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Principles for Studying and Managing Natural Quiet and Natural Darkness in National Parks and Other Protected Areas

Robert Manning, Peter Newman, Jesse Barber, Christopher Monz, Jeffrey Hallo, and Steven Lawson

A SUBSTANTIAL BODY OF RESEARCH ON NATURAL QUIET AND NATURAL DARKNESS in national parks, and protected areas more broadly, has been reported in the scientific and professional literature in recent years. However, this literature is widely scattered over many academic and professional journals that cover both the natural and social sciences. To help integrate and synthesize this body of work, we surveyed this diverse literature and collected representative examples in a book (Manning et al. 2018). We conclude our book with a series of principles that we have distilled to help guide park managers to protect natural quiet and natural darkness. This paper presents those principles.

Much of our book focuses on national parks in the United States, and in the remainder of this paper the phrase “the national parks” refers to them. But we feel that the principles we have derived from our review of the scientific and professional literature on natural quiet and natural darkness apply equally well to a variety of parks and protected areas in the United States and elsewhere.

Natural quiet is generally defined as the sounds of nature uninterrupted by human-caused noise, and natural darkness is darkness unaffected by human-caused light. It is important to note that natural quiet and natural darkness do not necessarily mean absolute quiet or darkness, as the natural world often generates sounds of its own (e.g., birds calling, wind blowing, rivers rushing) and has sources of illumination (e.g., the glow of celestial bodies and the fluorescence of some plants and animals).

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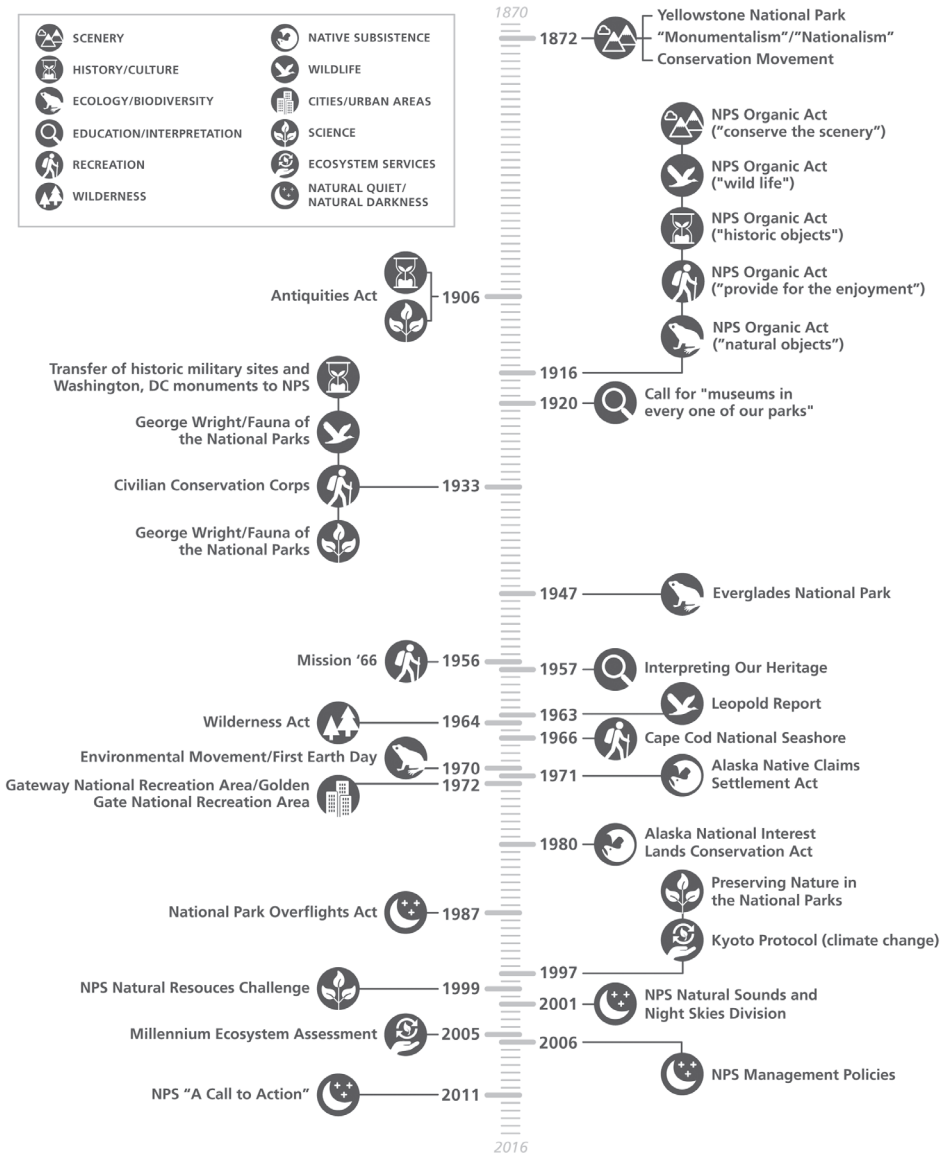
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Principle 1. Natural quiet and natural darkness are the “new” resources of the national parks.

This assertion is supported in three ways. First, the history of the national parks illustrates a clear expansion of the resources and values of the national park system. Figure 1 presents an outline of this evolution, starting with appreciation of grand scenery and moving through a

Figure 1. The evolution of US national park resources.



host of other valued aspects of national parks: history, cultural heritage, wildlife, education, ecology and biodiversity, recreation, wilderness, native subsistence, cities and urban areas, science, and ecosystem services. Natural quiet and natural darkness can be seen as the most recent additions to this growing list of resources. Second, natural quiet and natural darkness are increasingly recognized as important resources. The classic definition of a “resource” is something that has value, but is increasingly scarce. A growing body of scientific and professional literature illustrates the ways in which natural quiet and natural darkness are vital components of our natural environment (e.g., they facilitate natural processes such as predator-prey relationships and mating behaviors) and contribute to the quality of our lives (e.g., they enhance our enjoyment and appreciation of national parks and contribute to our health and well-being). Third, human-caused sound and light have made these resources increasingly scarce, even in national parks. For example, nearly all national parks include roads and other transportation corridors that produce a great deal of noise, and this noise is growing louder with the increase in the numbers of visits to the national parks—now measured in the hundreds of millions annually. More generally, some 63% of US protected areas have undergone a doubling of background sound levels due to noise, and 21% of these areas have experienced a tenfold increase (Buxton et al. 2017). Moreover, a landmark study found that almost a fifth of the earth’s land surface is polluted by light, and light pollution is increasing at a rate of 6% annually (Cinzano et al. 2001).

Principle 2. The emergence of natural quiet and natural darkness in the scientific, professional, and public conscience has been accompanied by a revealing set of concepts and terminology.

Much of the growing literature on natural quiet and natural darkness refers to human-caused sound and light as noise and light *pollution*, by-products of our economy and culture that are unwanted and damaging in the same ways as other, more conventional, forms of pollution. Excessive noise and light that flow onto another’s property are increasingly referred to as noise and light *trespass* and as *nuisance* noise and light, suggesting that people have a right to be protected against the detrimental effects of excessive human-caused noise and light. These terms reflect a growing appreciation of the ecological and experiential values of natural quiet and natural darkness and increasing concern about the detrimental effects of unwanted and damaging human-caused noise and light.

Principle 3. Noise pollution can have substantial impacts on the ecological and biodiversity values of national parks.

A growing number of studies document the multiple and wide-ranging impacts of human-caused noise on park resources (e.g., Francis et al. 2012; Francis and Barber 2013; Ware et al. 2015; Simpson et al. 2016; McMahan et al. 2017). A literature review on this topic illustrates several mechanisms by which these impacts occur (Francis and Barber 2013). For example, chronic and frequent noise interferes with animals’ ability to detect important sounds, whereas intermittent and unpredictable noise is often perceived as a threat. These

effects can lead to “fitness costs” to animals, either directly or indirectly—for example, by compromising predator or prey detection or mating signals, altering the timing of movement patterns, increasing psychological stress, altering spatial distributions of animals, decreasing foraging or provisioning efficiency, and altering mate attraction and territorial defense.

Principle 4. Light pollution can have substantial impacts on the ecological and biodiversity values of national parks.

Many studies detail the impacts of human-caused light on park resources (e.g., Kempeneers et al. 2010; Gaston et al. 2013; Lewanzik and Voigt 2014; Altermatt and Ebert 2016; French-Constant et al. 2016). For example, a literature review (Gaston et al. 2013) documents the mechanisms by which these impacts occur. The authors note that the biological world is organized largely by light and darkness: the rotation of the earth partitions time into a regular cycle of day and night. But the spread of electric lighting causes major perturbations in these natural light and darkness regimes, affecting life from the cellular to ecosystem levels. The effects can include foundational alteration of natural processes, including primary productivity; partitioning of temporal niches; repair and recovery of physiological function; measurement of time through circadian, lunar, and seasonal cycles; detection of resources and natural enemies; and navigation.

In addition to the impacts on individual species, research suggests that these impacts can extend from individuals and single species to whole communities of species along with ecological services. For example, reduced flight-to-light behavior of moths may reduce pollination by and the food source for bats and spiders; altered behavior of birds may lead to both a mismatch between time of peak demand for food and peak food availability, as well as females’ maladaptive choices of mates; and reduced feeding behavior in bats results in reductions in pollination and seed dispersal. Research has also addressed the interaction of noise and light pollution. For instance, both of these forms of pollution affect frog-biting midges and their túngara frog hosts, disrupting this parasitic relationship (McMahon et al. 2017).

Principle 5. Natural quiet can enhance the quality of the visitor experience in national parks; correspondingly, noise pollution can substantially diminish it.

Just as the experience of visiting national parks can be improved in the presence of natural quiet, it can be impaired by human-caused noise (Manning et al. 2010; Park et al. 2010; Weinzimmer et al. 2014; Benfield et al. 2014; Taff et al. 2014). For example, a survey of national park visitors found that more than 90% of respondents reported that the enjoyment of natural quiet and the sounds of nature were primary motivators for their visit (Weinzimmer et al. 2014). There is often a strong relationship between the impacts of noise pollution on the natural environment and on the experience of visiting national parks. For example, alterations in wildlife distributions and behaviors caused by noise pollution may diminish visitors’ opportunity to see and hear iconic wildlife. Moreover, natural quiet and lack of noise pollution can contribute not only to the quality of visiting parks, but also to human health and well-being (Benfield et al. 2014).

Principle 6. Likewise, natural darkness can enhance the quality of the visitor experience in national parks and light pollution diminish it.

As with natural quiet and noise, natural darkness can contribute to the quality of national park visitors' experience, while human-caused light can diminish it (Duriscoe 2001; Collision and Poe 2013; Mace and McDaniel 2013; Smith and Hallo 2013; Manning et al. 2015). For example, Smith and Hallo (2013) call attention to the popularity of nighttime recreation activities in national parks (e.g., camping, viewing nocturnal wildlife), but light pollution can damage the quality of these activities. It should be noted that, as is the case with the impacts of noise pollution described in Principle 5, light pollution's impacts on the natural environment can be strongly related to their impacts on the experience of visiting the national parks. For example, changes in distributions and behaviors of wildlife species caused by light pollution can affect visitors' ability to see and hear iconic nocturnal wildlife.

Principle 7. National parks are some of the last refuges of natural quiet and natural darkness and must be protected.

Many national parks and other protected areas are located far from large metropolitan areas and therefore have been somewhat insulated from the noise and light generated outside these parks. Moreover, in a visitor survey conducted at Bryce Canyon National Park, many respondents reported that national parks are the preferred sites to stargaze (Mace and McDaniel 2013). However, natural quiet and natural darkness are threatened in all national parks by increasing numbers of visits and human-caused noise and light—especially since both noise and light can travel substantial distances. For example, light can travel up to 200 miles from its source.

Principle 8. The National Park Service's recognition of the value of natural quiet and natural darkness, and its policies and programs to help protect these resources, are a major advance in the evolution of the agency.

Land-managing agencies need to explicitly value, and manage for, natural quiet and natural darkness. The National Park Service (NPS) has been a leader in this. Perhaps the most foundational guidance is the Organic Act of 1916 that created NPS, which directed the agency to manage the national parks to “conserve the scenery and the natural and historic objects and the wild life [*sic*] therein.” Of course, there was little thought about natural quiet and natural darkness at that time, but the act has provided a framework to protect all newly recognized park resources as scientists, managers, and the public become conscious of them. NPS took the initiative in 1999 with its creation of the Night Sky Team, designed to monitor light pollution in national parks and advise park staff on how to help prevent and reduce it. In 2000, NPS established its Natural Sounds and Night Skies Division, whose mission is to “restore, maintain, and protect acoustical environments and natural dark skies throughout the national park system.” Furthermore, in 2006 NPS added the protection of natural quiet and natural darkness to its management policies, the directives that guide the work of the agency. Many parks participate in this work, developing and presenting interpretive programming to park visitors, hosting stargazing parties to engage the public in discussions of natural darkness,

and implementing management actions to protect natural quiet and natural darkness. All this constitutes a major step forward by the agency toward realizing a full understanding of the mission set out in the Organic Act.

Principle 9. Protecting natural quiet and natural darkness is an important manifestation of the twofold mission of the NPS.

National parks are to be managed in ways that provide appropriate public access and enjoyment, but also protect park resources and the quality of visitors' experiences. But these objectives can often conflict when demand for access to the national parks is high and increasing. For example, very large numbers of visitors, or even a small number of noisy visitors, can degrade natural quiet. Visitors can also diminish natural darkness, as can the often extensive facilities and services in the parks (e.g., roads, hotels, and visitor centers) that are the infrastructure for visitor use. National parks should be managed to limit the impacts of visitor use on all important park resources, including natural quiet and natural darkness. An effective program of reducing visitor-caused noise through educational programming at Muir Woods National Monument is a good example (Manning et al. 2010).

Principle 10. More research is needed on natural quiet and natural darkness.

The scientific and professional literature on natural quiet and natural darkness is expanding. However, much more remains unknown than known. Coverage of the impact on species is spotty at best: we are only beginning to uncover the interrelationships among species, and the mechanisms by which these interrelationships work; and the important and often cascading ecological effects of noise and light pollution on plant and animal communities are poorly understood. More research is needed to help guide the formulation of ecological and experiential indicators and thresholds for both noise and light pollution. Research is needed to develop effective and efficient monitoring protocols and assess the effectiveness of management actions. Generally, the literature on noise pollution is more fully developed than that on light pollution, suggesting the need for a greater emphasis on the latter. Research on noise and light pollution's impacts on terrestrial animals and plants is more developed than that on the impacts on marine environments. Knowledge of the economic impacts of noise and light pollution (including the benefits of protecting the resources of natural quiet and natural darkness) is limited. These and many more topics warrant an expanded program of research to help ensure that the management of these resources is as informed as possible.

Principle 11. Research on natural quiet and natural darkness can and should draw on a range of scholarly disciplines and incorporate a variety of research methods.

Research on natural quiet and natural darkness comes from both the natural and social sciences, recognizing the multi- and interdisciplinary character of these resources. Where appropriate, work in the natural and social sciences should be integrated. For example, the natural sciences can help identify the ecological impacts of human-caused noise and light, while the social sciences can help determine societal norms for the maximum acceptable levels of this pollution. Research also employs a range of study methods, including both lab-

oratory and field experiments. Scientists should think broadly about the range of disciplines and methods that can be brought to bear on understanding and managing natural quiet and natural darkness.

Principle 12. Many of the impacts of human-caused noise and light are reversible, though it is becoming evident that some may not be.

Excessive noise and light can be reduced or even eliminated (sometimes with little cost or effort), and thus their impacts can be substantially diminished. For example, many traditional forms of transportation now employ new, quieter technology. Moreover, an increasing number of national parks are using forms of public transit such as shuttle buses to reduce the number of cars and associated noise (Manning et al. 2014). Similarly, new lighting technologies, including lights that are oriented more directly down at their target—which allows less light to escape into the atmosphere—can reduce the amount of light needed in national parks. The use of lights that are activated by motion sensors, so they come on only when needed, is another way to reduce light pollution. These technologies and best management practices can substantially reduce human-caused noise and light in the national parks and elsewhere, suggesting that natural quiet and natural darkness can be considered renewable resources. However, some impacts of human-caused noise and light may not be reversible. For example, the decreased moth flight-to-light behavior that has been found in some research may be the product of a microevolutionary response to contemporary light environments and thus likely difficult to reverse (Altermatt and Ebert 2016).

Principle 13. Human-caused sound and light can be important cultural resources in certain contexts.

In the context of some national parks and related areas, selected forms of human-caused sound and light can be considered valuable cultural resources. For example, at San Antonio Missions National Historical Park, the sounds of church bells add an authentic layer of sound to the park experience. And in national park sites related to the Civil War, such as Gettysburg National Military Park, booming cannons can add to the authenticity of the visitor experience. Similarly, light is not inherently deleterious in national parks, at least from an experiential perspective: well-designed and appropriate lighting allows some park resources to be viewed so as to be better appreciated. An obvious example is the caves of Carlsbad Caverns National Park (though these lights and visitors' use of the area has reduced the presence of bats). And well-designed lights can add drama and aesthetic appeal to cultural sites, such those that illuminate the American flag flying over Fort McHenry National Monument and Historic Shrine and the monuments and memorials of the National Mall and Memorial Parks in Washington, DC.

Principle 14. Natural quiet and natural darkness are common property resources that should be managed to protect the quality of park resources and visitors' experiences.

Natural quiet and natural darkness are examples of common property resources—resources

that are owned by all, but that are inherently vulnerable to use-related impacts caused by individuals. Common property resources are subject to overuse and degradation if they are not managed appropriately. In his classic paper “The Tragedy of the Commons,” Garrett Hardin suggested that “mutual coercion, mutually agreed upon” is needed to manage common property resources (Hardin 1968: 1247). In other words, society must agree on, and then abide by, rules that govern the amount and types of uses of common property resources in order to protect them. Government agencies responsible for managing common property resources—NPS, in the case of America’s national parks—must establish and enforce such rules. Of course, these rules must be developed in consultation with the public.

Principle 15. The closely related conceptual frameworks of carrying capacity, limits of acceptable change, and indicators and thresholds should be used to help protect important park resources, including natural quiet and natural darkness.

Carrying capacity is defined as the amount and type of visitor use that can be accommodated in a park or related area without having unacceptable impacts on park resources and the quality of visitors’ experiences. The concept of *limits of acceptable change* recognizes that visitors’ use of national parks will inevitably have some impacts, but these impacts must be limited to maintain the quality of park resources and experiences. *Indicators and thresholds* empirically define the limits of acceptable change. These three conceptual frameworks can be integrated and made operational in the form of an adaptive, management-by-objectives process such as Visitor Use Management (Interagency Visitor Use Management Council 2016). First, management objectives are formulated that describe the desired conditions of park resources and experiences. These objectives are then expressed in empirical terms in the form of indicators and thresholds. *Indicators* are measurable, manageable variables that serve as quantitative proxies for management objectives, and *thresholds* define the minimum acceptable condition of indicator variables. Second, indicators are periodically monitored to assess their condition. Third, management actions (as outlined in principle 16) are applied to help ensure that the condition of indicator variables does not fall below defined thresholds. Application of this management-by-objectives framework is an ongoing and adaptive process: it provides periodic information on the condition of indicator variables as well as the effectiveness of management actions, and managers can adjust those actions as warranted and guided by monitoring data.

Principle 16. A range of management strategies and practices can be used to protect natural quiet and natural darkness in the national parks, but new approaches will also be required.

The literature is suggestive of the ways in which NPS can help protect natural quiet and natural darkness. For example, a “quiet zone” and “quiet days” were designated at Muir Woods National Monument, and an educational program was implemented to communicate to visitors the importance of protecting natural quiet (Manning et al. 2010). This program was found to be effective, substantially reducing the level of visitor-caused noise, and was well received by visitors. In another study, educational messages about military flights over

Sequoia National Park were found to be effective in reducing the impacts of these flights on the visitor experience (Taff et al. 2014). However, these are only very limited examples. The professional literature suggests that there are four basic strategies for reducing recreation-related impacts in parks and related reserves: limit use, increase the supply of opportunities, reduce the impacts of use (through changes in visitor behavior), and harden park resources and experiences (that is, make them more resistant to potential impacts; Manning et al. 2017). In addition, six basic practices can be used to carry out these strategies: information/education, zoning, rules and regulations, law enforcement, rationing/allocation, and site design and maintenance. Relatively little is known about the effectiveness of these management strategies and practices in protecting natural quiet and natural darkness and related visitor experiences, and this topic deserves more study.

Principle 17. A landscape-scale approach is needed to protecting natural quiet and natural darkness in the national parks.

It is becoming increasingly apparent that many conservation issues require a landscape-scale approach to their solution, because some of the impacts on parks are caused by sources outside their boundaries. This is especially the case with natural quiet and natural darkness. Human-generated noise that is produced outside the parks may drift into them, disturbing natural quiet. Transportation-related noise is a good example. Human-caused light generated outside parks can also intrude, disturbing natural darkness. Most national parks and other protected areas are not large enough to be fully insulated from these types of external threats. Progressive national park management must include reaching out to neighboring landowners—other public land management agencies, surrounding communities, nonprofit organizations, and private landowners—working with them to limit impacts on natural quiet and natural darkness. This type of outreach has succeeded at Acadia National Park and Chaco Culture National Historical Park. NPS staff members at Acadia collaborated with officials in Bar Harbor, Maine, the gateway town to the park, and this resulted in passage of a progressive ordinance that reduces the amount of light that drifts into the park. And park managers at Chaco Culture worked with a group of stakeholders in New Mexico to convince the state legislature to pass an act that limits light pollution throughout the state. An innovative and promising landscape-scale initiative called the Dark Sky Preserve is now under way on the Colorado Plateau, a large geographic region in the American Southwest. This is an NPS-led effort to coordinate management of the many national parks in this region to help preserve the remarkable quality of their natural darkness. This landscape-scale approach to managing natural darkness is strongly supported by park visitors: for example, a survey of visitors to Bryce Canyon National Park found that nearly 90% of respondents believe “that areas near national parks should assist in maintaining dark night skies” (Mace and McDaniel 2013).

Principle 18. A large network of partners and stakeholders will be required to protect natural quiet and natural darkness in the national parks.

Many partners are needed to work with NPS to advance the protection of natural quiet and

natural darkness, for two basic reasons. First, as noted in principle 17, many threats to these resources emanate from outside the parks. Second, NPS has limited funding and staffing to do all the work that is needed. In the case of Chaco Culture National Historical Park, many stakeholder groups participated in successfully lobbying the New Mexico state legislature to pass the statewide outdoor lighting ordinance. Local astronomers and related organizations, along with a host of volunteers, are instrumental in hosting stargazing parties at many national parks, offering programming related to the night sky and setting up their telescopes for park visitors. In Sequoia National Park, managers are collaborating with the local military base to help minimize the impacts of aircraft overflights on the park's natural quiet (Taff et al. 2014). The International Dark Sky Association is instrumental in advancing the cause of night sky protection, certifying parks and local communities that meet best management practices. Local communities are interested in advancing tourism-based economic development through protecting high-quality natural quiet and natural darkness in the parks near them. Natural and social scientists are advancing our knowledge of natural quiet and natural darkness, which can inform effective park management. Perhaps the strongest advocates of natural quiet and natural darkness are park visitors, many of whom visit the parks, at least in part, to experience those resources (Mace and McDaniel 2013; Smith and Hallo 2013).

Principle 19. Natural quiet and natural darkness should be incorporated into comprehensive park management plans.

As is clear from several of the preceding principles, natural quiet and natural darkness are important natural, cultural, and recreational resources in the national parks. NPS has a planning process in which foundation statements are periodically prepared for all units of the national park system, followed by a portfolio of specific plans based on the operational and management needs of each park. Natural quiet and natural darkness should receive explicit consideration in this planning process. What resources related to natural quiet and natural darkness are found in each park? What are the challenges and threats to protecting these resources? Do these resources need to be restored? Many parks include specific plans that address resources or operations that are especially important to them; examples include natural and cultural resources, wilderness, transportation, and visitor use management. At parks with iconic natural quiet and natural darkness, plans focused on these resources may be justified. Alternatively, natural quiet and natural darkness should be explicitly considered within the foundation statements and more specific types of plans noted above.

Principle 20. More information and educational programs are needed on natural quiet and natural darkness.

NPS has a long history of providing high-quality education to visitors about the natural, cultural, and recreational resources of the national parks. In NPS lingo, this is called “interpretive programming” because it “interprets” technical information about the parks in ways that are engaging and aimed at a nontechnical audience. Classic examples are nature walks and campfire talks, though the form of these programs has been substantially updated to

include collaborative relationships with local schools and a strong presence on the Internet and through social media (Manning et al. 2016). More programming is needed on the newly recognized resources of natural quiet and natural darkness.

Principle 21. Management of natural quiet and natural darkness should be conducted in a proactive manner.

Like all good park management, potential problems should be addressed before they reach crisis proportions. Unfortunately, human-caused noise and light have already diminished park resources and the quality of the visitor experience. While a growing body of research has advanced our understanding of natural quiet and natural darkness, much remains to be learned (principles 10 and 11). But this should not be an impediment to an aggressive program of management. We will never have complete knowledge of the ecological and experiential impacts on natural quiet and natural darkness, the causes and consequences of these impacts, and the effectiveness of alternative management practices. After making a good-faith effort to inform themselves, park managers must ultimately exercise their professional judgment in protecting natural quiet and natural darkness. Managers should find courage in their knowledge of the burgeoning scientific and professional literature, the conceptual and management frameworks that have emerged from this literature, and the trust the public has placed in them to protect park resources and experiences. Recognition and protection of natural quiet and natural darkness will require strong and deliberate management action and a promise to manage by design, not by default.

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