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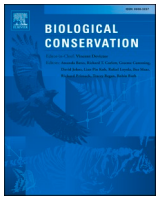

COVID-19 pandemic impacts on conservation research, management, and public engagement in US national parks

Abraham J. Miller-Rushing [a,*], Nicole Athearn [b], Tami Blackford [c], Christy Brigham [d], Laura Cohen [a], Rebecca Cole-Will [a], Todd Edgar [e], Elizabeth R. Ellwood [f,g], Nicholas Fisichelli [h], Colleen Flanagan Pritz [i], Amanda S. Gallinat [j], Adam Gibson [a], Andy Hubbard [k], Sierra McLane [l], Koren Nydick [m], Richard B. Primack [n], Susan Sachs [o], Paul E. Super [o]

[a] Acadia National Park, National Park Service, Bar Harbor, ME, USA
[b] Yosemite National Park, National Park Service, Yosemite, CA, USA
[c] Yellowstone National Park, National Park Service, WY, USA
[d] Sequoia and Kings Canyon National Parks, National Park Service, Three Rivers, CA, USA
[e] National Information Services Center, National Park Service, Bar Harbor, ME, USA
[f] iDigBio, University of Florida, Gainesville, FL, USA
[g] La Brea Tar Pits and Museum, Los Angeles, CA, USA
[h] Schoodic Institute at Acadia National Park, Winter Harbor, ME, USA
[i] Air Resources Division, Natural Resource Stewardship and Science, National Park Service, Lakewood, CO, USA
[j] Utah State University, Logan, UT, USA
[k] Sonoran Desert Inventory and Monitoring Network, National Park Service, Tucson, AZ, USA
[l] Denali National Park and Preserve, National Park Service, AK, USA
[m] Rocky Mountain National Park, Estes Park, CO, USA
[n] Boston University, Boston, MA, USA
[o] Great Smoky Mountains National Park, National Park Service, Gatlinburg, TN, USA

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ABSTRACT

The COVID-19 pandemic has disrupted the timing and substance of conservation research, management, and public engagement in protected areas around the world. This disruption is evident in US national parks, which play a key role in protecting natural and cultural resources and providing outdoor experiences for the public. Collectively, US national parks protect 34 million ha, host more than 300 million visits annually, and serve as one of the world's largest informal education organizations. The pandemic has altered park conditions and operations in a variety of ways. Shifts in operational conditions related to safety issues, reduced staffing, and decreased park revenues have forced managers to make difficult trade-offs among competing priorities. Long-term research and monitoring of the health of ecosystems and wildlife populations have been interrupted. Time-sensitive management practices, such as control of invasive plants and restoration of degraded habitat, have been delayed. And public engagement has largely shifted from in-person experiences to virtual engagement through social media and other online interactions. These changes pose challenges for accomplishing important science, management, and public engagement goals, but they also create opportunities for developing more flexible monitoring programs and inclusive methods of public engagement. The COVID-19 pandemic reinforces the need for strategic science, management planning, flexible operations, and online public engagement to help managers address rapid and unpredictable challenges.

1. Introduction

The COVID-19 pandemic has altered virtually all aspects of society worldwide, including protected areas (Bates et al., 2020; Chakraborty and Maity, 2020; Corlett et al., 2020). Some protected areas have seen increases in visitation while others have seen sharp declines (Rice et al.,

* Corresponding author at: Acadia National Park, PO Box 177, Bar Harbor, ME 04609, USA.
E-mail address: abe_miller-rushing@nps.gov (A.J. Miller-Rushing).

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2020). Tourist-based economies around many protected areas have been hurt as travel declined immediately after the start of the pandemic (Bakar and Rosbi, 2020). In some places, air and water quality have improved and wildlife behavior has changed in response to changes in visitation (Corlett et al., 2020; Rutz et al., 2020; Saraswat and Saraswat, 2020). The pandemic has reduced the ability of researchers and managers to do fieldwork and has shifted public engagement to mostly remote online interactions (Buckley, 2020; Gardner, 2020; Pennisi, 2020). These disruptions have been particularly hard on early career scientists and managers and those from underrepresented groups, who are vulnerable to interruptions in their research and gaps in their employment (Corlett et al., 2020; Inouye et al., 2020; Maas et al., 2020).

Here we take a deeper look at the impacts of the COVID-19 pandemic on one system of protected areas: US national parks. The US National Park Service (NPS) has long been a leader in the preservation of natural and cultural resources and the management of wildlife and ecosystems (Sellars, 2009). The agency protects some of the oldest and most-visited parks in the world, such as Yellowstone, Yosemite, Sequoia, Grand Canyon, Rocky Mountain, and Great Smoky Mountains. NPS protects a variety of ecosystems, cultural resources, and endangered species across a range of geographies, including urban and remote wilderness sites. In total, the 423 US national park units protect 34 million ha and hosted 328 million in-person visits in 2019 (Fig. 1). NPS is one of the largest informal learning institutions in the world, engaging millions of students and visitors each year (Washburn, 2020; Watkins et al., 2018). National parks also impact the economies of the communities around them. In 2018, visitors to US national parks spent an estimated $20.2 billion in local gateway communities, supporting 329,000 jobs (Cullinane Thomas et al., 2019). We discuss how the pandemic has affected nearly all parts of the functioning of US national parks and what lessons we have learned—lessons that can apply to other systems of protected areas around the world.

2. Methods

We gathered information on the effects of the COVID-19 pandemic from available data on research permits, visitation, and web traffic on NPS websites, as well as from a variety of public NPS communications (e.g., press releases and newsletters). We also made informal requests for information from staff at roughly 30 national parks and NPS programs, focusing on large parks. Nearly all responded. We initially asked everyone to describe the most significant challenges and opportunities posed by COVID-19 to their parks and programs. Based on their responses, we then asked for further detail and quantitative evidence. Most of the staff who responded are coauthors or are named in the Acknowledgements, but some asked not to be acknowledged. Most of the park staff who responded are heads of science, resource management, or interpretation at their respective parks, with years and decades of experience.

In this paper, we present the range of challenges and opportunities across national parks created by the COVID-19 pandemic and emphasize themes that were raised by respondents. Most of our park-specific information comes from national parks that protect large natural areas (e.g., Yellowstone, Yosemite, Denali, and Great Smoky Mountains), rather than smaller parks or parks that primarily preserve historical and cultural areas (e.g., Mesa Verde and Gettysburg) due to the limited time

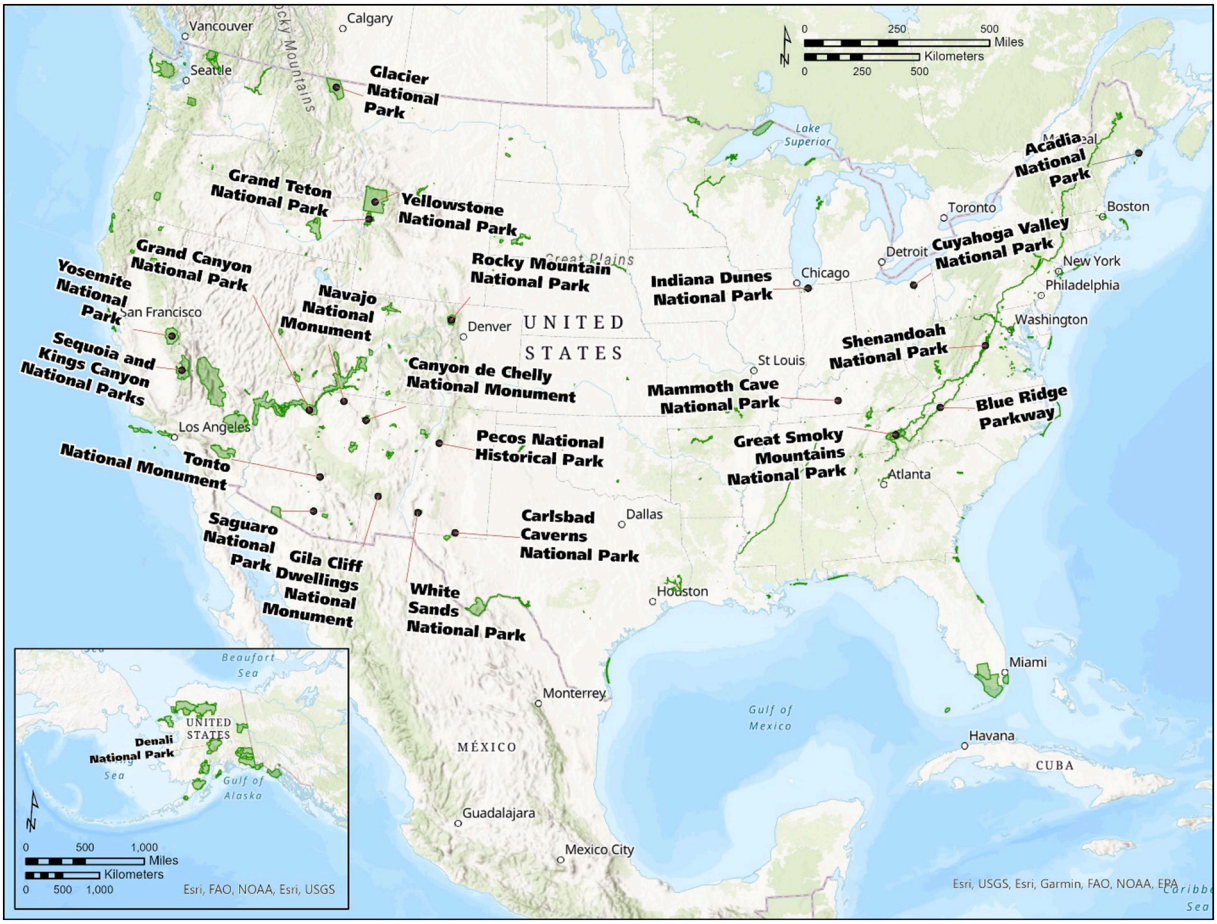

Fig. 1. Map of units of the US National Park Service (dark green polygons). Parks mentioned in this paper are labeled (solid black circles). Many of the 423 US national park units are small and may not be visible. Map courtesy of NPS. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

available to gather the information. Conditions in national parks and the nature of the pandemic are changing quickly, so some information presented here will have changed by the time of publishing.

3. Disruptions to fundamental operations, partner organizations, and visitation

Conservation research, management, and public engagement in US national parks rely on fundamental park operations, partnerships, and visitation. Operations include funding, housing, hiring, facilities, and safety protocols. Partner organizations—such as philanthropic partners, conservation nonprofits, and educational institutions—extend the capacity of NPS to support these operations. They raise funds, operate some facilities, monitor resource conditions, and run programs for school groups and the public. The COVID-19 pandemic has disrupted these fundamental operations, partnerships, and visitation, resulting in a complex array of obstacles to doing research, management, and public engagement.

3.1. Operations

Closures of park facilities and roads were among the early disruptions to national park operations, immediately halting research, many management operations, and in-person public engagement. Of the 62 large national parks for which we have data, 32 closed their roads and facilities for at least some time in 2020 (most in April) because of the COVID-19 pandemic. Even when parks remained open, many park facilities, such as visitor centers and campgrounds, were closed because of safety concerns related to the transmission of COVID-19 or because of staff shortages. Most visitor centers were still closed as of August 2020 and rangers instead interacted with visitors outside under tents. Restrictions on park operations typically followed state and federal Centers for Disease Control and Prevention guidelines and requirements.

Parks in the Southwest illustrate the varied nature of closures. Following state guidelines, national park units in New Mexico (e.g., Carlsbad Caverns, White Sands) largely closed in March and access remained restricted through the summer. In contrast, at the request of the Arizona governor, most national parks in Arizona (e.g., Grand Canyon, Saguaro) remained open to provide access to trails, scenic drives, and other low-density outdoor activities, but delayed reopening visitor centers and other indoor venues. Parks located in and around the Navajo Nation (e.g., Canyon de Chelly, Navajo) remained closed through 2020 at the request of tribal leadership.

US national parks depend on a mix of funds annually appropriated by US Congress and revenue from entrance fees, concessions fees, and other sources. Concession fees are generated from private businesses that operate hotels, restaurants, gift shops, and other commercial operations in national parks. Fees support public engagement activities and projects to enhance visitor experience, such as interpretive programs and restoration of wildlife habitat. Because of the pandemic, however, funding from entrance fees and concessions franchise fees were uncertain and, in some cases, severely reduced. In Yosemite National Park, for example, NPS collected 46% ($12.4 million) less in entrance fees in fiscal year 2020 compared to 2019. Thus, some public engagement and resource management projects were delayed in 2020. And because many fees collected in 2020 fund projects in 2021, lower visitation in 2020 will likely lead to reduced funds for projects in 2021. For perspective, recreation and concession fees represent a small portion of the NPS agency-wide budget (e.g., roughly 7% and 3%, respectively, in fiscal year 2018), but much larger portions of the budgets for many individual parks (e.g., 22% and 12%, respectively, in Yosemite on average between fiscal years 2015–2019) (DOI, 2019).

Like many protected areas around the world, NPS relies on seasonal staff to accomplish many activities that occur at particular times of year, such as technicians to do field monitoring and management during field seasons, interpreters to run public programs, maintenance staff to manage facilities, and visitor and resource protection rangers to help ensure public safety during high-visitation seasons. These seasonal staff make up a small but significant portion of the NPS workforce—6000 seasonal vs 17,000 permanent staff. Seasonal staff make up a much larger portion of staff at most parks, when compared to NPS national and regional support offices. For example, Acadia National Park on average hires 153 seasonal employees each summer, but the park has only 84 permanent staff.

Affordable housing near many national parks is limited, so many seasonal park staff typically stay in shared (sometimes dorm-style) park housing. However, in 2020 safe social distancing required housing to be occupied more sparsely—only one person per room or bathroom to reduce risk of virus transmission. As a result, less housing was available (Arizona national parks estimate ~30–50% of normal) and many parks were unable to hire as many seasonal staff or interns in 2020—perhaps as little as half or one-third the number they would hire in a typical year (Table S1). Many parks prioritized the available space for maintenance, visitor and resource protection, and fire management staff to make sure the parks could clean and maintain facilities and provide for public safety. Reduced housing and hiring disproportionately impacted internships, fellowships, and volunteer opportunities that typically provide youth and graduate students with opportunities to work in national parks during summer seasons (Table S2). For example, nationally, the number of NPS youth volunteers, youth interns, and youth conservation corps declined by 71%, 61%, and 80%, respectively, between 2019 and 2020, representing lost opportunities for 47,946 youth.

In addition to limitations on hiring seasonal staff and interns, reductions in housing decreased or eliminated opportunities for visiting researchers to stay in park facilities (Table S3). Many parks reallocated short-term dormitory housing typically used by researchers and used it to house seasonal staff. Some parks were able to open limited researcher housing. At several parks, lack of housing caused researchers to miss fieldwork and sampling during spring and early summer, disrupting studies of water, wildlife, and phenology.

The hiring of seasonal staff and interns that did happen, happened more slowly than in a normal year, because of a combination of delays in addressing housing and funding challenges and developing and implementing new safety protocols for COVID-19. Parks developed new administrative processes and required all major job activities to be approved and signed by several park officials—safety officers, division chiefs, and superintendents, and sometimes staff from the NPS Office of Public Health—to document that projects and activities could be completed while following COVID-19 safety guidelines. This process was used for work conducted by NPS staff, contractors, and external researchers, and helped to ensure that safe projects could proceed, but resulted in delays and difficult decisions to suspend some projects. In some states, new employees arriving from out-of-state had to self-quarantine for 14 days, delaying when they could start training and working.

Safety concerns forced park staff and partner organizations to rethink some normally routine tasks (Fig. 2). Social distancing often required people traveling to field sites in vehicles to travel by themselves or smaller groups, resulting in more intensive vehicle use or smaller field teams. Additionally, many activities—such as operating motorboats or working at back-country locations—that cannot be safely done alone, and had to be postponed.

Time and mental health concerns also became bigger constraints than normal for many park staff. Spring and summer field seasons are normally very busy times for staff at national parks; with COVID-19-related issues and limited staff, they were even busier in 2020. In addition to their normal responsibilities, staff had to address closures, safety and public health concerns, and increased levels of time-sensitive communications. At some parks, such as Yosemite, Rocky Mountain, and Denali, staff had to implement new reservation systems and other protocols to prevent overcrowding and maintain public health. During the summer and autumn of 2020, staff at some parks had to respond to fires

Fig. 2. Park and partner organization staff doing research, management, and public engagement activities while taking safety precautions. Clockwise from top-left: NPS technician monitoring lake water quality at Isle Royale National Park in Michigan; park ranger speaking with visitors outside the visitor center at Tonto National Monument; park ranger giving an interpretation program at Acadia National Park; participants in the new Smokies Hikes for Healing program, which facilitates conversations about racism and social justice at Great Smoky Mountains National Park; NPS employee raking as an experimental method to reduce damage to giant sequoias from bark beetles and drought at Sequoia National Park; researchers from Schoodic Institute at Acadia National Park monitoring a restoration experiment. The Schoodic Institute image is courtesy Schoodic Institute; all others are courtesy of NPS.

in or near parks, including two major fires at Rocky Mountain National Park. Staff also had to meet the needs of their families, whether managing finances in an uncertain time or caring for children, other dependents, or sick family members. Employee quarantines for known or suspected COVID-19 infections created further stress by reducing the number of available staff (which sometimes led to additional closures) and increasing concern for colleagues. These demands put a heavy mental health burden on staff. Understandably, many non-essential tasks—including some wildlife monitoring, interpretive programs, and issuing of research permits—did not happen in 2020, with significant implications for research, management, and public engagement.

3.2. Partner organizations

Most park partner organizations—which support research, management, and public engagement—have had to make major cutbacks. Many of these organizations rely on funds from retail sales, program fees, and philanthropy, all of which have been disrupted by the pandemic (Table S4). Even with the disruptions, some partner organizations were able to provide critical support to parks. For example, the Sequoia Parks Conservancy was still able to develop a new marketing campaign to support research on giant sequoia trees (*Sequoiadendron giganteum*) and threats to them. The Yosemite Conservancy continued to support many projects that could be conducted safely, including resources management and remote interpretation and visitor education programs. In Acadia National Park, Friends of Acadia and Schoodic Institute were both able to run scaled-back programs working on vegetation restoration projects, citizen science, and online public engagement.

3.3. Visitation

Visitation to US national parks fluctuated dramatically in 2020. Such fluctuations have important implications for local economies, the capacity of park staff (which can be stretched thin when visitation is extremely high), potential damage to resources from trampling and other uses, and the quality of visitor experiences. Preliminary data suggest that visitation to US national parks was down 87% in April 2020 (the height of stay-at-home orders) relative to April 2019 (Fig. 3). But visitation picked up later in the summer; preliminary data suggest that visitation in August 2020 was just 20% below that of August 2019. At many parks, this rebound in visitation occurred very quickly (Fig. S1). Nationally, park visitation is typically 75% higher in July compared to May; in 2020 visitation in July was about 335% higher than May (Fig. 3). National parks near urban areas experienced some of the largest surges in visitation (Fig. S2) (Rice et al., 2020). Tonto National Monument, near Phoenix, reported record numbers of visitors in summer, even as daytime temperatures exceeded 41 °C.

Traffic to the "Plan Your Visit" section of national park websites,

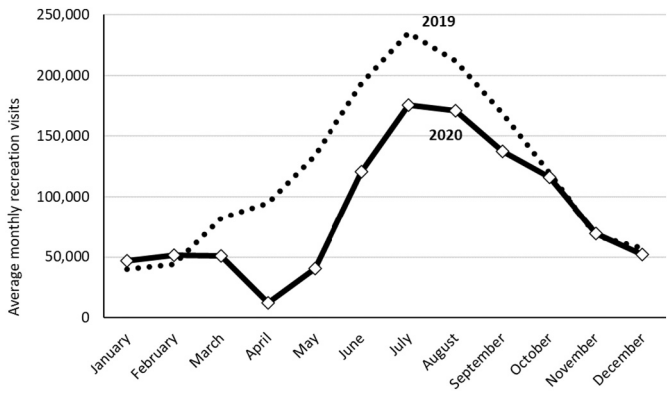

Fig. 3. Average monthly visitation in 2019 and 2020 at the 62 national parks. Data for 2020 are preliminary but reflect the magnitude and direction of change.

which historically have been tightly correlated with in-person visitation, reflect similar patterns (Fig. 4). People frequently use the Plan Your Visit sections of park websites to access maps and information about park facilities, campgrounds, programs, and transportation. For the period March 15–April 30, 2020, during the peak of stay-at-home orders in many states, traffic to the Plan Your Visit section of park websites was 51% below the same period in 2019 (16.0 M page views in 2020, 32.9 M in 2019). However, for the period May 1–August 15, 2020, after restrictions began to lift in many places, traffic to the Plan Your Visit section of park websites was 11% *above* what it was in 2019 (102.7 M page views in 2020, 92.7 M in 2019).

This rapid spike in visitation strained park capacity—staff levels were low and many facilities and campgrounds were closed—and forced staff to focus much of their attention on visitor management instead of other activities. For example, Indiana Dunes National Park, on the Lake Michigan shoreline near Chicago, saw about 128,000 more visitors from May to August 2020 compared to 2019 (likely because other beaches in the region were closed), forcing the park to divert some of its interpretation staff to help manage traffic instead of delivering interpretation programs to the public. Such spikes in visitation and crowding could damage habitats—e.g., increases in litter, trampling of sensitive plants, and widening of trails.

Remote parks did not see the same level of increased visitation. For example, visitation plummeted in Denali National Park and Preserve in Alaska (less than 10% of normal) where most out-of-state visitors typically arrive by a combination of cruise ship, train, or plane. Typically, Alaskans account for approximately 10% of visitors to Denali, but in 2020 Alaskans appeared to account for over 75% of park visitors, based on limited data available. This decline in visitation hurts the local economy—the community around Denali relies on tourism-related revenues for about 80% of its annual municipal budget.

Long-term changes in visitation are difficult to anticipate. Safety concerns associated with exposure to the SARS-CoV-2 virus during air travel or at indoor venues could disproportionately increase visitation to national parks within driving distances of major metropolitan areas. Poor economic conditions that broadly impact the US population could reduce visitation or change where visitors come from. US national park visitation has tended to decline during economic recessions (Poudyal et al., 2013), although visitation from people living relatively close to parks may remain stable (Loomis and Keske, 2012). In contrast, iconic parks that receive a large proportion of foreign visitors may be particularly impacted by travel restrictions.

4. Conservation research and management

4.1. Impacts

4.1.1. Reduced access to research facilities and collections

Access to park laboratories and natural history collections was suspended in many parks during the peak of pandemic-related closures (Table S5). Park natural history collections contain biological specimens (e.g., plants, birds, invertebrates), cultural and archeological materials, historical photographs and field notes, and other records associated with the history of each park. Most collections have not been digitized, so are not available for remote access, although some are available online at museum.nps.gov, irma.nps.gov/datastore, or bison.usgs.gov. The status of national park collections reflected the availability of natural history collections nationally—96% of natural history collections in the United States were unavailable for in-person use in April 2020 (Pandey, 2020).

4.1.2. Fewer research projects

Using research permitting as an approximate index of research activity, much less research was conducted in national parks in 2020 than is typical (Table S6). Over the past five years (2015–2019), the NPS on average issued 889 research permits to academic, government, and nonprofit researchers between March 20 and May 20. In 2020, the agency issued 331 research permits over that period, just 37% of normal—and some of those permitted research projects did not happen in 2020 or were reduced in scale due to pandemic-related barriers. Research was halted in many parks during state stay-at-home orders and park closures. Even if parks allowed it, safety policies and travel restrictions at many researchers' home institutions prevented them from doing fieldwork. Some research projects, such as those using sensors that had been deployed before the pandemic, were able to continue. In smaller parks, which have fewer staff and resources to support research, the impacts to research were particularly severe. Blue Ridge Parkway, for example, runs for 755 km (470 m) along the Appalachian Mountains from Great Smoky Mountains National Park in North Carolina to Shenandoah National Park in Virginia. Of 33 studies active in Blue Ridge Parkway in 2020, permits were issued for only six top-priority projects, such as acoustic surveys of bats susceptible to white nose syndrome.

4.1.3. Interruptions to research and long-term monitoring

The NPS Inventory and Monitoring program halted field operations across more than 280 NPS units (e.g., parks, monuments, seashores, and historical sites) during the last week of March and all of April 2020 because they could not be done safely—i.e., they require close interactions in the field or require travel that would be disrupted by state quarantine requirements (Table S7). These monitoring programs target

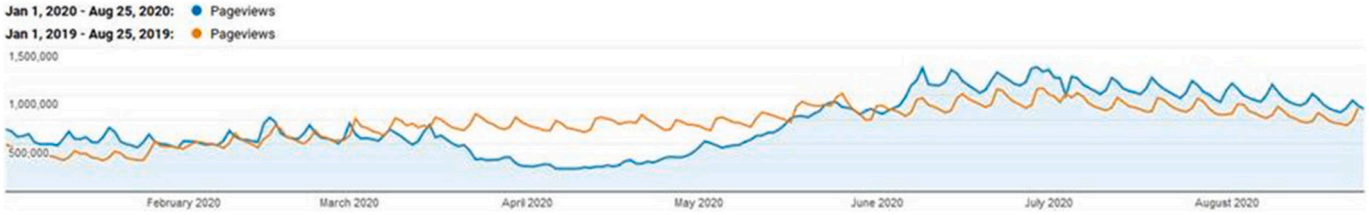

Fig. 4. Daily page views to the Plan Your Visit section of national park websites in 2019 (orange) and 2020 (blue). Peaks and valleys reflect weekly variation in web traffic. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

park "vital signs"—i.e., indicators of ecosystem health, such as weather and climate, water chemistry, plant community diversity, and soil nutrients (Fancy et al., 2009). Fortunately, most air quality monitoring in national parks, which contributes to air quality research across the United States, has continued during the pandemic because it is largely automated and can be easily accomplished while physically distancing (Table S7). Air quality data will help researchers assess impacts of changes in energy use and transportation on air quality across much of the United States and will be valuable for agencies charged with maintaining air quality standards to protect public health and the environment.

Most of the NPS monitoring sampling designs can tolerate brief gaps in sampling, so the main consequences of missed sampling in 2020 will be delays in trend detection and reduced ability to describe the status of resources in 2020. There are exceptions, however, such as in national parks in Arizona, where gaps in data from water quality and quantity monitoring can impact water rights and allocations, which could affect the amount of water available in rivers and other aquatic ecosystems in parks. Across all national parks, however, the reduced ability to document 2020 will be particularly impactful because it will diminish our ability to understand how COVID-19-driven changes in human behavior are affecting park ecosystems. For example, lapses in water quality and forest health monitoring across many parks will limit our understanding of how the rapid changes in air quality translate to changes in water and soils. Suspended, scaled-back, or delayed wildlife monitoring projects similarly missed opportunities to study wildlife behavior as visitation rates to parks fluctuated dramatically.

Additionally, lapses in monitoring will reduce our ability to study the impacts of other important and simultaneous climatological and ecological phenomena. For example, the Northeast has had below-average rainfall for four of the past five years. Reduced wetland monitoring in 2020 will affect our ability to understand the effects of reduced precipitation on wetland plants and hydrology, which could make future management decisions more difficult. Delays in the ability to detect trends in monitoring data could also be important for issues where management is particularly time-sensitive, such as invasive plant and forest insect pest detection and monitoring overabundant deer populations. Also, in national parks where monitoring occurs in late-winter and early-spring, such as parks in the Southwest, the gaps in data for 2020 closely follow gaps caused by the 2019 US Government shutdown, resulting in a two-year gap in data for key variables. For a second year, NPS staff were unable to collect data on cool-season exotic plant infestations or on water quality and quantity for many parks in Arizona, New Mexico, and Texas.

Many research projects that have been delayed address topics important to informing management (Table S8). For example, 11 species of bats in the United States are listed as threatened or endangered at the federal level, some of which are being studied in national parks, such as Mammoth Cave National Park in Kentucky and Cuyahoga Valley National Park in Ohio (Rodhouse et al., 2016). However, many research and management activities that involve handling bats, including in national parks, were postponed or cancelled for concern that researchers might expose bats to the SARS-CoV-2 virus (Runge et al., 2020).

Social science projects important to managing national parks and to understanding changes in human behavior and perceptions have been substantially affected by the COVID-19 pandemic. Research typically conducted by in-person surveys has dramatically reduced because of difficulties maintaining physical distancing while overseeing surveys (Table S8). For example, the Visitor Survey Card project, which has been running since 1998 as a method to assess visitor satisfaction with a variety of park experiences (e.g., visitor centers, ranger programs, learning about nature), was postponed for 2020 (Pacific Consulting Group, 2019). Given obstacles to in-person surveys, some research groups are using contactless survey protocols (Fig. 5). A study of how the pandemic is impacting national park experiences posted signs inviting visitors to scan QR codes or visit URLs that take them to online surveys that they can fill out on their smartphones. However, there is concern that altered methodology might affect the results.

4.1.4. Reduced, delayed, or postponed management actions

Many management actions in national parks have been cancelled, delayed, or scaled back, particularly non-essential management projects—i.e., those that could be put off without increasing risk to vulnerable species and ecosystems (Table 1). Even some essential management activities were suspended because they could not be done safely. In Sequoia and Kings Canyon National Parks, work to aid the recovery of endangered mountain yellow-legged frogs in four basins by removing non-native trout was reduced in scale to due to funding, housing, and safety concerns. In Rocky Mountain National Park (and many other parks), prescribed fires designed to reduce build-up of fuels were postponed until 2021, although park staff were able to do mechanical thinning to address fire risk in particularly vulnerable areas. Firefighters were among the first seasonal staff hired at many parks due to concerns related to fire safety.

4.1.5. Impacts on planning, collaboration, and consultations

Pandemic-driven demands on staff time resulted in delays in some science and management planning, including updating management plans, lining up funding for priority research and management projects, and strategic planning. However, in some parks, staff who could not do fieldwork were able to devote more time to planning. Many planning meetings and workshops shifted to online venues (Table S9). Post-workshop surveys at some of these events indicated that participants found the online formats valuable and worth consideration for future years, even after the pandemic.

In some cases, remote workshops allowed parks to experiment with

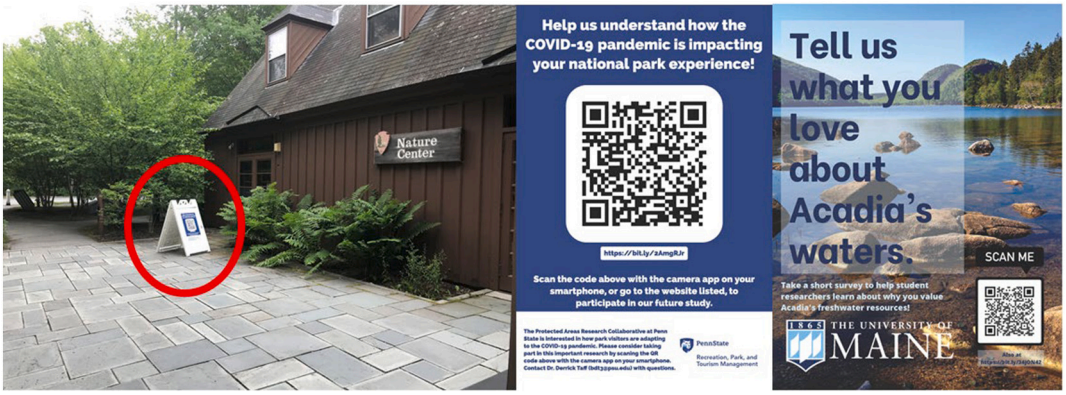

Fig. 5. Examples of signs encouraging visitors to participate in research—an alternative to in-person interactions.

Table 1
Examples of management actions that were delayed or cancelled at national park units in 2020.

Park	Management action	Consequence
Many parks	Delayed or reduced invasive plant management	Invasive plants had an additional year to grow and reproduce, making future management more difficult
Acadia National Park	Delayed vegetation restoration on Cadillac Mountain until 2021	Further degradation of restoration site and greater expense to maintain restoration plant stock
Gila Cliff Dwellings National Monument	Delayed new trail to reduce damage to archeological sites	Potential damage to archeological sites
Rocky Mountain National Park	Cancelled spring elk counts and moose collaring; limited winter elk counts	Less data to inform wildlife management
Rocky Mountain National Park	Cancelled monitoring and pruning of white pine blister rust (*Cronartium ribicola*) on limber pine (*Pinus flexilis*)	Increased damage to limber pines, a species of management concern
Sequoia and Kings Canyon National Parks	Delayed retrofitting of park restrooms to exclude bears	Additional problems with bears damaging restrooms
Tonto National Monument	Delayed post-fire vegetation restoration projects	Potential erosion and damage to plant communities
Yosemite National Park	Cancelled annual songbird banding	Disruption of 30-year annual dataset and reduced ability to detect population shifts associated with climate change

new technologies. In May, the Federal Highways Administration convened a workshop to estimate long-term geotechnical risks to the Denali Park Road where it traverses an area with severe landslides. Funds that would have been spent on travel were instead invested in mixed-reality hardware and software that allowed participants to manipulate immersive 3D holograms of satellite imagery, field data, and potential new infrastructure (bridges, roads, etc.). The technology allowed the group to access resources and assess possible solutions in ways that would not have been possible in person.

Consultations with Native American tribal partners on specific issues is a legally mandated requirement for national park staff. Shifts to remote consultations mostly worked well, but visiting field sites to discuss projects and strengthening relationships through in-person interactions was difficult. In addition, some tribes did not have the capacity or resources (e.g., internet connectivity) to engage remotely, as the US Advisory Council on Historic Preservation recognized in their guidelines for consultations with Indian tribes (ACHP, 2020). Tribal historic preservation officers with ties to Acadia National Park reported that, while they received more requests for consultations in 2020, it was easier to respond because they did not have to travel. As a result, some remote consultation meetings will likely continue after the pandemic.

4.2. Priorities and opportunities

4.2.1. Stress-test and adjust long-term monitoring

The pandemic has incentivized researchers and NPS staff to examine their sampling designs, monitoring, and analyses to determine how they can be improved and how they are affected by missing data. The NPS Inventory and Monitoring Division held a "stats-off" that brought together 50 quantitative ecologists to brainstorm and develop techniques to handle changes caused by the pandemic in the sampling and analysis of long-term monitoring of forest health, water quality, and other "vital signs" of ecosystem integrity in national parks. The group decided that in most cases conducting field work in 2020 with reduced sampling intensity, such as sampling fewer sites or on fewer dates, within parks was not worth the effort or safety risk because the resulting small sample sizes would limit the power to detect temporal trends. Instead, many inventory and monitoring networks put funds saved from missed fieldwork in 2020 toward increased staffing and sampling in 2021 and 2022.

4.2.2. Study the effects of the COVID-19 pandemic

National parks can play a unique role in studies examining the impacts of the COVID-19 pandemic because of the extent of the natural areas and the wealth of existing data describing long-term pre-pandemic conditions (Jacobs et al., 2020). Some national park researchers are examining the ecological and conservation impacts of the pandemic by adjusting existing study designs and starting new studies. A team of social scientists is investigating how the pandemic has changed people's relationships with parks in terms of their visitation patterns, valuing of park resources, and their stewardship behaviors at Acadia, Grand Teton, Shenandoah, Glacier, and Yellowstone National Parks. Researchers from the NPS Air Resources and Natural Sounds and Night Skies Divisions are studying the effects of the pandemic on air quality and soundscapes. And ecologists are studying changing wildlife behaviors as park visitation, air and water quality, and noise pollution change, using combinations of field work and remotely collected data (Table S10).

4.2.3. Catch up on data analyses and syntheses

Many parks and researchers used the time when fieldwork was more difficult to address backlogs of data processing, analysis, and synthesis. NPS staff synthesized years of water quality and quantity data for Pecos National Historical Park and Gila Cliff Dwellings National Monument, both in New Mexico. NPS staff also synthesized 83 years of historic vegetation data at Saguaro National Park and initiated a machine-learning approach to analyze wildlife images from camera traps across national parks in the Southwest.

4.2.4. Test new approaches to management and collaboration

The need to manage unusual closures of some park facilities and sections of parks has compelled managers to implement major changes in managing visitation and has provided social scientists opportunities to monitor and evaluate how visitors respond to changes in access. This could be particularly useful for parks that are implementing new measures—such as reservation systems, buses, and restricting private cars—to address overcrowding during peak park visitation times at Rocky Mountain and Yosemite national parks. Historically, limitations like these were very unpopular with the public; however, COVID-19 public health concerns may change public views on reservation systems and other limits on use of parks.

As a result of safety concerns, many parks are improving their capacity to collaborate remotely. Remote collaboration reduces travel costs and carbon footprints, and allows project leaders to draw on expertise of people anywhere in the country or the world. Such approaches will certainly continue after the pandemic ends.

For parks that have capacity, the pandemic may provide an opportunity to plan and support forward-looking natural and social sciences aimed at helping park managers and communities respond to rapid changes and emergencies (Jacobs et al., 2020). With ongoing environmental changes, national parks can expect other major disturbances—e.g., major storms, fires, droughts, and insect pest outbreaks—to become more common. It may be a good time for national parks, local governments, and surrounding communities to work together on planning, communications, research, and management to improve responses to disturbances, particularly when many staff must work remotely. Some of these efforts are already underway.

4.2.5. Invest in supporting early-career and under-represented researchers and managers

The COVID-19 pandemic has reinforced the need for NPS and its partners to increase support for early-career researchers and managers, particularly those from underrepresented groups who have been

disproportionally disadvantaged by the pandemic (Corlett et al., 2020; Inouye et al., 2020; Maas et al., 2020). The Scientists in Parks and Second Century Stewardship programs—which provide internships, fellowships, training, and networking—and park-specific internship and fellowship programs are examples of the types of programs that could serve this goal (NPS, 2020; Schmitt et al., 2020).

5. Public engagement

5.1. Impacts

5.1.1. Reduced in-person engagement

People who have been able to visit parks in-person during the time of the COVID-19 pandemic have had far fewer interactions with park rangers than normal. Because of safety concerns and lack of staffing, many parks and park partners cancelled most or all in-person interpretation and education programming and events (e.g., Earth Day) between mid-March and July 2020, and reduced in-person programs in the fall (Table S11). These changes are consistent with broader impacts to environmental and outdoor science education programs nationally and represent huge impacts in terms of lost experiences and learning outcomes for students. A survey of 995 organizations (including national parks) across the United States found that by the end of May 2020 the COVID-19 pandemic caused an estimated 4 million learners to miss opportunities to engage in environmental and outdoor science education programs, and estimated that 11 million learners would miss opportunities if the organizations were unable to reopen by the end of 2020 (Collins et al., 2020). More than half these students come from disadvantaged backgrounds (Collins et al., 2020).

5.1.2. Increased remote engagement

In place of in-person engagement for visitors, many parks offered remote engagement. Some parks, like Denali and Yellowstone National Parks, already had strong social media presences and virtual engagement programs, but developed them even further, including training most of their interpretive staff in digital media skills. In 2020, views of videos on park websites increased by 37% compared to 2019 (for the period January 1–August 25; 12.9 M page views in 2020, 9.4 M in 2019); views of NPS online articles and pages describing people and places increased by 72% compared to 2019 (for the period January 1–August 25; 9.6 M page views in 2020, 5.6 M views in 2019). Visits to education resources on NPS.gov increased substantially relative to 2019, particularly for the period between late March and late May, when many US schools had shifted to remote learning (Fig. 6).

NPS staff created new content to help meet this demand for online engagement, although particular activities and materials varied among parks. Examples include distributing more printed material, increasing online content, and offering live ranger programs to schools via video conference (Table S12). However, many parks had difficulty creating new online content because of limitations in staff time and expertise.

5.1.3. Shifts in why people engage with national parks

The COVID-19 pandemic appears to have changed how some people engage with national parks. In the past, park visitors came for recreation, family gatherings, and learning. During the COVID-19 pandemic, people increasingly began visiting national parks and other green spaces to maintain mental and physical health, partly because indoor recreation and exercise options were inaccessible during the pandemic (Kleinschroth and Kowarik, 2020; Razani et al., 2020; Rice et al., 2020; Samuelsson et al., 2020; Slater et al., 2020).

The number of volunteers in US national parks has declined during the COVID-19 pandemic as a result of the need to physically distance (most volunteer programs involve teamwork and strong social elements) and the reduced capacity of parks to support volunteer programs, such as the NPS-wide Volunteers-in-Parks program. Across NPS, there were roughly 97,700 volunteers in 2020, compared to 304,900 in 2019. Additionally, visits to the Get Involved portion of park websites, which contain information about volunteering and joining friends groups, declined 27% in 2020 relative to 2019 (for the period January 1–August 15; 429,000 page views in 2020, 591,000 views in 2019).

5.2. Priorities and opportunities

5.2.1. Increase online public engagement

It is likely that the pandemic will speed trends toward greater engagement through technology-based apps, social media, and citizen science for visitors in parks and at home. This is likely because: (1) people are using technology in more parts of their lives, including during visits to national parks, (2) people may be more comfortable with virtual interactions after the pandemic, and (3) NPS interpretation and education staff are building capacity for online engagement and are reducing capacity for in-person programs. Increasingly, visitors are engaging with app-based interpretive and citizen science materials during their national park visits, including through driving tours, apps that suggest in-park activities or challenges (e.g., apps developed by Chimani, National Geographic, TimeLooper, or other organizations), and app-based citizen science programs (e.g., iNaturalist, eBird, Nature's Notebook). People are also engaging with national parks from home, viewing webcams, taking virtual tours, and doing online activities. This trend toward technology-mediated engagement will likely continue after the pandemic. Disruption to current public outreach activities, growth in online engagement and citizen science, and new training also provide NPS and its partners with opportunities to enhance engagement with under-represented groups who have historically not visited national parks (Schultz et al., 2019).

The increase in remote engagement with the public also provides an opportunity to study efficacy of online methods of engagement in terms of their ability to contribute to learning and other outcomes for students and visitors. We need to know how remote engagement can best complement in-person visit to places of grandeur, one of the reasons US national parks were created (Thompson and Houseal, 2020; Watkins et al., 2018).

One of the challenges to increased online engagement is that national park staff may lack experience in technology. NPS staff who normally give in-person programs may not have the training to create online materials, especially materials that meet federally approved accessibility standards. After the pandemic, parks will have to choose how to best allocate their staff in public engagement; should they return to

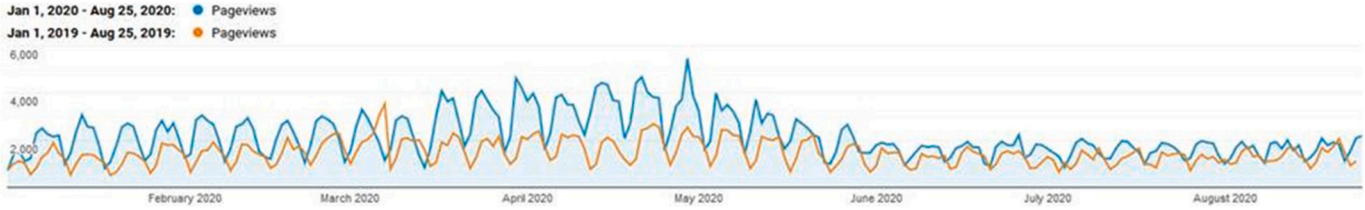

Fig. 6. Differences in daily page views to NPS education resources in 2019 (yellow) and 2020 (blue) for the period January 1–August 25. Peaks are weekdays and valleys weekends. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

engaging with the public or continue developing on-line materials?

5.2.2. Encourage people to engage with parks to support physical and mental health

It is possible that the increased emphasis on physical and mental health as reasons for visiting parks will continue. This emphasis is consistent with existing initiatives, such as Healthy Parks Healthy People (a global initiative that emphasizes the use of parks and public lands as health resources), and increasing trends of medical professionals advising patients to visit parks as a part of mental and physical healthcare (NPS, 2018; Seltenrich, 2015). This may mean that parks and partner organizations reach out to new audiences—such as health care professionals and community organizations—and run more health-based activities and programs, such as park-based fitness challenges, community gardens, art therapy, and nature play zones (NPS, 2018).

5.2.3. Build capacity and maintain trust in NPS as a source for science information

The COVID-19 pandemic has highlighted the importance of clear and effective science communication and engagement and the need for scientists, as well as professional communicators, to be able to communicate effectively (Andrews et al., 2020). NPS is currently among the most trusted sources of science information, and is a recognized leader in conservation and cultural resource preservation (Myers et al., 2017). Currently there is increased demand for science content on park websites, particularly as many students continue remote education during the pandemic (Fig. 3). In coming years, parks and partner organizations will likely place greater emphasis on science communication and public engagement as important skills for scientists and managers and will build training opportunities, such those being developed as a part of the Second Century Stewardship initiative (SCSParkScience.org).

6. Conclusions

Our assessment of the impacts of the COVID-19 pandemic on US national parks provides insights and lessons that could improve conservation research, management, and public engagement in protected areas around the world. First, agencies and partner organizations can benefit from strengthening and adding flexibility to systems of park management. Many of the impacts of the COVID-19 pandemic were exacerbated by difficulties of adjusting administration, staff hiring, communication and meeting, housing, and funding to changing circumstances. Dealing with safety issues often led to unexpected outcomes, such as reductions in volunteer activities and seasonal staffing and shifting public engagement online. Some skills developed during the pandemic—such as effective use of technologies for remote meetings and public engagement—could improve flexibility in dealing with future situations.

Second, agencies and partner organizations benefit from having clear priorities. During COVID-19, US national parks prioritized visitor and staff safety and identified essential research, management, and public engagement activities that could be done safely given the circumstances. Parks had to make painful trade-offs, in some cases foregoing essential research and management activities because they could not be done safely. Clear priorities make these decisions easier.

Third, the long-term impacts of the COVID-19 pandemic for conservation research, management, and public engagement are uncertain. It is not clear how long the COVID-19 pandemic will persist, nor is it clear how society will respond. For example, if hiring, research, management, and visitation return to normal sometime in 2021, it is possible that most impacts to early career staff, long-term studies, resource management, and public engagement may be relatively short-lived. However, if these activities are disrupted during the spring and summer of 2021 or even longer, impacts will be magnified. Careers and education programs will be disrupted, management of endangered species and other critical natural and cultural resources will be weakened, research projects will be compromised, and many park-related partner organizations, which rely on in-person programs for revenue, may be substantially weakened or put out of business.

We will only be able to assess impacts to park resources and audiences when the pandemic is over and national parks are operating at new normal conditions. We can use the time during and after the pandemic to investigate the impacts of altered management and research activities, levels of visitation, and visitor engagement on the health of national parks and the experiences of the public and the park staff. These data can help us better plan future conservation research, management, and public engagement strategies for protected areas.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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