Chapter 4

Shifting Environmental Foundations: The Unprecedented and Unpredictable Future

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Prediction is very difficult, especially about the future.

—*Niels Bohr*

As described in Chapter 2, protected area managers have been directed, through statutes and agency policy, to preserve natural conditions in parks and wilderness. Although preserving naturalness has always been a challenge for managers, there has never been much question about whether this is the right thing to do. But given what is known now about the pace and magnitude of ongoing global changes, the appropriateness of naturalness as a management goal must be reexamined. A host of anthropogenic environmental stressors are reshaping ecosystems, including those protected in parks and wilderness. Pollution is now ubiquitous worldwide, and invasive species are common in most landscapes. Habitats have become highly fragmented, and climatic changes are dramatically altering the abiotic conditions in which biota live. Given these changes, some attempts to restore and maintain naturalness may at best be ineffective; at worst, they could waste precious resources and even contribute to loss of some of the values that managers are trying to protect.

It was once assumed that natural conditions could be maintained largely by protecting a park from development and inappropriate uses. Now, ever-

expanding human impacts suggest that human intervention in ecosystems may be essential to protect critical values in parks and wilderness areas. Ecological restoration has moved toward the forefront of stewardship policy and practice. As a case in point, National Park Service (2006: 37) management policies call for the restoration of naturally functioning ecosystems and, if this is not possible, for the restoration and maintenance of "the closest approximation of the natural condition." Although restoration may enhance some of the values of naturalness, such as maintenance of native biodiversity, widespread intervention erodes other meanings and values of naturalness—natural areas as places where humans do not willfully manipulate ecosystems, where nature remains self-willed and autonomous.

Where intervention and restoration are needed and feasible, protected area managers must develop realistic objectives and devise effective strategies for achieving them. In part because of the centrality of historical fidelity to notions of naturalness, past ecosystem conditions have commonly been adopted as targets for the future. With recognition of the inherent dynamism of ecosystems (Chapter 3), reference targets for restoration are often prescribed as a range of past conditions, often called natural or historical range of variability (Landres et al. 1999), rather than conditions at a single point in time. But given the rapid pace of directional anthropogenic changes, such targets, even those expressed as a range, may be neither achievable nor desirable.

Although the range of past ecosystem conditions remains a valuable source of information about the forces that shape ecosystems (Swetnam et al. 1999), it no longer automatically serves as a sensible target for restoration and maintenance of ecosystems. Our world has entered an era in which keystone environmental drivers—those that define the possible range of characteristics of a protected area—simply have no analog in the past, no matter how distantly we look. Attempts to restore and maintain a semblance of past conditions therefore may be akin to forcing square pegs into round holes. Furthermore, at the spatial and temporal scales relevant to protected area management, the ability to predict future ecosystem conditions and outcomes of management actions is, at best, qualitative. Surprises are inevitable and are likely to be the rule rather than the exception.

In this chapter, we explore the implications of rapid global changes for protected area stewardship. We describe the major classes of anthropogenic drivers of changes in protected areas, including habitat fragmentation, loss of top predators, pollution, invasive species, altered disturbance regimes, and climatic change, concluding that resultant ecosystem changes are likely to be dramatic, ubiquitous, directional, and unprecedented. And even with management intervention aimed at responding to these stressors, protected areas inevitably will experience substantial effects of accelerating anthropogenic global changes. We describe the challenges of predicting the future, including how ecosystems are likely to respond to management actions. We identify some likely expectations for the future but conclude that uncertainty will be high. Consequently, many of the traditional approaches to protected area management that depend on natural conditions as benchmarks for restoration may no longer be tenable. We briefly point out some promising new goals and management strategies, topics that are covered in more detail in subsequent chapters.

Anthropogenic Change and the Unprecedented Future

To protect values such as native biodiversity and critical ecosystem functions, protected area managers need clear information on the nature and magnitude of anthropogenic influences on park and wilderness ecosystems. When change is deemed unacceptable and critical values are threatened, intervention will generally be needed. When interventions are taken, managers must identify desired outcomes and prescribe specific management actions likely to be effective in meeting those targets. Understanding change is fundamental to all these steps, each of which becomes increasingly difficult as anthropogenic changes increase and future conditions become less and less similar to those of the past. A handful of particularly important drivers of change have profound effects on park and wilderness ecosystems.

Habitat Fragmentation and the Loss of Top Predators

When Yellowstone National Park was first designated, it was generally assumed naturalness could be achieved by leaving the park alone. But it was soon discovered that even a large park such as Yellowstone was too small to remain natural without human intervention, particularly once top predators such as the wolf were eliminated. Loss of keystone species and processes has cascading effects that ultimately can be manifested in loss of biodiversity (Wagner 2006). And if this is a problem even in a large park such as Yellowstone, it is likely to be an even more severe problem in smaller protected areas. Increasingly, parks and wildernesses are isolated islands: relatively undisturbed biotic communities embedded in a matrix of land that has been substantially altered by humans (Hansen and DeFries 2007).

In many protected areas, top predators have been eliminated or are present in reduced numbers, cut off from other populations by adjacent developed lands. A common result is hyperabundant ungulate populations that have cascading effects throughout an ecosystem. For example, Ripple and Beschta (2008) have concluded that declining populations of black oak (*Quercus kelloggii*), an emblematic species in Yosemite Valley, may ultimately result from cougars (*Puma concolor*) now avoiding the valley, where people congregate. With predation reduced, populations of mule deer (*Odocoileus hemionus*), which browse on the oak seedlings, have expanded. Morell (2008) notes that with few small oaks to replace elders, other vegetation and animal species may be affected, potentially resulting in a decline in overall biodiversity. This decline in diversity may occur despite the natural appearance of the valley and its protection for more than a century.

Land use changes around a protected area, such as residential development, conversion to agriculture, or timber harvests, can have substantial effects on the reserve itself, such as through changes in ecological flows into and out of the reserve, loss of habitat crucial to mobile organisms, increasing exposure to invasive species along reserve edges, and changes in effective reserve size (Hansen and DeFries 2007). An example is Devil's Postpile National Monument, a small park unit in California that is surrounded by lands administered for diverse purposes by the U.S. Forest Service. Recreational uses in the multiple-use lands to the east of the monument contribute to a flow of invasive species into the adjacent portions of the monument; in contrast, a similar flow across the western boundary of the monument, which adjoins wilderness, has not been observed.

For species with poor ability to disperse across human-altered landscapes, such as species that depend on old-growth forest but that are unable to disperse across agricultural lands, habitat fragmentation may reduce genetic exchange between populations, possibly reducing adaptive potential to other novel stressors. Additionally, in the face of rapid climatic change, protected areas may become unsuitable for some of the species they protect. Habitat fragmentation by land use changes may preclude those species from migrating to new regions more suitable to them.

The Spread of Invasive Species

Another important driver of change in protected areas is invasion by nonnative species. Nonnative invasive species can substantially alter the structure, composition, and function of ecosystems. For example, chestnut blight (*Cryphonectria parasitica*) and the gypsy moth (*Lymantria dispar*) have had devastating effects in forests of eastern North America (Lovett et al. 2006). Often, the invasive species having the greatest effects on ecosystems are those that alter ecosystem processes and disturbance regimes. For example, cheatgrass (*Bromus tectorum*) has invaded the understory of many pine forests and shrublands in the western United States, increasing the amount and continuity of fine fuels and thus the frequency of fires. Increased fire frequency, in turn, affects ecosystem composition and structure and other ecosystem processes, changes that often increase vulnerability to further invasion.

Although nonnative species traditionally have been considered those that are recently arrived from anywhere outside a protected area's boundary (or even native species, such as trout, transplanted to new habitats within the boundary), rapid climatic changes will probably force a reassessment of this definition. Habitats within protected areas will probably become unsuitable for some current native species but may become suitable for species that historically may never have occurred in the protected area but that are native to the surrounding region. Such "displaced natives" may no longer automatically be treated as nonnative invasive species.

Invasive species provide important lessons regarding decisions about interventions and the relevance of naturalness to such decisions. First, most protected area managers agree that it is simply infeasible to eliminate all invasive species. For example, nonnative annual grasses have been abundant in many low-elevation park ecosystems in California since the 1850s. They are considered naturalized and are often perceived to be "natural." Interventions usually are focused on select invasive species. For example, managers intervene to fight a worrisome plant such as spotted knapweed (*Centurea maculosa*) rather than a more benign invasive because knapweed has a more deleterious effect on ecosystems (see Chapter 10 for more on invasives).

Altered Disturbance Regimes

Humans have substantially altered disturbance regimes over large parts of the earth's surface, including parks and wildernesses. For example, humans have altered fire regimes for millennia, particularly during the twentieth century. In western North America, fire exclusion after Euroamerican settlement resulted in unprecedented fire-free periods in some forest types. Lack of fire has modified forest structure and composition and increased the likelihood of wildfires sweeping through forests with a severity that was rarely encountered in pre-Euroamerican times. Fire exclusion has had cascading effects on biodiversity, biogeochemical cycles, and wildlife (Keane et al. 2002). This situation has been aggravated by climatic warming, which is

implicated in longer fire seasons and increases in the area burned in large, uncontrolled wildfires (Westerling et al. 2006).

Many aquatic and riparian organisms are adapted to periodic floods, which can greatly affect habitat structure and mobilize nutrients and sediments. Dams within or upstream of some protected areas have profoundly reduced seasonal flooding, altering ecosystems and in some cases contributing to extinctions. In the face of rapid climatic changes, even unregulated rivers and streams are likely to experience altered flood regimes.

Air and Water Pollution

One of the most pervasive anthropogenic global changes, affecting both aquatic and terrestrial ecosystems, is rising atmospheric carbon dioxide (CO_2) concentrations. Although CO_2 has always been a normal part of Earth's atmosphere, human activities such as fossil fuel combustion and deforestation have led to the highest atmospheric CO_2 concentrations of any period in at least the last 650,000 years (Intergovernmental Panel on Climate Change [IPCC] 2007; Figure 4.1). Elevated CO_2 concentrations have already resulted in ocean acidification, with potentially profound consequences for marine ecosystems (Orr et al. 2005). Furthermore, rising

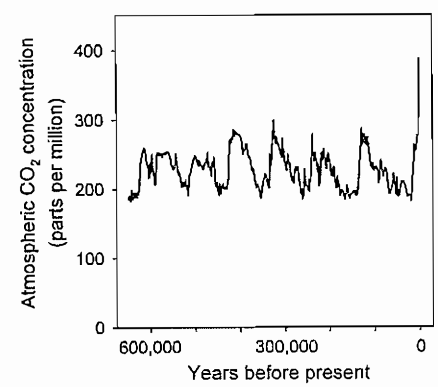

FIGURE 4.1. The nature of directional anthropogenic global changes illustrated by changes in atmospheric CO_2 concentrations through time. For at least the last 650,000 years, CO_2 concentrations have varied largely in concert with glacial advances and retreats, never falling below 180 ppm or exceeding 300 ppm. Mostly within the last 100 years, human activities such as fossil fuel combustion and deforestation have driven CO_2 concentrations well beyond 380 ppm, greatly exceeding any concentrations of at least the preceding 650,000 years. (Data from National Climatic Data Center and Oak Ridge National Laboratory)

CO_2 concentrations affect plant growth and competition, and therefore community structure and composition.

Compared with increases in atmospheric CO_2, many other forms of pollution are distributed more heterogeneously across Earth but can have regionally pervasive effects. Humans now release more biologically active nitrogen than is released by all natural processes combined, with cascading effects on ecosystems and feedbacks to climatic changes (Fenn et al. 2003; Galloway et al. 2008). Increased ground-level ozone concentrations contribute to the death or reduced growth of some plant species, thereby shifting species composition (Ashmore 2005), and acidic deposition further alters both terrestrial and aquatic ecosystems (Driscoll et al. 2001). Other widespread forms of pollution include pesticides, some of which act as endocrine disruptors.

As with invasive species, protected area managers often must accept that, at least for the foreseeable future, many of the adverse effects of pollution are inevitable. Managers can work with others to reduce pollution at its sources, but effective tools for doing so are limited. Within their protected areas, managers must identify which effects of pollution are both critically important and feasible to address. As with invasive species, priorities for action must be based not on how unnatural a pollutant is but on how critical its effect is to desired ecosystem characteristics and the likely efficacy of proposed management actions.

Global Climatic Change

As noted in Chapter 2, recognition of the magnitude of global climatic change has had the most profound effect on how we think about protected area stewardship and the relevance of naturalness to stewardship decisions. Earth may be warmer now than at any time in the last millennium, and perhaps much longer. If expected future climatic changes come to pass, by the end of this century large portions of the earth's surface will host climates that have no current analog anywhere on Earth (Williams and Jackson 2007). If we consider specific combinations of climate, soils, and topography as defining a particular habitat type, ongoing climatic changes may result in even greater proportions of the earth's surface being occupied by novel habitats than would be expected if climatic changes alone were considered (Saxon et al. 2005). Conversely, climatic changes are also expected to result in the complete disappearance of some contemporary climates and habitat types, both regionally and globally (Saxon et al. 2005; Williams and Jackson 2007).

Anthropogenic climatic change will drive park and wilderness ecosystems further from the natural condition mandated by policy, in which human influence is minimal and there is a substantial degree of historical fidelity. Currently, managers are often directed to respond by restoring as "natural" a condition as possible. But what do they use as a target or reference for their interventions if the future climate of a particular protected area is projected to have no contemporary analog? Can they expect to find a reference analog in Earth's past? Perhaps, but that past may be quite distant and its ecological setting quite different. For example, by the end of this century average global temperatures may have reached levels not seen since the last interglacial period or longer (more than 120,000 years ago), a period when now-extinct megafauna played significant roles as ecosystem architects. By century's end, global temperatures might even exceed any achieved in the last several million years, evolutionary time scales that have seen pervasive changes in Earth's biota. Even if it were possible to characterize the structure, composition, and processes of ancient ecosystems with adequate precision to use them as references, their biota differed from those on Earth today.

Although the extent of no-analog habitats (combinations of climate, soils, and topography) is likely to increase in coming decades, the altered future habitats of some protected areas might sometimes be analogous to habitats found elsewhere on the landscape within the past few centuries, particularly in environmentally complex mountainous regions (Saxon et al. 2005). Would such protected areas be sensible candidates for continued management for "natural" conditions, using analogs from the past as targets? We think not. A site's biotic potential in the future will be determined by more than just climate, soils, and topography. Specifically, climatic changes will interact with the other novel, pervasive agents of change (habitat fragmentation, loss of top predators, invasive species, altered disturbance regimes, and pollution) to such an extent that all habitats may be no-analog habitats.

Unprecedented Environmental Change Challenges Naturalness

The unprecedented future that will result from the convergence of rapid climatic changes with an additional suite of novel, pervasive environmental stressors such as those described above demands that managers and policymakers move beyond existing concepts of naturalness. Anthropogenic change is both ubiquitous and directional, and restoration of key aspects of naturalness (such as historical fidelity) is likely to be both unattainable and undesirable. However, directional change does not mean that change is either linear or predictable. In fact, as will be discussed in the next section, change may be nonlinear and increasingly unpredictable. We have entered an era in which environmental influences on ecosystems have no precedence in the history of Earth, no matter how far into the past we look.

Our entry into a no-analog future means that attempts to restore naturalness, using past conditions as targets, usually will demand greater and greater inputs of energy. Protected area managers may thus be committed to engage in Sisyphean efforts that ultimately are likely to fail (Hilderbrand et al. 2005). Even more significantly, the no-analog future means that management interventions could result in "restored" ecosystems that are inherently unstable to novel conditions, making them more susceptible to sudden, undesirable state shifts (Harris et al. 2006). For example, maintenance of a "naturally" dense forest in the face of a drying climate could result in the sudden loss of the forest to insects, pathogens, or an unusually severe wildfire, followed by soil erosion and a consequent reduction of biological potential. Thus, in the face of a suite of novel environmental conditions, restoration of ecosystems to resemble those of the past provides no guarantee of their sustainability into the future and in fact might lead to the catastrophic loss of some of the very ecosystem elements intended for preservation.

The Unpredictable Future

To decide whether and how to intervene in ecosystems, protected area managers normally need a reasonably clear idea of what future ecosystems would be like if they did not intervene. Management practices usually involve defining a more desirable future condition and implementing management actions designed to push or guide ecosystems toward that condition. Managers need confidence in the likely outcomes of their interventions. This traditional and inherently logical approach requires a high degree of predictive ability, and predictions must be developed at appropriate spatial and temporal scales, often localized and near-term. Unfortunately, at the scales, accuracy, and precision most useful to protected area management, the future not only promises to be unprecedented, it promises to be unpredictable. To illustrate this, consider the uncertainties involved in predicting climatic changes, how ecosystems are likely to respond to climatic changes, and the likely efficacy of actions that might be taken to counter adverse effects of climatic changes. Comparable uncertainties surround the nature and magnitude of future changes in the other ecosystem stressors we have discussed in this chapter and the interactions between these stressors.

The Challenge of Predicting Climatic Changes

Prediction of the rate and magnitude of future climatic changes requires knowledge of climate sensitivity, the average global warming expected from a doubling of atmospheric CO_2 concentrations. Recent estimates of climate sensitivity range broadly between 2.1° and 4.4° C, although lower and much higher values are possible. Additional research is unlikely to improve this range of estimates because the large degree of uncertainty is a general consequence of the nature of the climate system itself. Thus, our ability to predict the effects of increasing greenhouse gas concentrations even on global-scale climate is inherently uncertain.

This uncertainty is compounded by uncertainty about the magnitude of future greenhouse gas emissions. Emissions will be affected by the interactions of complex phenomena such as long-term demographic trends, economic development, land use change, technological change, geopolitics, and feedbacks between climatic changes, ecosystems, and societies. Recent international climatic change assessments have relied on greenhouse gas emission scenarios spanning a broad range of possible futures. Even so, actual emission reductions from technological advances have already lagged behind projected reductions that were assumed in even the most pessimistic of these scenarios (Pielke et al. 2008), underscoring the inherent uncertainty in predicting future emissions.

Uncertainty regarding both greenhouse gas emissions and climatic response to those emissions means that the rate and magnitude of future global climatic changes likewise remain uncertain. For example, recent estimates of increases in mean global temperature by the end of the century mostly range from 1.1° to 6.4° C, with even higher or lower values possible (IPCC 2007). Importantly, these are globally averaged predictions. The accuracy of climatic change predictions decreases as the scale of analysis is narrowed from global to regional to local. Local predictions, the most inaccurate ones, are what the managers of protected areas really need. Even for well-studied regions such as northern California, recent model projections do not agree as to whether future climates will be warmer and wetter or warmer and drier—alternative futures that have profoundly differing implications for protected areas and their management. At the spatial scales relevant to park managers, even higher levels of uncertainty arise from poorly understood microclimatic complexity, such as cold air pooling and hillslope effects.

The Challenge of Predicting Ecosystem Response to Climatic Change

Climate forecasts are relevant because those forecasts then drive models addressing the questions of greatest interest to managers: How will the plants, animals, and ecosystems they steward be affected by future climatic changes? Yet predictions of ecosystem responses to environmental changes are notoriously unreliable. Their accuracy would be low even if the rate and magnitude of future environmental changes were precisely known.

Models are useful for organizing thinking, giving a qualitative feel for a range of possible rates and magnitudes of future ecosystem changes, and providing grist for scenario planning (Chapter 13). However, their outputs cannot be used as predictions. Because the extraordinary complexity of ecosystems is not fully understood and cannot be adequately incorporated in models, models make numerous simplifying assumptions. For example, some common assumptions are that the effects of species interactions are negligible, that evolutionary responses to rapid environmental changes are negligible, and that contemporary correlations between environment and ecosystem properties imply simple cause-and-effect relationships. However, most such assumptions are questionable or are simply false (Dormann 2007; Suttle et al. 2007). Models based on different sets of simplifying assumptions yield widely divergent forecasts of the biological effects of future climatic changes. For example, projected changes in distribution of the South African shrub *Leucospermum hypophyllocarpodendron* between now and 2030 ranged from a 92 percent reduction to a 322 percent gain over the plant's current distribution, depending on which of several competing models was used (Pearson et al. 2006). Although forecasts might improve by considering the combined outputs of several models, significant uncertainties and surprises are inevitable (Williams and Jackson 2007; Doak et al. 2008).

Further hampering prediction of future ecosystem conditions, environmental stressors often interact in unexpected ways. For example, atmospheric nitrogen deposition can facilitate invasion by nonnative plant species, which in turn can alter fire regimes, ultimately leading to vegetation type conversions (Brooks et al. 2004). Such interactions are notoriously difficult to anticipate (Doak et al. 2008). Other surprises will occur as additional stressors emerge, a recent example being the rapid, global spread of a chytrid fungus (*Batrachochytrium dendrobatidis*) throughout frog populations. Effects of such diseases can trigger cascading effects throughout ecosystems.

A critically important class of surprises involves threshold events, in which gradual environmental changes trigger sudden, dramatic, and sometimes irreversible changes in ecosystem state (Scheffer and Carpenter 2003). For example, in some parts of western North America gradual climatic warming has contributed to sudden and extensive outbreaks of bark beetles (*Dendroctonus* and *Ips*), killing millions of hectares of forest within a few years (Raffa et al. 2008). Ongoing warming may trigger further outbreaks in regions formerly immune to them. Although critically important, thresholds remain difficult to identify (Scheffer and Carpenter 2003).

Some Broad Expectations for Future Conditions

Although the future is impossible to predict precisely, particularly at the local scales most important to managers, it is still possible to identify broad, qualitative expectations at regional scales that might be helpful to protected area managers. For example, even though the precise pace and magnitude of global or regional warming cannot be predicted, one can predict with high certainty that in coming decades most regions of the earth will get warmer (Jackson and Overpeck 2000). Thus, it is reasonable to expect that at the regional if not local scale, the amount of annual precipitation falling as snow will continue to decline and that snowpack itself will decline and, in some places, vanish. As summers become longer, the average regional fire season will lengthen, and area burned will probably increase (Westerling et al. 2006). Weather extremes, such as heat waves, droughts, and floods, are likely to become more common (IPCC 2007). Sea level will continue to rise, inundating some coastal ecosystems, and oceans will continue to warm and acidify (IPCC 2007). Land use changes are likely to continue driving habitat fragmentation, various sorts of pollution are likely to continue or increase, and novel invasive species will continue invading most ecosystems.

Paleoecological studies have clearly demonstrated that species behave individualistically in response to climatic changes (Jackson and Overpeck 2000). Thus, in response to climatic changes of the magnitude projected by the end of this century, most contemporary biotic communities (particular combinations of species that currently live together) are likely to have at least partly dissociated, and their component species will have reassembled in combinations that have no contemporary analogs. As alluded to earlier, either with or without human assistance, many species will migrate, with ranges expanding in some areas and contracting in others (Parmesan 2006; Thomas et al. 2006). Other species will almost certainly be driven to population extirpation or species extinction (Thomas et al. 2006). Many protected areas will no longer provide suitable habitat for many of their current species; conversely, "displaced native" species are likely to migrate into reserves. Rapid environmental changes will also drive evolutionary changes, altering biodiversity at the level of the genome (Parmesan 2006).

Unpredictability Makes Desired Future Conditions Problematic

In the next several decades, ongoing global environmental changes are almost certain to drive profound and unprecedented changes in ecosystems. However, the precise nature of those changes will not be clear until they happen. Despite the scientific community's ability to make some broad, qualitative generalizations about probable future conditions, it is impossible, especially at the spatial and temporal scales useful to protected area managers, to accurately predict either environmental changes or consequent ecosystem responses (Pilkey and Pilkey-Jarvis 2007). Given this uncertainty, narrowly defined desired future ecosystem conditions, particularly if they are historical conditions poorly aligned with the unprecedented future, will seldom provide useful targets for management intervention. Managers will need approaches to planning that are more suitable to a high level of uncertainty, approaches that allow for a much wider array of possible desired outcomes, and they will need ways to become even more adept at adapting to rapidly changing conditions.

Protected Area Stewardship in a Changing World

The nature and magnitude of anthropogenic global changes challenges managers to move beyond traditional concepts of naturalness to find guidance for dealing with the nuanced dilemmas of contemporary stewardship. The degree to which protected area ecosystems are affected by humans will almost certainly continue to increase, and it is probable that the pervasiveness of management interventions will follow suit. Although there will always be places where lack of funds precludes intervention and places where managers refrain from intervening despite human effects on ecosystems, many protected areas are likely to experience at least some intentional human manipulation. The numerous anthropogenic drivers of change and the

profound nature of change make it clear that substantial human influence is inevitable, even in our most valued parks and wilderness areas.

The future dominance of no-analog conditions, the inherent unpredictability of the future, and the virtual certainty of surprises all conspire to force protected area managers to adopt fundamentally new goals and management strategies. As we have noted, management actions aimed at restoring or maintaining ecosystems with high historical fidelity (using natural analogs from the past) or mimicking conditions that would exist in the absence of human influences will require continuously increasing inputs of energy and ultimately are likely to fail. Failures could be catastrophic. Attempts to resist rapid environmental changes could create inherently unstable conditions, leading to the sudden loss of some of the very species and ecosystem functions managers had hoped to sustain. Instead, protected area managers will probably need to redefine their goals. For example, they might seek to maintain regional native biodiversity and critical ecosystem functions, even if biotic community structure and composition no longer resemble what existed in the past. To reach these ends, new management approaches are needed. Interventions might emphasize facilitating, rather than resisting, certain ecosystem changes. A key to facilitating ecosystem transitions will be maintenance of ecosystem resilience, the ability to sustain environmental shocks and stresses without undergoing an undesirable and irreversible change in conditions. Resilience and other management emphases are addressed in Chapters 6 through 9.

Managers will need to act in the face of uncertainty. To do so, they may need to abandon traditional approaches to long-term planning that are based on the assumption that the future is known, or at least knowable. They are not likely to be able to use the outputs of computer models to determine a particular, narrowly defined future ecosystem trajectory to facilitate. Rather than attempt to define a specific set of desired future conditions, it may sometimes be more productive to define a broad set of undesired future conditions—conditions to be avoided. For example, undesired future conditions might include loss of regional native biodiversity or critical ecosystem functions. Outcomes that do not fall within the undesired future conditions may be deemed acceptable. In the face of high uncertainty, managers might engage in scenario planning (described in Chapter 13), the use of internally consistent visions of a range of possible futures to explore potential future consequences of different decisions. For example, scenario planning might suggest that a particular set of management actions could lead to ecosystems resilient to a wide variety of potential stresses, including both warmer and wetter and warmer and drier futures.

The anthropogenic threats to protected areas discussed in this chapter present profound challenges to protected area stewardship. These challenges are exacerbated by the unprecedented future that protected areas face and the limited ability of science to predict the future and the likely outcomes of management interventions. However, as challenging as our assessments may initially sound, we firmly believe that scientists, managers, and policymakers can work together to define new ways to protect key values of parks and wilderness areas: new goals, new institutions, new planning processes, and new management approaches, innovations discussed more fully in the chapters that follow.

BOX 4.1. GLOBAL ANTHROPOGENIC CHANGE AND NATURALNESS

- Anthropogenic forces—most notably habitat fragmentation and loss of top predators, invasive species, altered disturbance regimes, pollution, and climatic change—are having profound effects on protected areas.
- These profound, ubiquitous, and directional changes will lead to an unprecedented future for which there is no analog, now or in the past.
- Although useful sources of information for many purposes, past ecosystem conditions (historical or natural range of variability) often will make poor targets for management interventions.
- Despite management interventions, protected area ecosystems inevitably will suffer the effects of anthropogenic global changes and will lose much of their historical fidelity.
- Consequently, simple and traditional concepts of naturalness will prove inadequate to provide guidance regarding stewardship decisions about where and how to intervene in ecosystems.
- In addition to being unprecedented, the future will also be largely unpredictable at the scales useful to managers and full of uncertainty and surprises.
- Because the outcomes of management interventions will be uncertain, protected area managers will have to be adaptable, investing more in experimenting, monitoring, and learning and in more flexible approaches to planning.

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