Received: 1 June 2017 | Accepted: 17 December 2017
DOI: 10.1111/conl.12435

LETTER

WILEY Conservation Letters
A journal of the Society for Conservation Biology
Open Access

An assessment of threats to terrestrial protected areas

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Funding information
United States Agency for International Development; Villum Fonden, Grant/Award Number: VKR023371; Danmarks Grundforskningsfond, Grant/Award Number: DNRF096

Abstract

Protected areas (PAs) represent a cornerstone of efforts to safeguard biodiversity, and if effective should reduce threats to biodiversity. We present the most comprehensive assessment of threats to terrestrial PAs, based on in situ data from 1,961 PAs across 149 countries, assessed by PA managers and local stakeholders. Unsustainable hunting was the most commonly reported threat and occurred in 61% of all PAs, followed by disturbance from recreational activities occurring in 55%, and natural system modifications from fire or its suppression in 49%. The number of reported threats was lower in PAs with greater remoteness, higher control of corruption, and lower human development scores. The main reported threats in developing countries were linked to overexploitation for resource extraction, while negative impacts from recreational activities dominated in developed countries. Our results show that many of the most serious threats to PAs are difficult to monitor with remote sensing, and highlight the importance of in situ threat data to inform the implementation of more effective biodiversity conservation in the global protected area estate.

KEYWORDS
biodiversity, conservation, cumulative link mixed model, IUCN threat classification scheme, management

1 | INTRODUCTION

The international community has committed to conserving effectively 17% of terrestrial areas and inland waters, and 10% of coastal and marine areas by 2020 (CBD, 2010) and protected areas (PAs) now cover more than 14.7% of the terrestrial land surface (UNEP-WCMC, IUCN, 2016). Recent syntheses suggest that PAs are performing better than the broader landscape (Barnes et al., 2016; Gray et al., 2016), although numerous studies suggest that biodiversity continues to decline within many PAs (Craigie et al., 2010; Geldmann et al., 2013; Laurance et al., 2012).

A principal objective of PAs is to conserve nature by eliminating, minimizing, or reducing human pressures and threats operating within their boundaries. Our knowledge of the occurrence and severity of threats to PAs has largely been informed by remote sensing data (Geldmann, Joppa, & Burgess, 2014), modeling (Hole et al., 2009), as well as questionnaire surveys with an emphasis on tropical regions (Bruner, Gullison, Rice, & da Fonseca, 2001; Laurance et al., 2012; Leverington, Costa, Pavese, Lisle, & Hockings, 2010). Freely available satellite data offer global and standardized metrics for measuring those threats to PAs that can be observed remotely, such as deforestation (Joppa & Pfaff, 2011) and fires (Nelson & Chomitz, 2011). However, many other threats, including some of the most frequently reported threats to species, according to the International Union for Conservation of Nature (IUCN) Red List (e.g., overexploitation of species, invasive alien species, pollution, climate change), cannot be measured from space (Joppa et al., 2016) and require field-collected data (Mwangi et al., 2010).

Protected Area Management Effectiveness (PAME) assessments offer a potentially valuable source of site-level threats data. PAME assessments are conducted by PA managers, staff, and other stakeholders with the aim of improving PA management (Leverington et al., 2010). Most PAME methodologies include a systematic and comparable evaluation of threats to PA values and/or key taxa. This provides a basis for more coordinated efforts and targeted investment to reduce threats and enhance conservation outcomes in PAs.

We provide an overview of the threats facing terrestrial PAs, using data collected as part of PAME evaluations in 1,961 PAs from 149 countries. Following Salafsky et al. (2008), we defined threats as any human activity or processes that cause destruction, degradation, and/or impairment of biodiversity targets. We assess the main types of threats affecting PAs, their impact, and how their occurrence varies by region and biome. Finally, we use a Cumulative Link Mixed Model (CLMM) to investigate which environmental and socioeconomic factors correlate with more highly threatened PAs. We discuss the results in terms of PA management and international policy needs, with the aim of improving conservation responses on the ground.

2 | METHODS

2.1 | Threat data from PAME assessments

We compiled threat data from three different methodologies: (1) the Management Effectiveness Tracking Tool (METT; Version 3; Stolton, Hockings, Dudley, MacKinnon, & Whitten, 2007), (2) the World Heritage Outlook assessment (IUCN, 2012a; Osipova et al., 2014), and (3) BirdLife International's Important Bird and Biodiversity Area (IBA) monitoring protocol (BirdLife International, 2006, 2014, 2017; detailed descriptions for each approach are given in the SI). The METT was developed for use in individual PAs and contains 30 multiple-choice questions and general sections on threats and other descriptive attributes of the site. The evaluation of threats is done with a tick-sheet, containing 52 specific threats from 12 general threat classes and 4 possible ratings of threats (high/medium/low/NA; Stolton et al., 2007). The World Heritage Outlook assessment evaluates the state of conservation for natural World Heritage sites. Assessments include the state and trends of values, their threats, and the effectiveness and management of sites. Threats are evaluated with help of a checklist, containing 47 specific threats from 13 general threat classes. Current and potential threats are assessed against five threat ratings and a justification for the rating is given (IUCN, 2012a). The IBA monitoring system requires users to score the condition of the populations of bird species for which the IBA has been identified, the pressure upon them, and the adequacy of conservation responses in place. For each threat, users score the timing (ongoing, past, or future), scope (proportion of the site affected), and severity (rate of population decline for the species driven by the threat within its scope at the site), from which an impact score is automatically calculated. The overall score (on a 4-point scale) for threats at the site is taken as the worst score for any threat impacting any of the species for which the site has been identified as an IBA, following a "weakest link" approach (BirdLife International, 2006). All three methodologies adapt the IUCN and Conservation Measures Partnership (CMP) Threats Classification Scheme (IUCN, 2012b; IUCN & CMP, 2012), which lists 12 general threat classes (hereafter: "level one threats"; Table S1), subdivided into 45 specific threat types (hereafter: "level two threats"). We excluded threats that were not specified (i.e., "other"), or not recorded in any PA (i.e., Viral/Prion-induced Diseases and Diseases of Unknown Cause). The three methodologies differed slightly in how they recorded the impact of a threat (see Table S2 and explanation in SI). To account for this, all threats were reclassified into four levels of impact: (1) Low, (2) Medium, (3) High, and (4) Not Applicable (Table S2). Reclassification was based on the descriptions of the individual categories in the three methodologies to ensure a consistence and comparable assessment of threat impact (Table S2). Our data set covers the period 2005–2015. For PAs with multiple assessments over time or for those that are overlapping (i.e., an international designation is covering a PA of an IUCN category), we used the most recent assessment. IBA monitoring data were available for 3,807 IBAs, which covered both protected and nonprotected sites. As our objective was to assess threats to PAs, we excluded all IBAs where less than 90% of the site overlapped with a PA, resulting in a final sample of 520 protected IBAs. All other data sets were retained in their original form. We extracted data on PA location, size, and IUCN management category from the World Database on Protected Areas (WDPA; IUCN, UNEP-WCMC, 2015) and spatial data for IBAs were taken from BirdLife International (2016). GIS layers were projected in the Mollweide equal area projection.

2.2 | Occurrence and high impact likelihood of threats

We assessed the occurrence for both level one and level two threats in the sampled PAs (Table S1). The relative frequency of high impact scores for each threat was calculated as the number of PAs where a particular threat was reported as "high" as a percentage of all PAs where the threat was reported.

To investigate geographical differences in the type of threats occurring, we calculated the occurrence of all level two threats within major geographical units. Biomes from the WWF Ecoregion of the World were grouped to: (1) Tropical Forest, (2) Nontropical Forest, (3) Tropical and Subtropical Savannah, Shrublands, and Grasslands, (4) Non tropical Savannahs, Shrublands, and Grasslands, and (5) Mangroves (Table 1) and furthermore distinguished according to their location within a realm (Olson et al., 2001). Hereafter, this classification is referred to as "realm-biomes." This ensured that all geographical units had at least seven PAME assessments to determine the occurrence of threats (Table S4).

2.3 | Statistical analysis

Data analysis was conducted using QGIS version 2.14.0 (Quantum GIS Development Team, 2015) with the GRASS 7.0.3 plugin and R (R Development Core Team, 2015). We used a CLMM from the ordinal package (Christensen, 2015) to analyze likelihood of a PA being highly threatened. CLMMs are suitable when the dependent variable is an ordered categorical factor (i.e., ordinal data; Agresti, 2013). Threat levels to PAs were aggregated into three ordinal levels: (1) no threats reported as high impact in the PA, (2) one threat reported as high impact in the PA, and (3) multiple threats reported as high impact in the PA. The aggregated high threat variable was modeled against a set of explanatory variables related to: (1) accessibility in general (i.e., mean travel time to major cities) and for land use (i.e., mean elevation or mean slope), (2) national socioeconomic factors (i.e., Gross Net Income, Human Development Index (HDI), inequality adjusted HDI (all three: UNDP, 2014), or Indicator for control of corruption (World Bank Group, 2017), and (3) remotely sensed pressures (i.e., Human Footprint; Venter et al., 2016a, 2016b). Locations within a realm-biome and IUCN category or international designation were used as random terms. Where explanatory variables were collinear (e.g., elevation and slope [VIF = 0.89, Figure S3]), we excluded the one with the lowest absolute R^2-values based on univariate modeling against the dependent variable. Model selection was based on Akaike information criterion.

3 | RESULTS

3.1 | Occurrence of threats

Our final data set contained 1,961 unique terrestrial PAs from 60 realm-biomes across 149 countries from all continents except Antarctica (Table S7). For level one threats, the most frequently reported threat was "Biological Resource Use" (75%), followed by Natural System Modification (72%), Human Intrusions/Disturbance (69%), and Unsustainable Agriculture/Aquaculture (60%; Figure 1 and Table S5). For level two threats, unsustainable hunting and collection of terrestrial animals was the most frequently reported (61%), followed by impacts of recreational activities (55%), fire or its suppression (49%), invasive alien species (48%), and gathering of terrestrial plants (48%; Figure 2 and Table S5).

3.2 | Spatial patterns of threats

Across the sampled PAs, hunting and the collection of animals, recreational activities, logging, fire or fire suppression, and invasive species were frequently reported threats across realm-biomes (Figure 3). Hunting and the collection of animals was the most common threat in PAs in the Afrotropical, Indo-Malaya, and Neotropical realms. Impacts of recreational activities were reported as one of the two most common threats in PAs in all realms with sufficient data, except the Afrotropics (Table 1).

3.3 | Occurrence of high impact threats

For the most frequent level one threats, 28% of Biological Resource Use threats, 31% of Natural System Modifications threats, and 22% of Agriculture and Aquaculture threats were reported by the assessors as having a high impact, while this

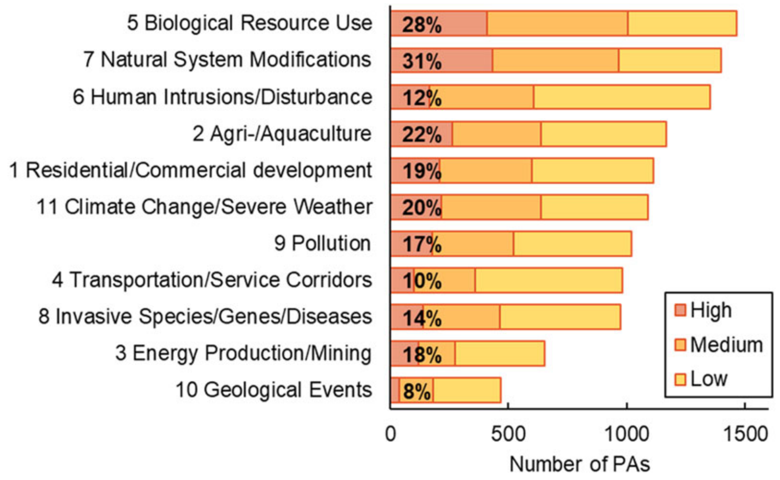

FIGURE 1 Ranked frequency of threats across the 11 level one threats in the IUCN-CMP Threats Classification Scheme. The figure displays the amount of PAs where individual level one threats are reported. Additionally the percentage of these threats reported as high related to the occurrence at any level is given

was less often the case for Human Intrusion and Disturbance (12 %, Figure 1).

Energy infrastructure, such as oil and gas drillings, mining, constructions of dams, and renewable energy facilities were among the least frequently reported threats to PAs. But if they occurred, they were more typically reported to have a high impact, compared to other threats (Figure 2). Invasive alien species, while the fourth most frequently reported threat, were only considered to have a high impact in 15% of the PAs where they occurred, while disturbances by problematic native species were the least frequently documented threat, but had the highest proportion of records scored as high impact. Roads and railways were only reported to have a high impact in 8% of the PAs where the threat occurred.

3.4 | Modeling the characteristics of highly threatened PAs

We used a statistical modeling approach to evaluate the underlying characteristics of highly threatened PAs (those PAs where more than one threat is ranked high). Our final model included travel time (estimate = −0.18, SE = 0.08, $P < 0.05$), inequality-adjusted human development (estimate = −0.44, SE = 0.22, $P < 0.1$), control of corruption (estimate = −0.54, SE = 0.12, $P < 0.001$), and mean elevation (estimate = −0.18, SE = 0.08, $P < 0.01$) see Figure 4.

4 | DISCUSSION

4.1 | Patterns of threat

The two most frequent threats (including those of low impact) to PAs in our data set were hunting and recreational activities. Notably, there were distinct geographical differences in the distribution of these threats between developing and developed countries. In the former, threats from overexploitation were most prevalent, in part, because local communities in and around PAs in developing countries typically depend on hunting and other resource collection for their livelihood, whereas threats in developed nations were more frequently linked to human disturbance through recreational activities, such as off-road vehicle access, cross-country skiing, mountain biking, or hiking (IUCN & CMP, 2012; Jones, Newsome, & Macbeth, 2016; Reed & Merenlender, 2008). Such spatial differences in the importance of threats also suggest very different solutions to address threats on the ground, for example, to ensure sustainable livelihoods for local communities in developing countries ideally emphasizing areas outside of reserves, and to regulate and control visitor activities in PAs in developed countries. There is already a considerable literature on both of these broader intervention categories, with the details of what needs to be done varying between countries and parts of countries.

The most frequent level 2 threat within Natural System Modifications was fire and fire suppression. The IUCN CMP threat classification system, on which the data analyzed here is based, specifies the threat of human activities causing fire and fire suppression as being outside of the "natural range of variation" (IUCN & CMP, 2012), that is, fire per se is not a threat, but its frequency and/or severity are greater or less than natural. Our data thus suggest that PAME assessors consider that fire frequency/severity and fire suppression patterns are becoming more intense, as fire and fire suppression was the third most commonly reported threat globally. This could be linked to climate change, the frequency of uncontrolled or inappropriate burning (e.g., from agricultural clearance activities close to PA boundaries), and fire suppression, leading

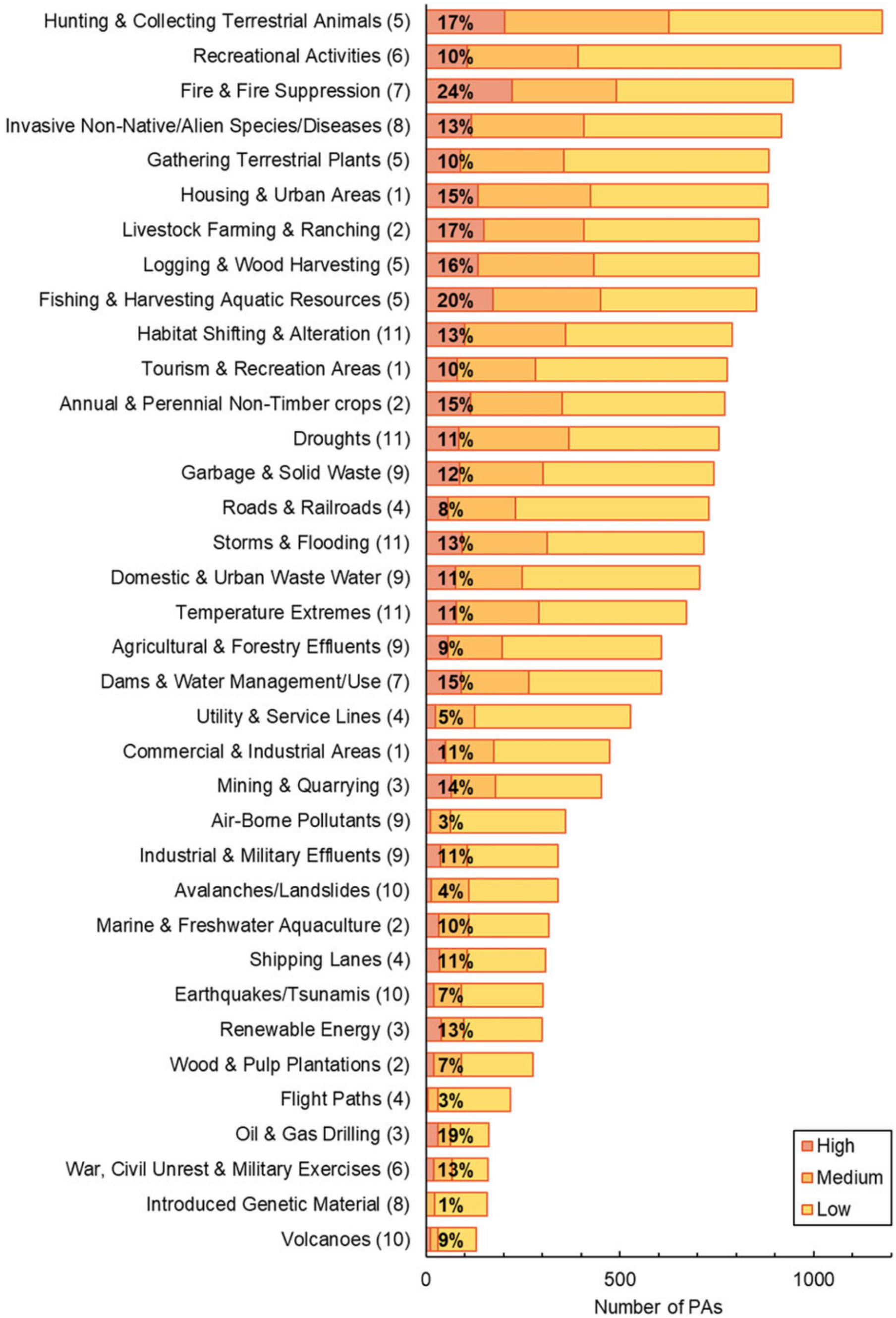

FIGURE 2 Ranked frequency of threats across the level two threats in the IUCN-CMP Threats Classification Scheme. The figure shows the number of PAs where individual level two threats are reported and the percentage of the threat being reported as high in relation to the occurrence at any level. The number behind the name of the specific threats indicates to which level 1 threat it is classified, following the IUCN-CMP Threat Classfication Scheme. (1) Residential/Commercial development, (2) Agri-/Aquaculture, (3) Energy Production/Mining, (4) Transportation/Service Corridors, (5) Biological Resource Use, (6) Human Intrusions/Disturbance, (7) Natural System Modifications, (8) Invasive Species/Genes/Diseases, (9) Pollution, (10) Geological Events, (11) Climate Change/Severe Weather

to more severe wildfires once ignited. It is likely that there are different drivers according to geographical and socioeconomic factors as noted by Lehmann et al. (2014), but further enquiry, such as comparison with remotely sensed fire and land use change patterns, is needed to investigate the cause, and thereby inform options for the appropriate responses and policy initiatives.

Invasive alien species comprised the fourth most frequently reported threat globally. Our results support previous findings, not restricted to PAs, showing that in particular islands are vulnerable to invasive species (Dawson et al., 2017), with invasives being most often reported in our analysis from PAs in North and South America, Australasia, and the smaller islands in Oceania. Dawson et al.

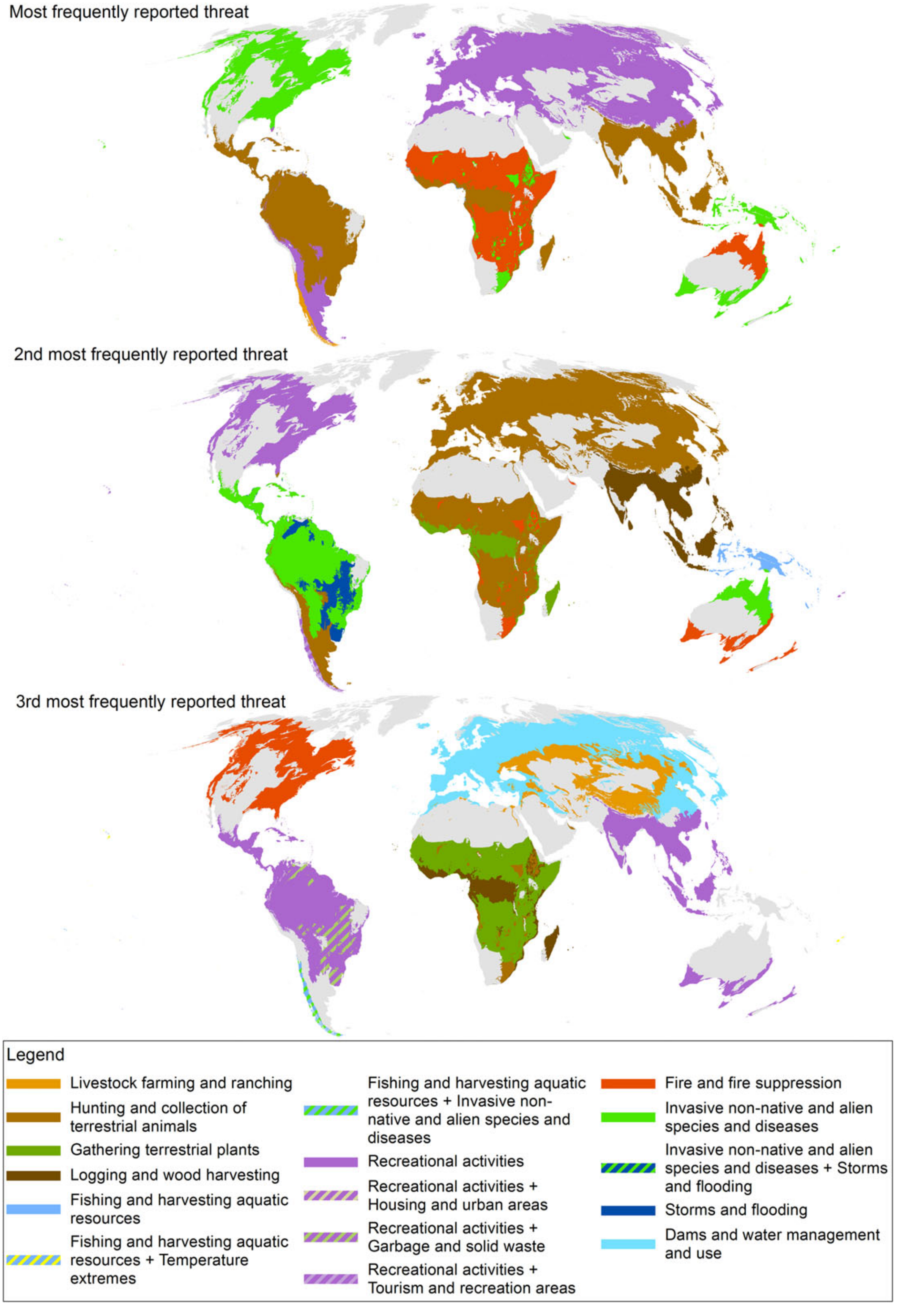

FIGURE 3 Most frequently recorded three threats (at any impact level) for the biome-realm combinations

Note: When two threats are recorded at the same number of sites, they are displayed with hatched lines as indicated in the legend. When more than two threats are recorded at the same number of sites (which occurred in some biome-realm combinations with few PAs assessed), none of them are displayed in order to make the figure intelligible

TABLE 1 The three most frequently reported threats by realm and biome group

Realm	Biome group	Sites (*N*)	Most frequently documented threat	2nd most frequently documented threat	3rd most frequently documented threat
Australasian	Tropical forest	8	Invasive non-native/alien species/diseases	Fishing & harvesting aquatic resources	–
Australasian	Nontropical forest	25	Invasive non-native/alien species/diseases	Fire & fire suppression	Recreational activities
Australasian	Tropical savannahs, shrub- and grasslands	7	Fire & fire suppression	Invasive non-native/alien species/diseases	–
Afrotropical	Tropical forests	150	Hunting & collecting terrestrial animals	Gathering terrestrial plants	Logging & wood harvesting
Afrotropical	Nontropical savannahs, shrub- and grasslands	22	Invasive non-native/alien species/diseases	Fire & fire suppression	Recreational activities
Afrotropical	Mangroves	7	Fishing & harvesting aquatic resources	Hunting & collecting terrestrial animals	Gathering terrestrial plants
Indo-Malayan	Tropical forests	85	Hunting & collecting terrestrial animals	Logging & wood harvesting	Recreational activities
Nearctic	Nontropical forest	11	Invasive non-native/alien species/diseases	Recreational activities	Fire & fire suppression
Neotropical	Tropical forests	253	Hunting & collecting terrestrial animals	Invasive non-native/alien species/diseases	Recreational activities
Neotropical	Nontropical forest	30	Livestock farming & ranching	Recreational activities; tourism & recreation areas	Fishing & harvesting aquatic resources; invasive non-native/alien species/diseases
Neotropical	Tropical savannahs, shrub- and grasslands	18	Hunting & collecting terrestrial animals	Storms & flooding	Recreational activities; garbage and solid waste
Neotropical	Nontropical savannahs, shrub- and grasslands	27	Recreational activities	Hunting & collecting terrestrial animals	–
Neotropical	Mangroves	51	Fishing & harvesting aquatic resources	Invasive non-native/alien species/diseases; storms and flooding	Recreational activities; housing and urban areas
Palearctic	Nontropical forest	479	Recreational activities	Hunting & collecting terrestrial animals	Dams & water management/use
Palearctic	Nontropical savannahs, shrub- and grasslands	51	Recreational activities	Hunting & collecting terrestrial animals	Livestock farming & ranching
Oceania	Tropical forests	7	Invasive alien species/diseases	Recreational activities	Fishing & harvesting aquatic resources; temperature extremes

Note: The table summarizes our findings for each realm biome and gives for each the number of PAs that were assessed.

(2017) did not find North or South America to be hotspots for invasive species, but richness of alien mammal, amphibian, and vascular plants were high in regions of both continents. Approximately one in five threatened species on the IUCN Red List is impacted by invasive alien or other problematic native species (Joppa et al., 2016), with invasive vertebrates such as rats and cats being among the most problematic species. On islands, eradicating such species is an increasingly practical and effective conservation solution, with nearly 600 populations of over 200 native terrestrial insular fauna species estimated to have benefitted from eradications of invasive mammals on over 181 islands to date (Jones et al., 2016).

The fact that threats resulting from agriculture (at level two in the threats classification scheme) were rather infrequent might reflect the fact that agriculture is divided rather finely in the classification scheme. When considering only high, or high and medium, threat levels, unsustainable agriculture and aquaculture ranked as the third-most important threat to PAs, reflecting the fact that it is the most important threat to terrestrial threatened species (Joppa et al., 2016).

4.2 | Predictors of threats

Our best-fit model showed an increased likelihood of PAs with multiple high-intensity threats being in countries with low

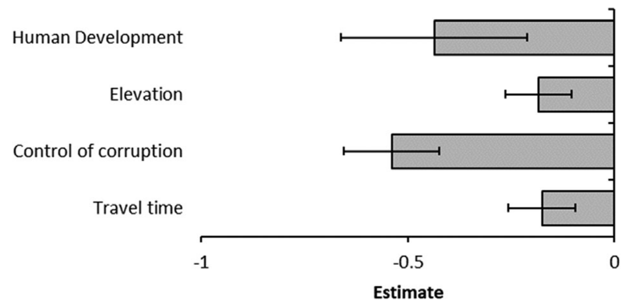

FIGURE 4 Effects of accessibility (elevation and travel time) and national socio-economic factors (inequality adjusted human development index and control of corruption) on aggregated high threat variable. All variables show negative effects

HDI scores (inequality-adjusted). This finding agrees with results using remotely sensed change in pressure (Geldmann et al., 2014) or changes in wildlife populations (Barnes et al., 2016). Thus, our results show a need for action particularly countries with lower human development. This is particularly important in the light of the post-2020 agenda and the Sustainable Development Goals (UN, 2015), where focus will increasingly be on balancing the protection of nature with ensuring improved livelihood for people. The negative relationship between control of corruption and the number of high-ranked threats reflects that more has to be done in the fight against corruption in PAs and to support PA management efficiency (Watson, Dudley, Segan, & Hockings, 2014). PAs at higher elevations and further away from major cities experienced fewer threats. This pattern is consistent with evidence showing that many PAs are in remote regions and that those have lower overall pressure from human activities compared to less remote PAs (Joppa & Pfaff, 2009). Protecting such environments may, therefore, require fewer resources and efforts may be better directed to areas where protection leads to the highest level of avoided threats (Craigie, Pressey, & Barnes, 2014). Understanding the underlying drivers of threat is hugely important when determining where to protect and what management strategies are optimal within PAs. Many of the most important threats cannot be monitored from space (e.g., natural resource use, recreational impacts, and invasive species). Hence, PAs are likely to be under considerably higher pressures than currently estimated using remote sensing (Redford & Feinsinger, 2001). A combination of both remote and locally gathered threat data, and evaluation of how threats are connected to each other, can provide deeper insights into pressures on PAs, including impacts from the adjacent areas (Broadbent et al., 2008; Cochrane & Laurance, 2002). Such combined approaches will likely lead to better allocation of resources and more effective management.

4.3 | Final considerations

Our data set had several limitations. For some regions, most of the data came from one country, which might have affected the model results concerning national variables. However, this should not largely influence the spatial patterns analysis, which was not conducted on a national level but within regions.

We restricted our analysis to "level one" and "level two" threats, but the IUCN CMP classification specifies "level three" threats in some cases (e.g., specifying whether a threat from fire and fire suppression relates to an increase or suppression of fire frequency/intensity). While this level of detail would be useful to inform management, and is captured in some systems (e.g., IBA monitoring), it is not in others, and there is little appetite to increase the complexity of PAME assessments among some implementing organizations. We suggest that the patterns shown here are a valuable source of policy-relevant information that could be improved with greater implementation of assessments, standardization between methodologies, and potentially the collection of a greater level of detail. We encourage implementing organizations, Pas, and NGOs that use PAME assessments as part of their evaluation systems to strengthen and increase their application, rather than the converse.

ACKNOWLEDGMENTS

We thank the thousands of people involved in completing the threat assessments globally, and GEF, UNDP, WWF, CEPF, University of Queensland, University of Oxford, University of Copenhagen TNC, and World Bank who have helped support the collation of data. We also thank the Danish National Research Foundation (DNRF096), VILLUM FONDEN (VKR023371) and USAID for financial support. We thank the anonymous reviewers for their time, effort, and insightful comments.

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How to cite this article: Schulze K, Knights K, Coad L, et al. An assessment of threats to terrestrial protected areas. *Conserv. Lett*. 2018;e12435. https://doi.org/10.1111/conl.12435