Climate Change: Responding to the Crisis Portended by George Perkins Marsh

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Introduction

Climate change is the challenge of our age. It is here and now, it is pervasive, and it is—unfortunately—our future. George Perkins Marsh clearly recognized the major environmental crises of his time in the mid-1800s, when most still saw the taming and subjugation of nature as imperative improvements to the planet (Lowenthal 2009). He perceived the impacts of unsustainable logging, overfishing, overgrazing, and non-native species, as well as the floods, erosion, and desertification that followed unwise land conversion. And, he pushed to reverse these changes and restore landscapes to their previous conditions. Our climate change challenge today is immense and complex, and interacts synergistically with many of the human-caused stressors Marsh observed. A whole body of science, which Marsh anticipated with his prescient concerns about human impacts to climate, establishes that the planet is already committed to substantial climate change (Wigley 2005; Hansen et al. 2013). Thus, we must both adapt to ongoing changes and minimize future impacts. The future will not look like the past, and the disconcerting reality is that by exposing Earth's climate to significant and ongoing human influence, we have now committed ourselves to the immense stewardship challenge of determining desired future conditions within protected areas.

Past change

George Perkins Marsh's Woodstock, Vermont, birthplace—now home to Marsh-Billings-Rockefeller National Historical Park (NHP)—provides a useful backdrop and context for understanding past, ongoing, and future changes. Marsh (1801–1882) witnessed tremendous environmental changes. He was born near the beginning of rampant deforestation that

The George Wright Forum, vol. 32, no. 3, pp. 276-289 (2015).

ISSN 0732-4715. Please direct all permissions requests to info@georgewright.org.

reduced forest cover in the state by more than half, from about 80% to around 30% during the century (Foster 2006). Short-sighted land use and poor land clearing practices caused highly visible erosion and tremendous loss of topsoil from previously forested areas. These same areas, now lacking the shade of a forest overstory and devoid of a thick organic soil layer, were also more prone to the effects of drought. "Too general felling of the woods [is] the most destructive among the many causes of the physical deterioration of the earth" noted Marsh in *Man and Nature* (1864). Marsh lamented that the Vermont landscape was under such rapid transformation that areas were unrecognizable to the traveler after only a short number of years. Unsustainable fishing was also an unacknowledged issue Marsh recognized as requiring management attention.

In addition to land use impacts, Marsh was startlingly prescient about human impacts to the Earth's climate. In a speech in 1847 to the Agricultural Society of Rutland County, Vermont, Marsh articulated multiple ways in which humans influence local and regional climate, such as through changes in landscape albedo, desertification, urban heat islands, and heat, energy, and moisture held in the atmosphere:

> Man cannot at his pleasure command the rain and the sunshine, the wind and frost and snow, yet it is certain that climate itself has in many instances been gradually changed and ameliorated or deteriorated by human action. The draining of swamps and the clearing of forests perceptibly affect the evaporation from the earth, and of course the mean quantity of moisture suspended in the air. The same causes modify the electrical condition of the atmosphere and the power of the surface to reflect, absorb and radiate the rays of the sun, and consequently influence the distribution of light and heat, and the force and direction of the winds. Within narrow limits too, domestic fires and artificial structures create and diffuse increased warmth, to an extent that may effect vegetation. The mean temperature of London is a degree or two higher than that of the surrounding country, and Pallas believed, that the climate of even so thinly a peopled country as Russia was sensibly modified by similar causes.

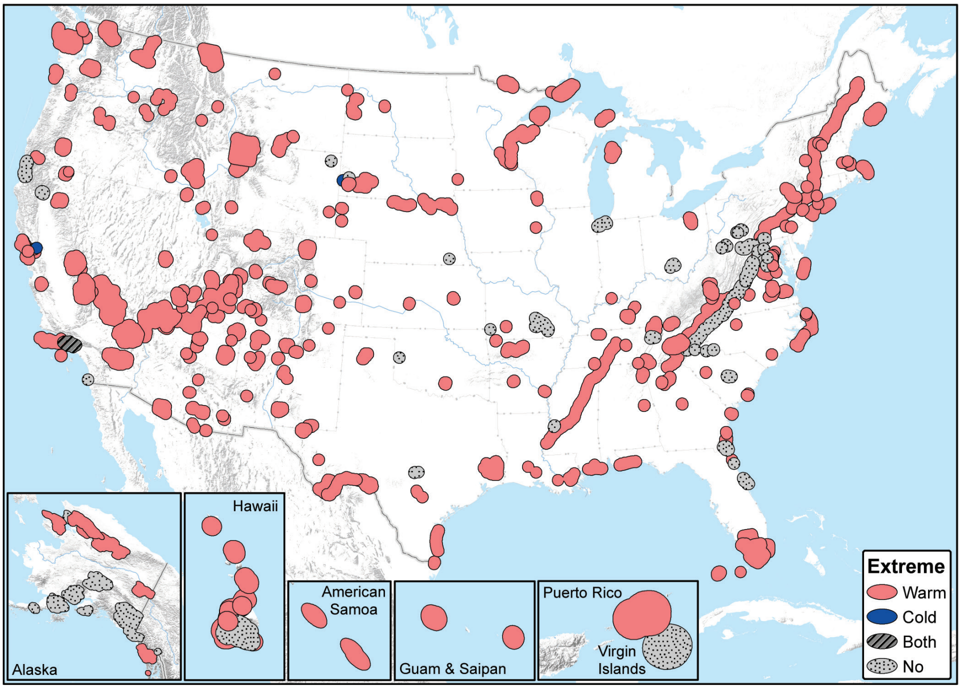
Marsh died in 1882 and therefore lived before the earnest beginnings of the fossil fuel-driven industrial revolution. Thus, his observations and amazing insights were based primarily on land-use changes rather than on the tremendous increases in greenhouse gas emissions that have occurred in the interim. Since Marsh's day, atmospheric concentrations of carbon dioxide have climbed from roughly 290 to recently over 400 parts per million (NOAA 2015), an unwelcome milestone and the highest concentration in well over 800,000 years (IPCC 2013). Although Marsh did not witness this change, he did appreciate that incrementally small actions (such as daily emissions of greenhouse gases) could accumulate and ultimately cause immense impacts (Lowenthal 2009).

Ongoing climate change

The signs and symptoms of anthropogenic climate change are clearly evident today. The above-mentioned greenhouse gas emissions are driving increasing atmospheric temperatures, sea-level rise, and acidification of the world's oceans (IPCC 2013). Air temperatures in recent decades are significantly warmer than the longer-term record; for example, the past 30 years likely represent the warmest period of the past 1,400 years, on average, in the northern hemisphere (IPCC 2013). Within the US national park system, recent conditions (past 10–30 years) in over 80% (235) of the 289 parks with significant natural resources have been warmer than 95% of the historical record (1901–2012) (Figure 1; Monahan and Fisichelli 2014). Thus, even many of those long-tenured park managers who have worked at the same park for several decades have spent their entire careers under relatively anomalous conditions.

Marsh-Billings-Rockefeller NHP is experiencing both extreme warm and extreme wet conditions (Figure 2). Annual temperature, summer temperatures, and winter temperatures of the past 10–30 years are, on average, warmer than 95% of historical conditions going back to 1901. Long-term temperature records from the region suggest—unsurprisingly—that recent years are much warmer when compared with the time Marsh spent there. This warming pattern has been fairly consistent, with annual mean temperatures of the past 10, 20, and 30 years each being warmer than all other periods of equal length since 1901. Rainfall

Figure 1. Recent (past 10–30 years) mean temperature relative to the historical range of variability (1901–2012) in 289 US national parks (park plus surrounding landscape—30-km buffer). Park temperature is considered "extreme" if one or more of seven temperature variables examined is <5th percentile ("Cold") or >95th percentile ("Warm") of the historical distribution (adapted from Monahan and Fisichelli 2014).



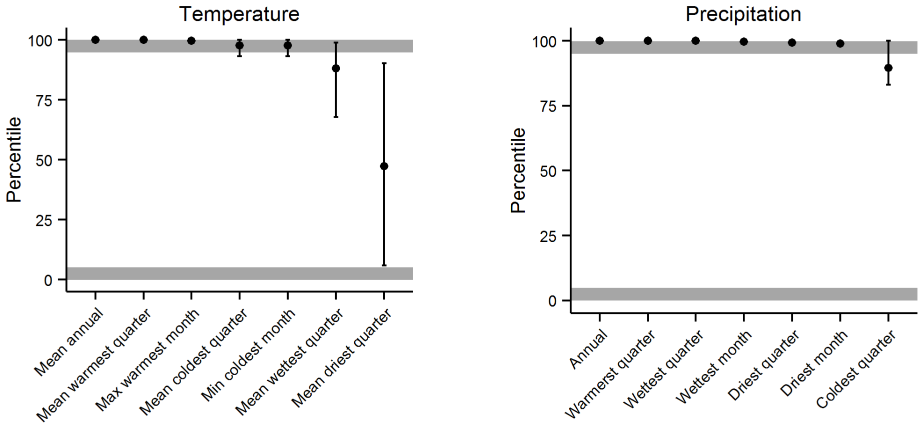


Figure 2. Recent temperature and precipitation percentiles at Marsh-Billings-Rockefeller National Historical Park (including areas within 30 km [18.6 mi] of the park's boundary). Black dots indicate average recent percentiles across the 10-, 20-, and 30-year intervals. Variables are considered "extreme" if the average percentiles are <5th percentile or >95th percentile (i.e., the gray zones, where recent climate is pushing the limits of all observed climates since 1901). Black bars indicate the range of recent percentiles across 10-, 20-, and 30-year moving windows (adapted from Monahan and Fisichelli 2014).

events are becoming more intense across the Northeast (Melillo et al. 2014), and seasonal rainfall totals are also extremely high in the park.

We need not only look to future "potential" changes; climate change is happening now in parks and is having impacts to park resources, infrastructure, and operations. Across the continent, resource responses to ongoing climate change include changes in glaciers, birds, insects, mammals, and vegetation (Carrara and McGimsey 1981; Moritz et al. 2008; Tingley et al. 2009; Dolanc et al. 2013; Giersch et al. 2015). Climate change is also accelerating weathering, deterioration, and loss of cultural resources (Colette 2007; Sabbioni et al. 2010), exacerbating maintenance backlogs, challenging park operations, and impacting visitor use and experience (Buckley and Foushee 2012; Fisichelli et al. 2015).

At Marsh-Billings-Rockefeller, carriage roads are experiencing greater erosion and requiring more maintenance than in the early years of the park, due to increased heavy-rain events (Figure 3). Projects are underway to increase the size of culverts along the carriage road system to handle the increased amount of runoff generated during these more frequent and heavy summer rainstorms. Warming spring temperatures may be linked to increases in visitor use and demand for more interpretive programs earlier in the spring.

Future climate change

Climate change is multifaceted, and future climate will likely differ significantly from even the

Figure 3. Recent heavy rainfalls have overwhelmed culverts and caused substantial erosion and damage to historic carriage roads in Marsh-Billings-Rockefeller National Historical Park. Park managers are adjusting culvert size to adapt to current and projected future changes in rainfall intensity.

recent past (IPCC 2013; Melillo et al. 2014). For example, future combinations of temperature and precipitation in many areas may have no current analogues on the planet (Williams et al. 2007). Climate change also includes changes in climate variability and extreme events, such as potential increases in the frequency, duration, and intensity of droughts, heat waves, and storms (Melillo et al. 2014). Additionally, many uncertainties and as-yet-unknown surprises will influence the rate and direction of future change. It is beyond the scope of this essay to delve into details, and many authoritative references, such as those cited above, provide comprehensive future projections. Importantly, climate change will interact with other stressors (Fisichelli et al. 2014a), such as those noted by Marsh in the 1800s.

One of the greatest challenges of climate change is that it is a directional and unrelenting change. Much work in disturbance ecology has focused on understanding responses to press and pulse disturbances (Bender et al. 1984). Press disturbances are sustained changes and pulse disturbances are short-term, distinct events. Both involve a limited period of change followed by a return to stable original conditions (pulse) or new conditions (press), such that in theory the ecosystem ultimately attains equilibrium (Bender et al. 1984). It is easiest to understand ecosystem responses to either of these two types of disturbance when examined in isolation. For example, examining forest regeneration after a fire (pulse), or studying a river system under a new, higher sedimentation regime (press). Climate change is neither simply a press nor a pulse disturbance; it is ongoing and accelerating directional change, a disturbance without an endpoint (Lake 2000) or stable "new normal."

To add to the complexity, climate change also influences and interacts with familiar press and pulse disturbances. It is difficult and often erroneous to attribute individual hurricanes, storms, or other pulse-disturbance weather events to climate change (in the same way that it is difficult to attribute any single outcome of a roll of loaded dice to the fact that they have been subtly manipulated), but what is clear is that these pulse events and their impacts occur on top of directional climate change (Trenberth et al. 2015). For example, Hurricane Sandy in 2012 occurred atop 20 cm of climate change-induced sea-level rise (since 1880) that caused the storm to flood an additional ~70 km^2 in New York and New Jersey (Miller et al. 2013). Did the storm happen because of climate change? Unknowable. Was it made worse because of it? Most assuredly. Disturbance impacts such as tree mortality from pests, droughts, and wildfires may also be magnified by ongoing climate change (van Mantgem et al. 2013; Allen et al. 2015; Anderegg et al. 2015).

Climate change, it must be stressed, is directional. When examined over multi-decadal scales—as by climate's own definition—this change is continuous and has no foreseeable equilibrium (Hansen et al. 2013). Thus, we cannot assume that restoration to a pre-existing state will be achievable. The past climate is just that, and as a key component of that pre-existing ecological state, already does not exist or will soon cease to exist.

Responding to change

The response to climate change must be broad, deep, and persistent, and involve both mitigation and adaptation. Mitigation in a climate change context is the reduction in greenhouse gases through reduced emissions and enhanced sequestration. Adaptation is, in simple terms, adjustment to changing conditions. It is, more formally, adjustment in natural or human systems in anticipation of or response to a changing environment in a way that effectively reduces negative effects or capitalizes on opportunities (see Executive Order no. 13653, 2013). Adaptation and mitigation are inextricably linked. Early responses to climate change focused on mitigation, but climate change impacts and the need to adapt to them soon became obvious. Furthermore, the long residence time of greenhouse gases in the atmosphere, lag times in the climate system, and our current greenhouse gas emissions trajectory suggest that climate change will continue for centuries (Hansen et al. 2013). Mitigation is now vital to ensure that ongoing adaptation efforts are successful—much of our efforts at adapting to change may only be effective in the near term and under moderate amounts of climate change (Bierbaum et al. 2014). Failure to mitigate will have cascading impacts that may overwhelm adaptation actions. The focus below is on adaptation; mitigation efforts at local, national, and global scales are integral to the climate change response (NPS 2012; Executive Office of the President 2013; IPCC 2014).

Climate change and other global change stressors not only challenge land managers' abilities to protect natural areas but also demand that we re-think conservation concepts, goals, and objectives in a continuously changing world (Hobbs et al. 2010; NPSAB 2012). Adapting to climate change means either resisting effects or facilitating change (Millar et al.

2007; Stein et al. 2014). Ongoing and future climate change will likely affect all aspects of protected area management, including natural and cultural resource protection, operations and infrastructure, and visitor use and experience. To structure adaptation thinking for protected area management, a spectrum of adaptation strategies can be described as spanning persistence, autonomous change, and directed change (Figure 4; Fisichelli et al., in review). Persistence strategies aim to resist change and maintain current or past conditions. Directed change actively manages a target (resource, asset, or process) towards specific new desired conditions. With autonomous change, the target responds to climate change and management may support its capacity to do so but does not aim to steer the target back towards past conditions or move it towards a strictly defined desired future state. There is no single adaptation option that is appropriate in all situations; rather, the appropriate strategy will vary across resources, space, and time. For example, many persistence strategies are suitable in the near term but are likely to become increasingly risky and costly as time goes on (Millar et al. 2007). The stewardship response to climate change therefore needs to be continuous, and continually reassessed. This paradigm shift in management is nascent and will take many decades to fully form, but we are beginning to take the first tentative steps and develop the forward momentum to achieve critical mass (Stephenson 2014).

The past has been a tremendous stewardship guide and past conditions have been a widely agreed-upon goal for conservation across protected areas. Past ecosystem states, in essence, made the decisions regarding stewardship and guided management interventions to preserve the structure, composition, and function of landscapes. This one-size-fits-all approach worked across landscapes, jurisdictions, and ecosystem types. Certainly, variability in ecosystems states was understood; however, this was seen as variability around a static baseline, or at least within familiar bounds. Climate change challenges these ideas and strongly points to a future that will not resemble the recent past. The past, therefore, cannot be the sole guide for the future; this is a core challenge of climate change. Human influence over the landscape, in the form of climate change and other broad-scale global change stressors, obscures even the idea of the natural condition of protected areas (NPS 2006; Cole and Yung 2010). There is no one-size-fits-all approach in climate change adaptation (Bierbaum et al. 2014). Decisions will vary tremendously across space, time, and resources. Managers and stakeholders need to have open conversations about desired future conditions, what is

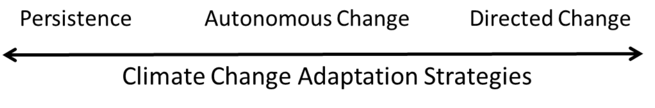


Figure 4. Climate change adaptation is about managing change and includes a spectrum of strategies. Persistence strategies resist climate change. Directed change actively manages towards specific new desired conditions. With autonomous change, the target responds to climate change and management may support its capacity to do so, but without steering the target towards a specific future state. Appropriate strategies will vary across resources, space, and time.

achievable, what the major tradeoffs are, and how to proceed. These are difficult decisions and the "wisdom" of past natural conditions cannot be used as the sole goal for stewardship. This does not mean that management need be capricious and change course with every record warm year or disturbance event. It also does not mean that intense management intervention is necessary everywhere and at all times. Restraint is always needed, is an important tool in the manager's toolbox, and given limited management resources, is often a forced norm (Stephenson 2014).

Climate change does mean that decisions need to be made, often with limited information and under major irreducible and high-impact uncertainties. Furthermore, these decisions will need to examine multiple tradeoffs, such as fostering a free-flowing river and its erosion and deposition dynamics or protecting cultural resources from these erosional forces. Decision-support approaches such as scenario planning and structured decision-making can guide and inform the process, especially in elucidating uncertainties and tradeoffs (Gregory et al. 2012; Moss et al. 2014). The science and decision support approaches, however, do not define conservation goals. An iterative process of co-learning and knowledge co-production of achievable future landscape conditions is needed to shape conservation goals (Dilling and Lemos 2011; Nel et al. 2015).

Although climate change adaptation is a relatively new aspect of conservation, the tools of adaptation, in most instances, are the same ones managers are already using. The fundamental change is in understanding the impacts of climate change and then using conventional tools to ameliorate these impacts (NFWPCAP 2012; Stein et al. 2014). Invasive species management is already a recurring action in many protected areas and climate-informed decision-making can lead to both more effective treatments and accomplishment of multiple climate adaptation goals. Examples include: promoting native species persistence within potential climate refugia by controlling invasive species; fostering transitions (directed change) among native natural communities by managing non-native invasions within areas likely to experience major climate-mediated changes; selecting non-native pest and disease targets within a park unit based on host species future habitat suitability; and examining which invasive species and areas within parks may require greater management in the future and—as importantly—which invasives may decline in identified areas under a changing climate.

Marsh-Billings-Rockefeller NHP is typical of most national park areas in that it has both significant natural and cultural resources and that many of the significant cultural resources are composed of natural resources. The forest at Marsh-Billings-Rockefeller is the oldest surviving example of planned and managed reforestation in the country (Figure 5). It is a living history of the evolution of forest stewardship in the United States. It tells the story of bringing state-of-the-art European silvicultural practices to the US in the late 1800s and of modern sustainable forest practices. These forests are now also telling the story of global change impacts and adaptation. Managers at the park and forest scientists are incorporating climate change vulnerability information into management plans and developing strategies to encourage the establishment and growth of a broad suite of present native tree species adapted to emerging and future climatic conditions (Figure 6; Fisichelli et al. 2014b).

Figure 5. Active forest management is a core component of the cultural landscape at Marsh-Billings-Rockefeller National Historical Park, and managers are currently adapting practices to promote native species adapted to a changing climate.

Changes to management include minor shifts in silvicultural practices that will encourage future climate-adapted tree species such as oak, cherry, and pine.

This adaptation is a subtle but important change in management that seeks to bring about the desired future condition of an intact, healthy forest in the park. Historical (and historic) reforestation efforts at this site were a deliberate and conscious effort at improved stewardship and were some of the first-in-the-country efforts to restore working forests. The methods were untested in the US and these pioneering stewards faced multiple uncertainties analogous to climate change adaptation challenges today. What tree species would do well here? What would the next 100 years look like? Presently, managers are adding to this rich history and the cultural significance of the park through ongoing stewardship and climate change adaptation.

Marsh's writings, especially *Man and Nature* (1864), did catalyze change in forest stewardship and fish management. These stewardship changes often occurred incrementally and took multiple decades to manifest. Similarly, our willingness and ability to adapt to climate change is evolving and improving. Coming on the heels of the 150-year anniversary of *Man and Nature* is the centennial of NPS (1916–2016). This is an opportunity to reflect on the past 100 years of management, recognize how much it has changed, and begin to envision how much and in what ways management must change for the next 100 years of park stewardship.

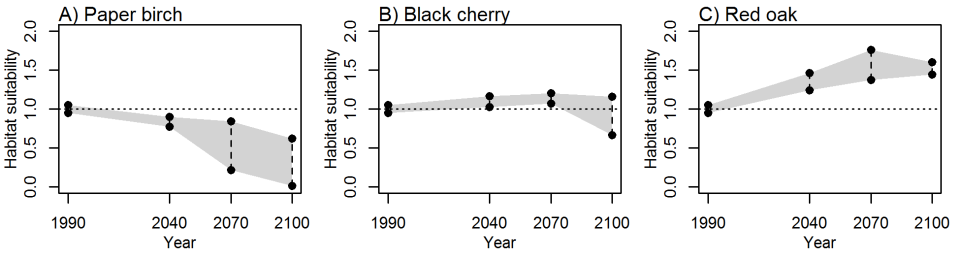


Figure 6. Projected changes in potential habitat suitability for three common tree species in the Marsh-Billings-Rockefeller National Historical Park area. "Least change" and "major change" projections (black dots) are for three future periods, compared with late 20th century habitat. Y-axis is the ratio of future to late-20th-century habitat suitability (e.g., 2.0 = doubling of suitable habitat; 0.5 = 50% reduction in habitat). Data from Fisichelli et al. (2014b).

Conservation goals are reflections of human values, and human values evolve and change (Riley et al. 2002). Decisions made during one era of management may have been appropriate and the right decision at the time, but the "right" decision changes with time along with our values. Feeding bears in national parks was integral to the visitor experience during the early days of NPS. Managers understood the detrimental effects caused by feeding wild animals, but at that time and perhaps for a fledgling organization attempting to establish itself, visitor experience and expectations trumped early wildlife concerns. Over time, through increased scientific understanding and evolving public perceptions and park stewardship values, management changed. Park managers reassessed goals and objectives and brought them in line with evolving conservation values. We may well be making decisions today that will seem like poor choices in the future; it is hubris to assume otherwise. But what is vital is that we continually reassess our actions and our goals and tailor them to changing ecological and social conditions.

Changes in Marsh's day provide both warnings and some encouragement that global society can respond to and mitigate climate change. As mentioned above, the rate of deforestation in New England during the 1800s was phenomenal. Surprisingly, the rate of reforestation during the 1900s was almost as rapid. It is hard to imagine anyone in the late 1800s looking at the deforestation trend of that century and positing that the next century would see reforestation of much of these areas. This massive transformation from forest to pasture and agricultural fields and then back to forest illustrates the types of changes that can occur as a result of human choice. A major driver of this change was economic forces reducing demand for potash and sheep and new agricultural opportunities opening up in the West. Thus, although this reforestation, in large part, cannot be attributed to conservation efforts, it nevertheless illustrates the magnitude of human behavioral changes that can be directed through economic forces, and suggests the types of measures that are needed to foment broad-scale change.

Climate change is a disconcerting reality. It is also an opportunity for improving stewardship of protected areas. It is an opportunity to recognize, appreciate, and work with the dynamism of nature. It is an opportunity to move beyond assumptions of a single past condition or reference state (Pickett and Parker 1994). It is an opportunity to recognize the emerging relevance of protected areas for adaptation. It is an opportunity to work across jurisdictions, at broad regional spatial scales, and over multi-decadal time scales (Zavaleta and Chapin 2010). It is an opportunity to value, rather than discount, the future; we have the ability to forecast future climate better than any generation in history (Lemos and Rood 2010) and are obligated to respond.

Protected area networks did not exist during Marsh's time. National parks, national forests, wildlife refuges, and other protected lands were specifically established to conserve natural resources and safeguard them from the types of impacts Marsh observed and brought to the attention of society. One of the greatest contributions of today's global network of protected areas is providing the space and time for species to adapt to ongoing change, although this was not the original intent. Thus, the insights and efforts of Marsh 150 years ago are still relevant and, in fact, are contributing to today's climate change response.

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