Perceived impacts of the Covid-19 pandemic on protected area management and conservation outcomes in Mexico

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Abstract Protected areas are under immense pressure to safeguard much of the remaining global biodiversity and can be strained by unpredicted events such as the Covid-19 pandemic. Understanding the extent of the effects of the pandemic on protected area management and conservation outcomes is critical for recovery and future planning to buffer against these types of events. We used survey and focus group data to measure the perceived impact of the pandemic on protected areas in Mexico and outline the pathways that led to these conservation outcomes. Across 62 protected areas, we found substantial changes in management capacity, monitoring and tourism, and a slight increase in non-compliant activities. Our findings highlight the need to integrate short-term relief plans to support communities dependent on tourism, who were particularly vulnerable during the pandemic, and to increase access to technology and technical capacity to better sustain management activities during future crises.

Keywords Covid-19, management capacity, Mexico, non-compliance, protected areas

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Introduction

Unexpected events such as the Covid-19 pandemic can have substantial impacts on conservation outcomes. These impacts can be difficult to predict and could vary over time. Initially, global restrictions on human mobility led to positive impacts on the environment, including clearer skies, cleaner waterways, reduced ecosystem stress and increased sightings of sensitive species in human-dominated landscapes (e.g. Bates et al., 2020; Cheval et al., 2020; Corlett et al., 2020; Manenti et al., 2020). However, as the pandemic and the associated restrictions continued, there was a rise in illegal activities such as wildlife trafficking and illegal logging, and growing pressure within many protected areas (e.g. Hockings et al., 2020; Cumming et al., 2021).

Research on the impact of the pandemic in protected areas has found increased threats to biodiversity and negative management capacity and tourism outcomes, with the impact often varying regionally (Buckley, 2020; Hockings et al., 2020; Jacobs et al., 2020; Lindsey et al., 2020; McCleery et al., 2020; Singh et al., 2021; Spenceley et al., 2021). For example, illegal logging, encroachment and subsistence hunting were found to increase in South America and Africa, whereas grazing and non-timber forest product gathering were identified as the primary threats in most other regions (Singh et al., 2021). Additionally, although changes in tourism have been negative overall, the specific impacts (e.g. changes in visitors, tourism income or non-compliance with protected area regulations) have varied across countries (Spenceley et al., 2021). Continued research is needed to fully understand the impacts of the pandemic on protected areas and how they vary geographically. Here we add to the growing body of knowledge on the impacts of Covid-19 on protected areas by summarizing the impacts of the pandemic as perceived by protected area managers across Mexico.

In addition to understanding the impact of the pandemic on protected areas it is critical to understand how and why these impacts occurred. However, clear models identifying specific impact pathways as well as protected area characteristics that could influence the level of impact remain limited, with only a few studies presenting evidence of these links in South Africa (Smith et al., 2021) and for marine protected areas globally (Phua et al., 2021). We used survey and focus group data to develop a theory of change to help fill these knowledge gaps. Specifically, we drew on survey data from 62 protected area managers to identify changes to protected area inputs (e.g. human and financial capacity), mechanisms (e.g. monitoring) and non-compliant activities (e.g. illegal logging) as a result of the Covid-19 pandemic. We then used qualitative data from focus groups and open-ended survey questions to better understand how these changes were connected.

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Perceptions of protected area managers and rangers have been identified as important yet understudied sources of information for assessing conservation trends in protected areas (Cook et al., 2014; Cvitanovic et al., 2014; Pyhälä et al., 2019; Moreto & Charlton, 2021). Given their responsibility to monitor protected area resources on a regular basis, they are well positioned to provide insights regarding the impacts of significant events such as the Covid-19 pandemic, especially when limited alternative forms of data are available. Our research joins a growing number of studies presenting perspectives of managers as critical evidence of the impact of the pandemic on protected areas (e.g. Singh et al., 2021; Smith et al., 2021; Waithaka et al., 2021) whilst also aiming to outline the specific pathways that led to the perceived conservation outcomes. Understanding the pathways through which unexpected events such as the Covid-19 pandemic impacted protected area performance could help protected area managers and conservation practitioners to design post-pandemic relief efforts and plan for future crises such as political instability, economic shocks and the climate crisis.

Study area

Our study sought to measure the impacts of the Covid-19 pandemic across protected areas in Mexico, a global biodiversity hotspot. The country has an extensive network of > 1,000 designated protected areas, covering 14.5% of its terrestrial surface and 21.6% of its coastal and marine area. We focused on a subset of these areas, specifically those managed and monitored by the Comisión Nacional de Áreas Naturales Protegidas (National Commission for Natural Protected Areas; CONANP) because of our previously established relationship with CONANP and knowledge of their protected area network (Fig. 1).

CONANP manages 182 protected areas, including National Parks (IUCN Category II), National Monuments (IUCN Category III), Flora and Fauna Protection Areas (IUCN Category VI), Natural Resource Protection Areas (IUCN Category VI), Sanctuaries (IUCN Category II) and Biosphere Reserves (IUCN Categories 1a and VI). These areas cover diverse ecoregions and protect unique ecological and cultural resources, including critical habitat for threatened species and archaeological sites. The diversity of these protected areas creates a unique opportunity to investigate the full range of potential impacts, from tourism to resource extraction.

Methods

To measure the perceived impacts of the Covid-19 pandemic on protected areas in Mexico, we first designed a theory of change to identify the potential areas of change. Theories of change facilitate understanding of complex situations by outlining key factors and causal mechanisms that lead to specific outcomes (Mayne, 2015). Researchers have argued for the increased application of theories of change in conservation to improve project design and evaluation (e.g. Rice et al., 2020). We developed our initial theory of change with the help of CONANP and through a review of the existing literature. The theory of change outlines how protected area inputs link to conservation outcomes through various mechanisms and moderators (Table 1). Mechanisms are the processes through which inputs lead to positive or negative outcomes, which can be enhanced or obstructed by moderators, or external factors (not affected by inputs), ultimately affecting the ability to achieve a specific goal (Ferraro & Hanauer, 2014).

We refined the theory of change using data from two virtual focus groups, and we used the refined theory of change to guide the design of an online survey. We present the theory of change as part of our results, adjusted to highlight the survey findings (Fig. 2). The following sections outline the components of our theory of change, our justification

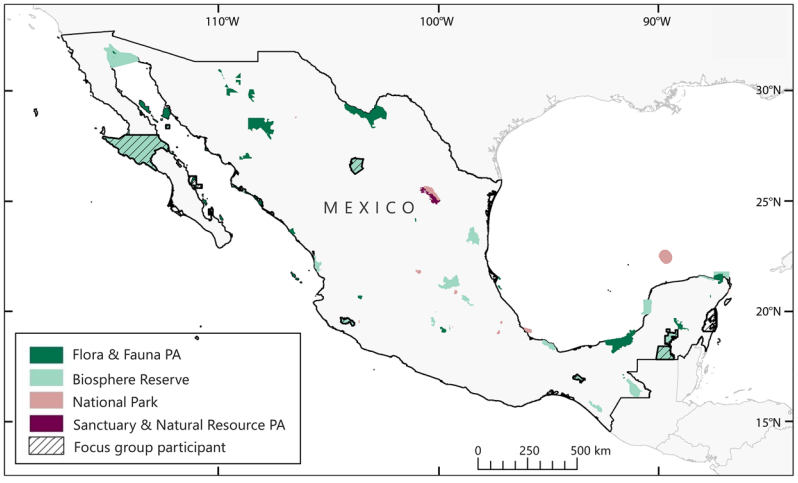

FIG. 1 Protected areas (PA) in Mexico that participated in the focus groups and responded to the survey (23 Flora and Fauna Protection Areas, 19 Biosphere Reserves, 18 National Parks, one Sanctuary and one Natural Resource Protection Area). (Readers of the printed journal are referred to the online article for a colour version of this figure.)

Table 1 Main components of the theory of change (Fig. 2).

Category	Component
Inputs	Management inputs (human & financial capacities)
Mechanisms	Monitoring activities, visitation
Moderators	Governmental & NGO programmes, emergency funds, in-person support
Outcomes	Non-compliance, changes in ecosystem health

for the inclusion of each component and our hypothesized impacts of the pandemic.

Theory of change: impacts of Covid-19 on protected areas

Inputs: human and financial capacity Greater management capacity has been found to have a positive relationship with conservation outcomes in protected areas in Mexico (Powlen et al., 2021) and globally (Geldmann et al., 2018). Management capacity includes human and financial capacity, which influence the ability to carry out management activities such as monitoring, maintenance and collaborative decision-making. Recent evaluations have noted several negative impacts of the pandemic on human capacity, including anxiety, fatigue and communication challenges, as well as reduced financial capacity and increased financial uncertainty (Smith et al., 2021; Waithaka et al., 2021).

In addition, by March 2021 at least 24 countries had proposed cuts to protected area management agency budgets or environmental regulation rollbacks, including Mexico (Cumming et al., 2021; Kroner et al., 2021). Researchers predicted a similar reduction in philanthropic and international aid for protected areas as a result of the pandemic (e.g. Lindsey et al., 2020). Based on these findings we chose to examine both human and financial capacities as the primary management inputs for our theory of change.

We hypothesized that the pandemic would lead to a reduction in human capacity in Mexico because of restrictions on mobility, illness and a reduction in staff availability as a result of new tasks (e.g. increased cleaning and sanitization in public spaces, virtual technology) or for familial reasons (e.g. lack of childcare, ill family members; Jacobs et al., 2020). Additionally, we predicted a shift in government spending priorities, reducing the overall financial capacity of protected areas in 2020.

Outcomes: biodiversity threats During the pandemic threats to biodiversity have increased in protected areas, with some regional variation (Hockings et al., 2020; Singh et al., 2021; Waithaka et al., 2021). We identified a list

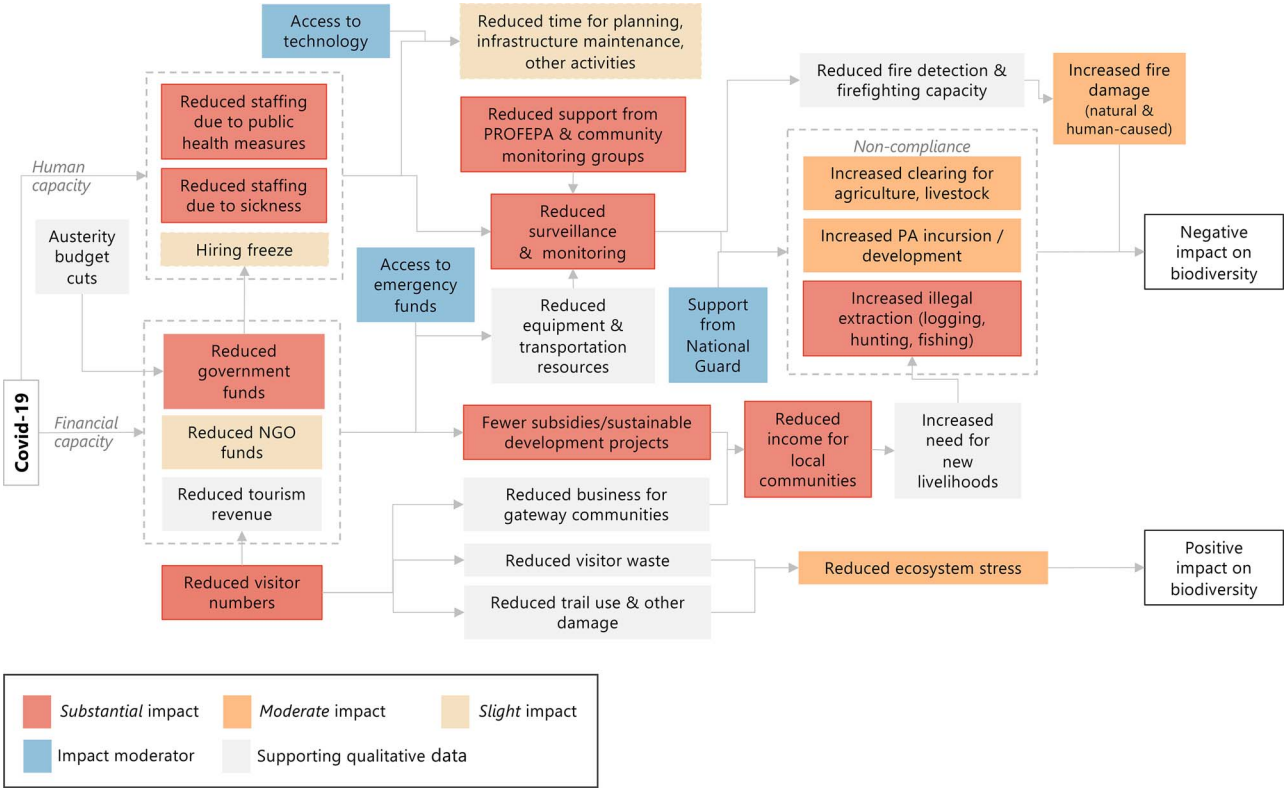

Fig. 2 Theory of change (Table 1), indicating the findings from the survey results. Substantial area of impact: change reported in > 50% of the participating protected areas in Mexico; moderate impact: change reported in 25–50% of participating protected areas; slight impact: change reported in < 25% of participating protected areas. PROFEPA, Procuraduría Federal de Protección al Ambiente (Federal Attorney for Environmental Protection). PA, protected area. (Readers of the printed journal are referred to the online article for a colour version of this figure.)

of non-compliant activities that pose a threat to the protected area network in Mexico using responses from the Management Effectiveness Tracking Tool (Stolton & Dudley, 2016), existing literature and our prior knowledge, to measure changes in threats to biodiversity. The non-compliant activities included illegal or unpermitted hunting, fishing, logging, mining, camping and trail use, land clearing for agriculture, settlements and human-caused fires.

Mechanisms: tourism and monitoring Previous pandemic-related research has identified impacts on two key protected area mechanisms that can shape protected area performance: monitoring activities and tourism (e.g. Bates et al., 2020; Hockings et al., 2020; McCleery et al., 2020; McGinlay et al., 2020; Mitchell & Phillips, 2021; Spenceley et al., 2021). Monitoring is a critical mechanism for reducing non-compliant activities in protected areas. Tourism provides financial support to protected areas and livelihood opportunities to neighbouring communities, in addition to increasing overall human presence in protected areas, ultimately decreasing the likelihood of non-compliant activities. Although we recognize that other mechanisms exist that can influence protected area performance, we focused on these two mechanisms and sought to understand how changes in each can lead to changes in the non-compliant activities identified previously.

Protected area monitoring can vary in terms of total area monitored, monitoring frequency, number of personnel responsible for monitoring and support from community monitoring groups. We expected reductions in staff availability and financial capacity and mobility restrictions to reduce the capacity for monitoring across all four dimensions. We also expected that the Procuraduría Federal de Protección al Ambiente (Federal Attorney for Environmental Protection; PROFEPA), the agency responsible for the enforcement of protected area regulations, would experience similar reductions in staff availability and mobility, reducing their capacity for enforcement. We expected that a reduction in monitoring and enforcement capacity amongst protected area staff and PROFEPA would lead to an increase in non-compliance with protected area regulations, and threats to biodiversity.

As part of the response to the pandemic, protected areas in Mexico were closed to the public during March–June 2020, with restricted reopening thereafter, starting at 20% capacity (CONANP, 2020). We therefore predicted a decrease in the total number of visitors to protected areas in 2020. Based on previous studies (e.g. Manenti et al., 2020), we expected this to lead to an improvement in ecosystem health because of a reduction in damage caused by visitors. However, we also expected that reduced visitation would decrease protected area financial capacity and income opportunities for local communities, potentially increasing the risk of non-compliant activities.

Moderators We expected that non-compliant activities would be moderated by additional income gained through government subsidies and sustainable development programmes such as the Programa de Conservación para el Desarrollo Sostenible (Conservation for Sustainable Development Program), as well as support from NGOs, based on our prior knowledge. We predicted that reductions in government spending and human capacity would reduce the ability to carry out these programmes. We expected fewer government support programmes, in combination with less tourism-related business, to decrease income for local communities. We expected the decrease in income for local communities to create a need for new livelihood activities, potentially increasing non-compliance and threatening biodiversity.

Focus groups

To verify the components in our initial theory of change, we conducted two virtual focus groups in February 2021 with 10 directors from various marine and terrestrial protected areas. We selected participants to represent a range of ecoregions and IUCN protected area categories, and we invited them to participate via email. In the focus groups we gathered a range of information about the experiences of each director in their respective protected areas. Each focus group began by asking what changes to protected area management inputs and activities were experienced because of the pandemic. We then used guiding questions to gather more information on the reported changes (Yin, 2015).

After receiving verbal permission from all participants, we recorded the focus groups, and then a member of the research team transcribed and translated the recordings from Spanish to English. We coded the transcriptions using a multi-level coding scheme, grouping key themes into broader categories of protected area inputs, mechanisms, moderators and outcomes (Yin, 2015).

Survey

We used *Kobo Toolbox* (Harvard Humanitarian Initiative, 2021) to create an electronic, Spanish-language survey to measure perceived changes in protected areas on a national scale. The design of the survey was guided by the theory of change, focus groups and a management effectiveness monitoring tool used nationally (*i-efectividad*; CONANP, 2019). We distributed the survey via e-mail to the directors of all 132 national protected areas in Mexico that had a management plan and annual operating programme. The survey took a mean of 25 min to complete.

The survey included binary and multiple-choice question formats to measure changes in the inputs, mechanisms, moderators and outcomes (Table 1), and a seven-point

scale bar to measure the degree to which perceived changes were considered attributable to the pandemic. Additionally, multiple optional open-ended questions allowed respondents to expand on their responses or share additional thoughts (see Supplementary Material 1 and 2 for survey details).

We piloted the survey with five protected area directors before sending the survey to all protected areas in March 2021. We made limited adjustments after piloting the survey, specifically increasing the number of optional open-ended questions, and therefore included piloted responses in the final sample. The survey was available for 6 weeks, and we sent seven reminders via email. If the director was not able to take the survey, we invited other management staff with knowledge of management decisions and operations to participate.

We used descriptive statistics to identify the degree of change in various protected area dimensions measured using structured questions. We translated and coded all open-ended questions using a multi-level thematic coding approach similar to the focus group transcripts (Yin, 2015). We coded major patterns in the data using open codes and then organized these into broader themes. We used the codes to verify links in the theory of change and to identify changes not included previously.

Results

We received responses from 62 protected areas (60 directors and two managers), representing 47% of the protected areas with a management plan and annual operative budget in Mexico (Fig. 1). The protected areas in our sample were primarily Flora and Fauna Protection Areas (37%), Biosphere Reserves (31%) and National Parks (29%). One Natural Resource Protection Area and one Sanctuary also participated. Our sample primarily consisted of terrestrial protected areas (77%), with only 8% marine and 15% mixed terrestrial and marine protected areas. Protected areas in our sample were designated 4–84 years prior to our study (median 29 years). Prior to 2020 respondents had worked at their respective protected areas for 1–34 years (median 8 years).

Our results indicate that protected area managers generally perceived negative impacts on protected area management capacity, tourism and support for local communities from the pandemic (Fig. 2). Additionally, we found a general perceived increase in non-compliance in 2020 compared to 2019. However, as detailed below, we also note that impacts varied widely across different protected areas. Using our survey responses to identify substantial areas of change and qualitative data to link these changes to reported conservation outcomes, we highlight the potential pathways through which the Covid-19 pandemic has impacted protected areas.

Inputs

Respondents reported that the most prevalent impacts of the pandemic on human capacity were illness (63%) and reduced time availability (52%; Fig. 3a). Of the 39 protected areas with staff who became sick with the virus, 47% had $<$ 20% of staff who became ill and 33% reported 20–40% of staff who became ill. At one protected area 60–80% of staff became ill.

Less than one-third of the protected areas in our sample experienced hiring freezes on new positions (27%) and only three protected areas were forced to dismiss staff. No protected areas placed staff on unpaid leave. Additional effects reported by four managers included emotional impacts such as stress and anxiety caused by the uncertainty of the pandemic. Ten protected areas reported no impacts on their staff.

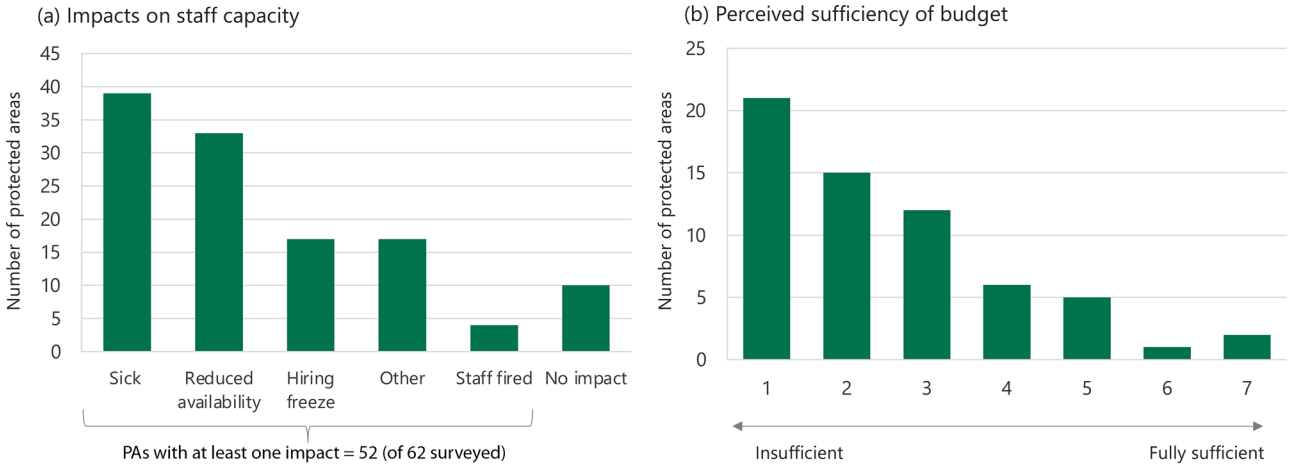

FIG. 3 Number of protected areas (PAs) in Mexico that reported (a) perceived impacts of the Covid-19 pandemic on staff capacity, and (b) level of sufficiency of budget for basic needs in 2020 compared to 2019, on seven-point scale.

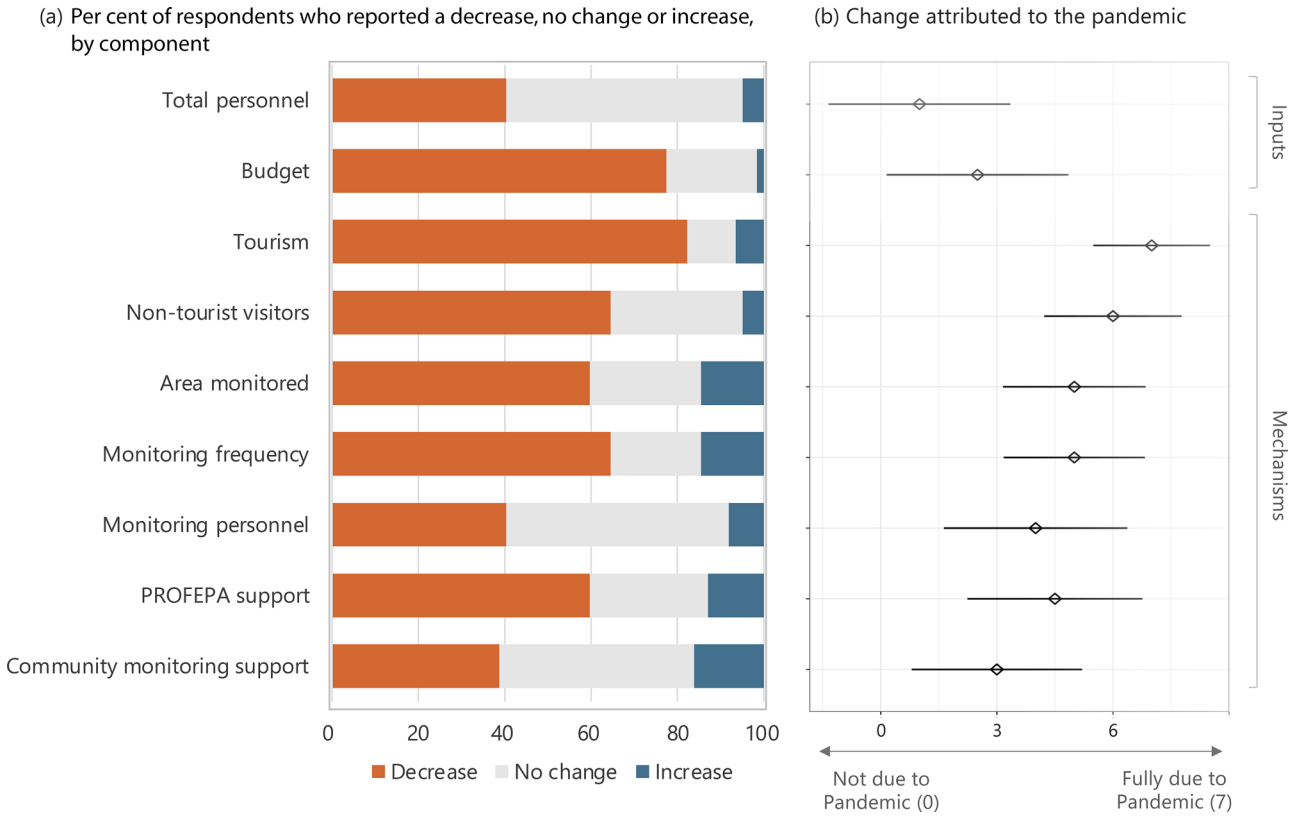

FIG. 4 (a) Per cent of the participating protected areas in Mexico that reported an increase, decrease or no change in protected area inputs and mechanisms, and (b) the degree to which the changes were attributed to the Covid-19 pandemic, on a seven-point scale (median ± SE). PROFEPA, Procuraduría Federal de Protección al Ambiente (Federal Attorney for Environmental Protection).

A total of 77% of respondents reported budget reductions in 2020 compared to 2019, with 42% reporting significant reductions (Fig. 4). Some 19% of respondents reported no change in their budgets and one protected area reported an increase in their budget. The mean estimated budget reduction from 2019 to 2020 amongst all respondents was 39%. When rating the sufficiency of budgets, 77% of respondents rated their budget at a 3 out of 7 or lower, with a mean rating of 2.5 (Fig. 3b). Although many managers reported a decrease in financial capacity in 2020, few perceived the pandemic as the primary driver of this, with a median attribution of 2.5 out of 7 (Fig. 4). As one survey respondent stated: 'The Covid-19 pandemic aggravated and complicated our activities even more. They were already reduced due to lack of money and now also uncertain due to the pandemic.'

Mechanisms

Protected area managers reported dramatic declines in the number of tourist and non-tourist visitors (e.g. researchers, maintenance staff) in 2020. Almost 91% of protected areas reported a reduction in tourism of ≥ 25%, with little difference across protected area type. A total of 36% of protected areas reported a reduction of ≥ 75%. Similarly, 76% of protected areas reported a reduction in non-tourist visitors, with 19% reporting a reduction of ≥ 75%. Approximately 7% and 6% saw increases in tourist and non-tourist visitors, respectively.

Directors linked the change in tourist (median attribution 7 out of 7) and non-tourist visitors (6 out of 7) closely to the pandemic. In addition to Covid-19 closures and other health and safety procedures, respondents reported, in an optional open-ended question, that reduced visitation had probably been driven by reduced household spending on recreational activities (n = 5), reduced budgets for research and project development (n = 5) and a perceived increase in crime around protected areas (n = 3).

Protected area managers perceived the reduction in tourism to have had significant impacts on local community livelihoods, including tourism-related occupations and supporting industries. As one focus group participant explained: 'The pandemic did not directly impact the management of the protected area, but rather the economy of the communities. Since there is no tourism . . . their income fell to zero.' As a second participant explained, the impacts went beyond just those directly engaged in tourism activities: 'Fisheries, like tourism service providers, were influenced by [changes in] tourism . . . When there are no tourists, there is no market where fishermen can sell their product.'

In general, the monitoring capacity of protected areas decreased in 2020 compared to 2019 (Fig. 4). Approximately 60% of respondents reported a decrease in monitoring frequency, 53% reported a decrease in the total area monitored and 39% reported a decrease in the total number of staff responsible for monitoring. In contrast, 16% of respondents reported increases in both the frequency and area monitored and 11% reported an increase in the total number of staff.

In general, respondents estimated that the frequency of monitoring decreased, with a 23% reduction in the number of monitoring trips (median −25%). The total area monitored also decreased by almost 18%, and the number of staff responsible for monitoring fell by a mean value of 12% (area median −25%; personnel median 0% (i.e. no change)). Respondents estimated that the pandemic had the greatest influence on the change in total area being monitored and the frequency of monitoring trips, with the median pandemic attribution rate of the change in both being 5 out of 7. The attribution rate of the change in the number of personnel responsible for monitoring was 4 out of 7.

Respondents perceived the reduction in monitoring capacity to be because of reduced human and financial capacity, reduced access to equipment and the restricted ability to collaborate with groups that support these activities. As one respondent explained: 'Changes in the individuals responsible for inspection and surveillance and budget adjustments, coupled with problems generated by the Covid-19 pandemic, have hampered inspection and surveillance activities in the protected area.' A second respondent stated: 'Monitoring requires collaboration with local [groups], and this collaboration was reduced by the Covid pandemic.'

Over half of the protected areas in our study (57%) reported a decrease in the level of support provided by PROFEPA in 2020 compared to 2019. This reduction was attributed partially to the pandemic, specifically to the mobility restrictions, inability to be in the office, and reduced staff availability. However, respondents also reported a multi-year trend of decreasing PROFEPA capacity because of budget cuts that have left their organizations under-resourced.

Although community monitoring groups were present in almost all of the participating protected areas (89%), changes in the level of support provided by these groups varied. A total of 40% of respondents reported no change in the level of community monitoring support, 40% reported a decrease and 20% reported an increase.

Moderators

Over half of the protected areas reported impacts on subsidy programmes implemented by the protected area for local communities (57%), as well as impacts on other government programmes (36%) and non-governmental programmes (31%). Twenty-five of the 35 protected areas reporting changes to subsidy programmes experienced an overall reduction in the value of the subsidies provided. Six protected areas reported delays in subsidy delivery and four reported other impacts, such as reduced participation and freezes on new project enrolment.

Approximately 60% of the protected areas perceived a reduction in other government programmes, 23% reported a pause and 14% reported a delay. For non-governmental programmes, 42% of managers reported a pause in implementation, with 32% perceiving a reduction and 11% a delay. There was a high level of uncertainty regarding the impacts on non-subsidy government programmes and non-governmental programmes, with 27% and 31% reporting unknown impacts, respectively.

Almost half (48%) of the participating protected areas reported accessing emergency funds that helped to compensate for their limited financial capacity in 2020. Fund-providing organizations included national and international conservation funds (e.g. Mexico's National Fund for the Conservation of Nature and the Global Environmental Facility). Many protected areas also reported obtaining additional support to manage activities that were non-compliant with protected area regulations, which was most often provided by the National Guard.

Additionally, access to technology (e.g. internet, computers, social media) emerged as an important moderator from our focus group and survey data. For those with access, technology facilitated the continuation of regular management activities, monitoring of subsidy programmes and communicating health and safety guidelines, and such access helped them to continue the collaborative decision-making processes of the advisory council. Other participants highlighted the lack of such technology as a barrier to maintaining key management activities. For example, when talking about the advisory council, one respondent reported: 'Only one meeting could be held over the year and it was held virtually. Many of the counsellors from local communities found it difficult to attend because they did not have internet and computers.'

Outcomes

Although responses varied, respondents reported generally that non-compliance increased across the protected area network in Mexico in 2020 (Fig. 5). The largest increase perceived by managers was in fishing, followed by hunting, the establishment of new settlements, logging, land clearance for agriculture and mining. Directors perceived a slight decrease in the number of human-caused fires and unpermitted camping and trail use. The specific patterns of perceived changes in non-compliant activities did not appear to vary across protected area types.

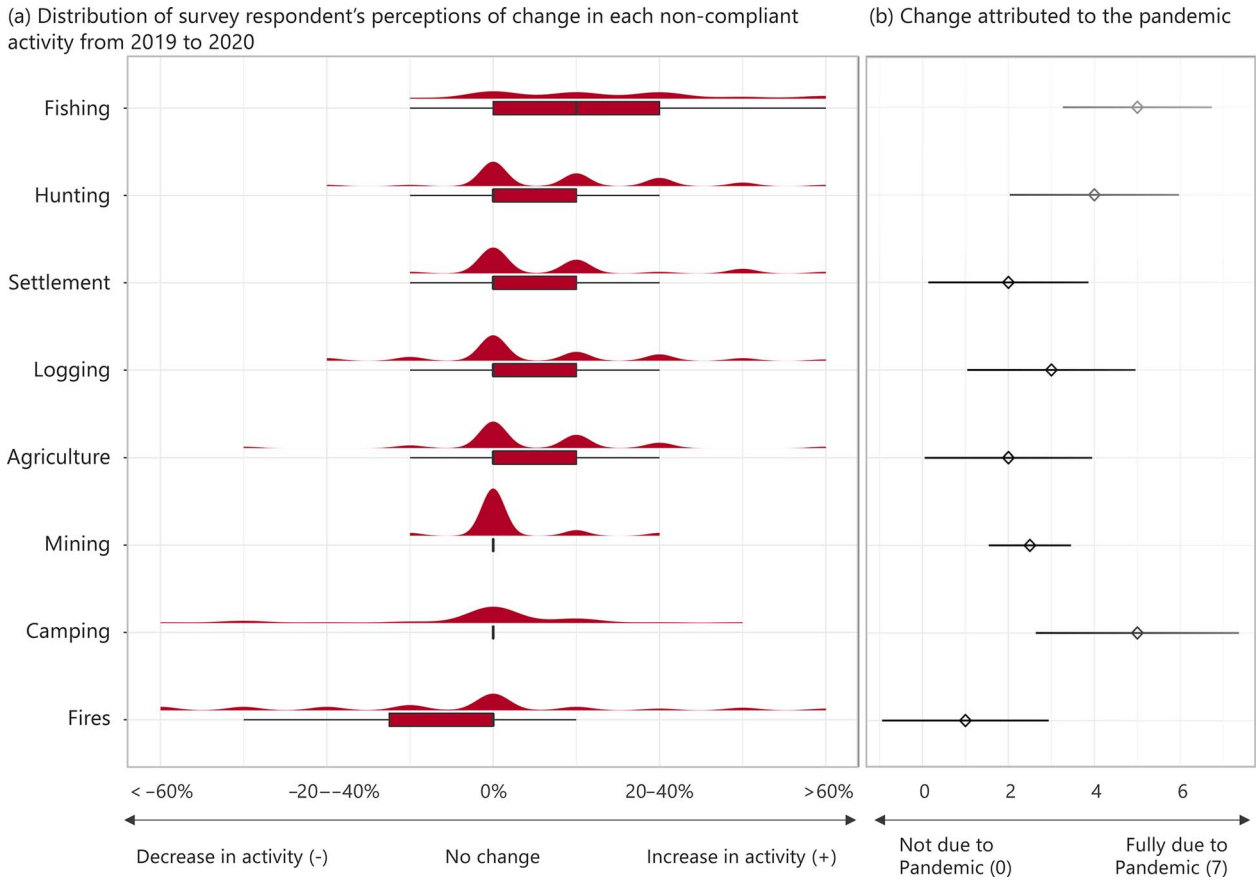

FIG. 5 (a) Survey participants' perceptions of perceived changes in each non-compliant activity occurring in protected areas in Mexico from 2019 to 2020, from all survey respondents; the violin plot shows the distribution of responses (i.e. the height of the curves indicates the number of respondents who perceived the per cent change indicated on the x-axis) and the box plot summarizes those responses as quartiles ($Quartile_1$ and $Quartile_3$ of mining and camping are equal to 0, resulting in no boxplots). (b) The degree to which perceived changes were attributed to the Covid-19 pandemic, on a seven-point scale (medians ± SE).

Although respondents reported increases in most non-compliant activities, the perceived degree of attribution to the pandemic varied. Changes in activities perceived to be most attributable to the pandemic included fishing (median 5 out of 7), camping and trail use (median 5), hunting (median 4) and logging (median 3).

Many protected area managers perceived the lack of a presence of authorities as the main reason for the perceived increases in non-compliant activities. One focus group participant stated: 'In March, April, and May, CONANP [National Commission for Natural Protected Areas] personnel were confined. However, essential activities continued, such as fishing. It was said to be taking place in the protected area and that irregular fishing activities had increased. We received many calls from other fishermen noticing.'

Similarly, other survey respondents also noted: 'In the absence of … authorities such as PROFEPA [Federal Attorney for Environmental Protection], the National Guard and the police who monitor the roads, we have detected an increase in illegal activities around the protected area, such as clearings, illegal construction and trespassing'; and 'Budget cuts and staff illness reduced monitoring, and the poachers increased their activity.' These comments highlight the links between the lack of a presence of authorities and increased non-compliance.

Other respondents highlighted the decrease in livelihood opportunities as a potential driver of non-compliance, stating: 'In the case of illegal fishing, [activity] increased due to the need to obtain additional sources of economic income'; and '[T]he impact of Covid on the economy increases demand for natural resources that are used and traded illegally.'

Discussion

We found that protected area managers perceived the Covid-19 pandemic as having had substantial impacts on many of the factors outlined in our theory of change. Specifically, we found considerable impacts on human capacity and well-being, such as staff illness, increased stress and

anxiety and an overall reduction in staff availability, similar to other research (Smith et al., 2021; Waithaka et al., 2021). Respondents also reported a decrease in financial capacity, with many respondents perceiving their annual budgets to be insufficient for their management needs. However, respondents did not perceive changes in financial capacity to be attributable solely to the pandemic. Rather, they felt that the financial limitations resulting from the Covid-19 pandemic further compounded a more significant general trend in reduced capacity for protected areas.

These findings are in line with existing evidence on protected area capacity limitations in Mexico and globally (e.g. Watson et al., 2014; Coad et al., 2019; Singh et al., 2020). A recent evaluation found that 50% of protected areas in Mexico experienced partially effective or ineffective management prior to the pandemic (CONANP et al., 2020), and it has also been found that $>75\%$ of the protected areas in a global analysis did not have adequate staff and financial resources (Coad et al., 2019). Although CONANP has made significant progress in strengthening management effectiveness recently (Powlen et al., 2021), the agency has continued to experience budget cuts over the past few years. Thus, as Cumming et al. (2021, p. 149) argues, the impact of the current global crisis has been found to 'magnify, intensify, and exacerbate existing structural and systemic financial constraints and weaknesses.'

Tourism, a key mechanism in our theory of change, was reduced significantly in most protected areas across Mexico, in line with global trends (e.g. Spenceley et al., 2021). Our respondents perceived these decreases to be attributable largely to the pandemic because of closures and capacity restrictions. The decrease may have been exacerbated by international travel bans, given the large number of international visitors that Mexico usually receives. Although tourism decreased overall, a small number of protected areas in our study (7%) reported an increase in tourism. Research elsewhere has found visitation increases in more accessible protected areas (e.g. near urban areas), driven by increases in domestic tourism and interest in outdoor activities because of their reduced virus transmission risks (e.g. McGinlay et al., 2020; Spenceley et al., 2021). Given the small number of protected areas that experienced an increase in tourism, we cannot determine any significant differences between the protected areas that reported increased or decreased tourism in 2020.

Survey respondents and focus group participants perceived the overall reduction in tourism to have significant implications for local livelihoods, reducing opportunities for tourism service providers as well as linked activities. Additionally, survey respondents reported negative impacts on community programmes such as subsidies, further exacerbating the negative impacts on local communities. Previous research has also found that local populations living in and around protected areas, especially those in remote areas, have been the most affected by the reduction in tourism in terms of employment, income and health (Mitchell & Phillips, 2021). Future research is needed to document community perspectives so that we can fully understand the extent of this impact.

Survey respondents reported substantial changes in monitoring, the second key mechanism. The reductions in monitoring, in addition to reduced tourism-related income, were perceived to be the main drivers of the increase in non-compliance, similar to predictions in previous research (e.g. Buckley, 2020; Hockings et al., 2020; McCleery et al., 2020; Mitchell & Phillips, 2021). The perceived increase in subsistence and economic-driven activities, such as fishing, hunting and logging, and decrease in unpermitted camping and trail use support this hypothesis.

The challenges in monitoring and measuring illicit behaviour and non-compliance are well documented (Gavin et al., 2010; Solomon et al., 2015). Given the sensitivity of the topic and challenges related to detecting certain activities, it is often best to triangulate evidence using diverse data sources. For example, the occurrence of a fire could be spotted easily because of smoke or the burn scar after the event, but illegal hunting can be more difficult to detect. Given the range of our outcomes of interest and the ongoing practical limitations to field research during the pandemic, additional data sources for triangulation of the impacts of the pandemic on biodiversity remain limited. However, we did test the relationships between observed and perceived forest loss for robustness using data from Global Forest Watch (Hansen et al., 2013). We found a general increase in forest loss in 2020 compared to 2019 across all responding protected areas, and the direction of change (i.e. decrease, increase, no change) perceived by protected area managers was generally consistent with the observed changes (Supplementary Tables 1 & 2).

We recognize that potential biases could be introduced when using the perceptions of protected area managers to measure management conditions and outcomes. For example, protected area staff could be incentivized to exaggerate positive performance measures whilst providing more conservative answers for other indicators. Additionally, protected area managers might not have referred to existing documents if they were unsure about specific details when responding to the survey questions. Managers are also often informed by rangers, who have more direct roles in monitoring resources, which could introduce additional reporting biases or varied perceptions of protected area effectiveness (Moreto & Charlton, 2021). However, previous research has highlighted the importance of protected area manager perspectives and found strong evidence of the ability of managers to identify broad conservation trends (Pyhälä et al., 2019), and their perspectives on management trends are relied upon regularly in management effectiveness evaluations (e.g. the Management Effectiveness

Tracking Tool). Nonetheless, future research should attempt to triangulate these findings with additional perspectives such as those of rangers, community members and tourism service providers, which we were not able to accomplish because of pandemic-related travel restrictions.

Our results point to two potential avenues for reducing the impacts of future global crises on protected areas, similar to those identified previously (Cumming et al., 2021; Waithaka et al., 2021). The first involves providing protected area managers with the skills and equipment required to adopt technological solutions that can help them to maintain critical management activities in times of unexpected crises. There has been an increasing use of technology in biodiversity conservation, including new management tools and methods for data collection and resource monitoring. However, these approaches often fall short of their potential because of low user capacity and financial constraints (upfront or maintenance costs; Speaker et al., 2021). Overcoming these limitations and expanding technology access across protected area networks could increase protected area performance during crises by allowing administrative tasks to be completed remotely, helping with the sharing of new information and providing new opportunities for reporting non-compliant activities.

Secondly, protected areas should consider integrating relief plans into their management strategies, which would help them to prioritize critical management activities when capacity is reduced, provide emergency funds to cover management needs in times of financial uncertainty (e.g. when government funds are redirected to other sectors) and provide short-term support to communities, specifically those reliant on tourism and vulnerable to global economic fluctuations. Almost 90% of the participating protected areas received support from community monitoring groups, demonstrating the important contributions that communities play in protected area success. Therefore, it is important to maintain a positive relationship between communities and protected area management, especially during unexpected events. Given the negative trends in institutional support from governments (Kroner et al., 2021; Waithaka et al., 2021), it will be important that these relief plans are supported by diverse funding mechanisms.

Planning in anticipation of future events should help to build protected area networks that are more resilient to unexpected crises, ultimately leading to more positive outcomes for biodiversity. The Covid-19 pandemic has highlighted the importance of preparedness for shocks and stressors on protected areas. Our research has identified potential pathways of impact on conservation outcomes as perceived by protected area managers across the protected areas in Mexico during the initial years of the Covid-19 pandemic. Specifically, we found a perceived reduction in human capacity and tourism, ultimately reducing monitoring capacity and financial benefits for communities in and around protected areas. Additionally, we found a general increase in multiple non-compliant activities in 2020. The theory of change presented here is not static, and with borders reopening future research should focus on understanding how the impacts of the pandemic on protected areas change over time.

It will be critical to provide support for protected area managers to help them plan, design and implement management activities efficiently and effectively, as well as to help them engage and collaborate with stakeholders to improve adaptive capacity in protected areas globally. Protected area planning should also begin to integrate relief plans and build technological capabilities in anticipation of future unexpected events and crises. Finally, to be effective, these plans will need to pay particular attention to the impacts of such future unexpected events and crises on local communities.

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Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards. Appropriate institutional review board approval was given by Colorado State University prior to conducting the research (ID: 19-8870H).

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