969, *Time* magazine published an iconic image of the burning Cuyahoga that "fired" the public imagination. Unfortunately, *Time*'s fact checkers tripped up, and the magazine actually published a picture of a much more serious fire on the Cuyahoga in 1952. Despite that error, the story of the burning river and the image on the cover of the magazine augmented popular support for the environmental movement and reinforced a growing public constituency for federal action (Rotman n.d.).

Early in 1971, Ruckelshaus attempted to gain President Nixon's support for an accelerated cleanup of the Great Lakes. Ruckelshaus forwarded to the White House his cleanup plan along with a cover memo, in which he laid out arguments intended to persuade Nixon to support EPA's plan. Ruckelshaus told the president that his reputation "as a strong advocate for environmental improvement had suffered," because among other things "the very people RMN appeals to are also vitally interested in the environment. The white middle class suburbanite (particularly women) are very concerned over this issue." He pointed out that these suburbanites likely would not vote for someone they believed insensitive to the environment. Ruckelshaus added that "the one area that stands out for the environment and its degradation in the minds of the American people is the Great Lakes." Ruckelshaus then listed the eight states that touched the Great Lakes and reminded Nixon that he had won only four of those states in the last presidential election (1968).[6] The EPA administrator's message to the president was crystal clear: an effective politician who wants to win elections will pay attention to the environmental attitudes and values of the voters. A few months later, in April 1972, Nixon traveled to Ottawa, Canada, to sign the Great Lakes Water Quality Agreement. Again, it is absolutely clear from the records that President Nixon signed this agreement because he understood the power of the popular environmental movement in the United States and Canada (Scarpino 2010).

Culture also plays a powerful role in shaping the interaction between people and the environment in the present. Science alone is not enough to either understand or alter the behaviors that drive environmental change, especially when both the problems and the potential solutions are complex and the relationships between cause and effect are indirect and long term. Climate change offers a case in point. Under the headline, "In U.S., Most Do Not See Global Warming as Serious Threat," Gallup provided a March 13, 2014, update on Americans' attitudes toward climate change. In 1998, 65 percent of respondents to a telephone poll told Gallup's pollsters that they believed "global warming" was either under way or would happen during their lifetimes; the percentage of respondents who shared that point of view rose slowly to 75 percent in 2008 and then slipped back to 65 percent in 2014. Respondents who reported that they believed "global warming" represented a serious threat to their way of life stood at 25 percent in 1998, climbed to 40 percent in 2008, and then slid to 36 percent in 2014. While approximately 65 percent of Americans accepted the reality of global warming, about the same percentage also believed it did not represent a serious threat to their way of life. According to Gallup's survey in 2014, political party affiliation was a key variable in determining opinions of respondents on global warming. On the one hand, 73 percent of Democrats stated that they believed global warming had already begun, and 56 percent thought it represented a serious threat to their way of life. On the other hand, just 36 percent of Republicans believed global warming had already begun, and only 19 percent thought it represented a serious threat to their way of life (Jones 2014).

In 2014, the Intergovernmental Panel on Climate Change published its Fifth Assessment Report, which rested on the input of thousands of scientists worldwide, unequivocally stating that climate change was real, under way, and a result of anthropogenic activity. Among its many summary findings the report concluded, "Science now shows with 95 percent certainty that human activity is the dominant cause of observed warming since the mid-20th century."[7] During a time when the accumulating weight of scientific opinion demonstrated the veracity of climate change beyond any reasonable doubt, the percentage of Americans who believed that to be the case did not change, and political party affiliation was one of the most important variables in predicting attitudes toward "global warming." This situation stands in sharp contrast to the broad public constituency for "the environment" and cleaning up the Great Lakes that persuaded Republican resident Richard Nixon to sign the National Environmental Policy Act, to create the Environmental Protection Agency by executive order, and to sign the Great Lakes Water Quality Agreement. Or, for that matter, the popularized understanding of a clear association between chlorofluorocarbons (CFCs) and human health that pushed forty-six nations, including the United States, to sign the Montreal Protocol and to agree to the banning of CFCs. When it comes to changing behaviors that adversely impact the environment, what people think and believe is just about as important as the verifiable results of scientific research.

Scholars interested in using the concept of the Anthropocene need to realize that human agency is not a single, undifferentiated variable. Culture differs from group to group, and cultures evolve over time. If we are really going to understand human impact on rivers worldwide—or human impact on global environmental systems—then we need to study and understand the historical fabric of cultural contexts that produced those changes. We also need to pay attention to the unintended and unanticipated consequences of human actions.

A final point about the Anthropocene relates to the opportunity for, and importance of, interdisciplinary collaboration. When considering the history of human interaction with the environment, there are two tremendous intellectual watersheds in the past two centuries: Darwin's ideas on natural selection and the science of ecology. Both fundamentally changed the way people thought about their relationship with the natural world. The concept of the Anthropocene has the potential to become a third great intellectual watershed. If we accept the idea of the Anthropocene as an epoch in which human agency represents the most significant variable driving environmental changes on earth, then understanding those changes will take the combined and integrated efforts of scholars in science, social science, and the humanities. Part of the "magic" of the Anthropocene may be its potential for drawing scholars out of disciplinary silos and into collaborative research aimed at creating not only new knowledge but also a new synthesis that views barriers between natural history and human history as highly permeable. But then the question should become, knowledge to what end? Persuading people of the seriousness of climate change or a range of issues surrounding freshwater will require education, effective leadership, and informed policy. By itself good science will not be enough.

In the past few decades, it has become increasingly clear that human beings have done exactly what science fiction writers like Robert Heinlein and Arthur C. Clarke and Isaac Asimov wrote about in the 1950s and thereafter. That "Blue Marble" hanging in the vastness of space turned out to be our own terraformed world. Acting on the values and attitudes embedded in our cultures and employing science and technology and energy, we have literally terraformed our own planet, including hydrologic and atmospheric systems. We did not do it in the planned, ordered, science-based manner imagined by science fiction writers, and in many cases what we did not mean to do has played as much of a role as what we actually set out to accomplish.

Transformation cut in at least two directions: on the one hand, reorganized earth systems favor human beings and support a vast and growing worldwide human population; on the other, the unintended and unanticipated consequences of those reorganized earth systems pose serious threats to human societies and to the integrity of earth's environment. Among those threats are availability and distribution of freshwater, species extinction, and climate change.

A historian should be very cautious about claiming lessons from history. With that caveat in mind, a few general lessons emerge from studying the historical interplay between people and rivers—and people and the larger global environment. (1) Rarely do people set out to intentionally inflict damage. They almost always modify their surroundings for what they believe are socially beneficial purposes. (2) There are always unintended and unanticipated consequences associated with human actions. In order to really understand the Anthropocene, we need to consider what people set out to do, as well as what they did not mean to do or what they didn't see coming. (3) If the Anthropocene is distinguished by global environmental impact so far reaching that it left a stratigraphic record, then gaining insight into the emergence and evolution of the Anthropocene requires careful study of human actions driven by attitudes and values embedded in culture. In order to gain insight into what people did in the past, how they act in the present, and what they are likely to do in the future, it is essential to pay attention to the complex and subtle tapestry of culture over time.

Finally, knowledge of how profoundly past human actions transformed earth systems should go hand-in-hand with a sense of responsibility for the consequences of terraforming our own world. Writing in 1864, George Perkins Marsh saw the significance of the historical transformation of earth by human action, and the responsibility that came with that knowledge. Marsh pointed out

> the dangers of impudence and the necessity of caution in all operations which, on a large scale, interfere with the spontaneous arrangements of the organic or the inorganic world; to suggest the possibility and the importance of the restoration of disturbed harmonies and the material improvement of waste and exhausted regions; and, incidentally, to illustrate the doctrine, that man is, in both kind and degree, a power of higher order than any of the other forms of animated life, which, like him are nourished at the table of bounteous nature. (Marsh 1864, iii)

Despite our power, human beings, like all other life on earth, "are nourished at the table of bounteous nature." In the end, an obligation to be stewards working to restore "disturbed harmonies" may be the most important lesson derived from studying the history of the Anthropocene. It is a lesson that carries on its shoulders the knowledge of earth systems produced by science; insights into human culture and motivation gained from history and other disciplines; and political and policy issues that highlight the value of applied, transdisciplinary research.

NOTES

1. In 1955, the domestic American fleet of cars and light trucks averaged 3,562 pounds "curb weight" and 16 miles per gallon. Average miles per gallon of American-made cars and light trucks had fallen to a post–World War II low of 12.2 miles per gallon in 1973, corresponding with their highest postwar average curb weight of 4,022 pounds. Figures on weight and miles per gallon: http://www.nhtsa.gov/cars/rules/cafe/historicalcarfleet.htm.

2. Elkins (1999) explains the safety risk of refrigerants used before chlorofluorocarbons as follows: "Refrigerators in the late 1800s and early 1900s used the toxic gases, ammonia (NH_3), methyl chloride (CH_3Cl), and sulfur dioxide (SO_2), as refrigerants. After a series of fatal accidents in the 1920s when methyl chloride leaked out of refrigerators, a search for a less toxic replacement began as a collaborative effort of three American corporations—Frigidaire, General Motors, and Du Pont."

3. When Rachel Carson published *Silent Spring* in 1962, concerns she helped to highlight—the widespread, indiscriminate use of synthetic, organic pesticides and related chemicals—jump-started the modern, ecology-based environmental movement.

4. For a relatively recent and cautious examination of the possibility of a sixth mass extinction, see Barnosky et al. 2011. This article also contains a thorough bibliography. Also helpful for understanding the science and the assumptions underlying examination of a possible sixth period of mass extinction is De Vos et al. 2015. The author thanks Dr. Samuel Scarpino and his colleagues at the Santa Fe Institute for recommendations on literature related to mass extinction.

5. See also Scarpino 1997. The relatively recent work by Hamilton and Grinevald (2015) offers a useful discussion of writers (largely scientists) who called attention to the profound human impact on

the natural world and who many recent writers have identified as having foreseen the idea of the Anthropocene. Hamilton and Grinevald argue that it has become "accepted wisdom that the Anthropocene was foreseen by scientists in the 19th and early 20th centuries," and although "the present authors initially accepted this view, after critical reflection and rereading the historical sources we now disagree with this intellectual phylogeny" (60). While this article seems to confuse the history of an idea with "foreseen," it nonetheless offers a highly useful overview and a very helpful bibliography.

6. William D. Ruckelshaus, Administrator, EPA, to John C. Whitaker, "The President and the Environment," 11 January 1971, National Archives and Records Administration II, College Park, MD, Nixon/Whitaker, Box 135, Great Lakes Agreement, 2 of 2. Cited in Scarpino 2010.

7. See, e.g., the foreword to *Climate Change 2013: The Physical Science Basis*, the Working Group One Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, which states, "*Climate Change 2013: The Physical Science Basis* presents clear and robust conclusions in a global assessment of climate change science not the least of which is that the science now shows with 95 percent certainty that human activity is the dominant cause of observed warming since the mid-20th century." See also Intergovernmental Panel on Climate Change, *Climate Change 2014: Synthesis Report Summary for Policy Makers*, 4: "Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century." Also: "About half of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years (high confidence)." The IPCC was created in 1988. It was set up by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) as an effort by the United Nations to provide the governments of the world with a clear scientific view of what is happening to the world's climate.