A global-level assessment of the effectiveness of protected areas at resisting anthropogenic pressures

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One-sixth of the global terrestrial surface now falls within protected areas (PAs), making it essential to understand how far they mitigate the increasing pressures on nature which characterize the Anthropocene. In by far the largest analysis of this question to date and not restricted to forested PAs, we compiled data from 12,315 PAs across 152 countries to investigate their ability to reduce human pressure and how this varies with socioeconomic and management circumstances. While many PAs show positive outcomes, strikingly we find that compared with matched unprotected areas, PAs have on average not reduced a compound index of pressure change over the past 15 y. Moreover, in tropical regions average pressure change from cropland conversion has increased inside PAs even more than in matched unprotected areas. However, our results also confirm previous studies restricted to forest PAs, where pressures are increasing, but less than in counterfactual areas. Our results also show that countries with high national-level development scores have experienced lower rates of pressure increase over the past 15 y within their PAs compared with a matched outside area. Our results caution against the rapid establishment of new PAs without simultaneously addressing the conditions needed to enable their success.

counterfactual | Human Development Index | human footprint | impact assessment | management effectiveness

The Anthropocene is characterized by an unparalleled "human impact on the global environment" (1) leading to dramatic declines in biodiversity and potentially the first mass extinctions brought on by a single species (2). To reverse this trend, a growing number of multilateral environmental agreements have been adopted, most importantly the Convention on Biological Diversity (CBD) (3). A chief instrument of the CBD is the Strategic Plan for Biodiversity 2011–2020, whose Aichi targets call for the protection of 17% of the earth and 10% of the oceans (4). This has resulted in the rapid expansion of the global network of protected areas (PAs), which currently cover approximately 15% of the terrestrial surface and 7% of the world's oceans (5). This is an impressive policy achievement, but merely designating PAs does not ensure protection of biodiversity. PAs must deliver real conservation benefits by buffering the wild populations and habitats they contain from human pressures on the environment.

Despite wide recognition of the importance of understanding the role PAs in conserving biodiversity (6), assessing the performance of PAs has proved challenging, and evidence remains relatively sparse (7) although more recent studies have started to examine PA performance. Reviews of case studies have shown that PAs can be and often do contribute to the persistence of biodiversity (7) and for many of the world's flagship species, PAs are now their only remaining stronghold (8). Using remotely sensed vegetation data, studies have shown that while PAs are losing forest, these losses on average are less inside than outside PAs (9–13). Other studies have related observed biodiversity changes inside PAs to conditions immediately outside (finding that PAs surrounded by more disturbed landscaped performed worse) (14) to socioeconomic conditions and governance (finding PAs in more developed countries to be more effective) (9, 15), and to management capacity and resources (finding that more adequately resourced PAs perform better) (16). However, these studies have been restricted in scope by the availability of remote-sensed data for only 1 habitat (i.e., forest) or the subset of PAs with in situ monitoring of only a subset of the biodiversity values of the PAs. Further, assessing the performance of existing PAs requires counterfactual thinking (17)—comparing outcomes to what would most likely have happened if PAs had not been established. This is important because PAs are not randomly located in the landscape but often biased toward remote areas where pressures on nature are expected to have remained low even without formal protection (18). Without explicitly accounting for this contextual bias in the location of PAs, changes in conservation outcomes cannot be convincingly attributed to PA designation.

To measure the ability of PAs to mitigate pressure, we used the Temporal Human Pressure Index (THPI—the first global spatially explicit data layer on recent temporal changes in human pressure over 15 y from 1995). Our measure of THPI has 2 important strengths. First, our global measure of pressure, while not perfect, is not biased by a specific habitat type (i.e., forest) or a potentially nonrepresentative monitoring effort. Second, the global coverage allows us to compare changes inside PAs with changes in unprotected areas similar to our PAs in terms of their initial exposure to pressure and location biases (i.e., their

Significance

Protected areas (PAs) are a key strategy for conserving nature and halting the loss of biodiversity. Our results show that while many PAs are effective, the large focus on increasing terrestrial coverage toward 17% of the earth surface has led to many PAs failing to stem human pressure. This is particularly the case for nonforested areas, which have not been assessed in previous analysis. Thus, we show that relying only on studies of remote-sensed forest cover can produce a biased picture of the effectiveness of PAs. Moving forward beyond the current biodiversity targets, there is a need to ensure that quality rather than quantity is better integrated and measured.

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counterfactual). We use this to assess the performance of 12,315 PAs (Fig. 1). Our sampled PAs are from 152 countries and together covered 81.8% of the 1995 global PA estate by area (the start date for the THPI). To investigate large-scale geographical differences, we examined PA performance for the Afrotropics, Australasia, Indomalaya, the Nearctic, the Neotropics, and the Palearctic, respectively. Additionally, we wanted to understand the role of site-level factors, such as PA design and management, as well as system-level factors, such as national land-use planning and legislation in mitigating human pressure. All factors that have been linked to the performance of PAs (19). To test this, we examined the relationship between our measures of PA performance and a suite of contextual factors for which we had data for 11,491 of the PAs. Finally we included the most widely applied site-specific assessment of PA management (the Management Effectiveness Tracking Tool [METT]) to examine the role of management inputs for a smaller subset of 407 PAs for which we had METT data.

Results

Across all 6 realms, PAs experienced increased human pressure (as revealed by positive THPI scores) over the period 1995 to 2010, with the largest increases observed in Indomalaya (mean = 5.53, SE = 0.12), followed by the Afrotropics (mean = 2.95, SE = 0.05), and the smallest in Australasia (mean = 0.27, SE = 0.02) and the Nearctic (mean = 0.14, SE = 0.03) (Fig. 2*A*). Comparing THPI scores inside PAs to their counterfactuals, we found that PAs underwent lower pressure increases over the last 15 y than the counterfactuals in the Palearctic (Df = 40,073, $F = 2{,}934$, $P < 0.001$), Australasia (Df = 8,912, $F = 388$, $P < 0.001$), and the Nearctic (Df = 18,670, $F = 520$, $P < 0.001$). However, changes in pressure over the past 15 y were significantly higher inside PAs than in the counterfactuals in Indomalaya (Df = 5,878, $F = 319$, $P < 0.001$), the Afrotropics (Df = 24,747, $F = 2{,}540$, $P < 0.001$), and the Neotropics (Df = 18,645, $F = 592$, $P < 0.001$). These results are counter to previous studies that have been restricted to using avoided deforestation as a proxy for effectiveness. To examine this discrepancy between our results from forested PAs, we replicated previous analysis for the Brazilian Amazon (11, 13), Malagasy forested PAs (12), and forested Sumatran PAs (20) covering the 3 realms. Our results, restricted to forested areas from these regions corroborated previous matching studies and showed that for forested PAs, pressure has increased less inside than in the counterfactual, highlighting a key difference in the patterns found in forest and those we show for nonforested habitats.

When disaggregating these patterns by the 3 components of the THPI, Indomalaya experienced the largest increase in both PAs and unprotected lands in terms of human population density (Fig. 2*B*), night lights (Fig. 2*C*), and agriculture (Fig. 2*D*). Comparing the individual THPI components inside versus outside PAs, we found that agriculture expanded more over the last 15 y inside than matched outside PAs in Indomalaya ($F = 551$, $P < 0.001$), the Afrotropics ($F = 2{,}329$, $P < 0.001$), and the Palearctic ($F = 3{,}420$, $P < 0.001$), while differences in changes in agriculture, albeit significant, were indistinguishable between PAs and their counterfactuals in the Nearctic ($F = 850$, $P < 0.001$), Australasia ($F = 934$, $P < 0.001$), and the Neotropics ($F = 577$, $P < 0.001$) (Fig. 2*D*). For human population density, there was little difference in 15-y changes between PAs and the counterfactuals (Fig. 2*B*), except for in the Afrotropics where population growth was lower inside PAs ($F = 916$, $P < 0.001$), and the Neotropics where increases in population numbers were higher inside PAs than the counterfactual ($F = 163$, $P < 0.001$). PAs in the Nearctic ($F = 227$, $P < 0.001$), Palearctic ($F = 2{,}335$, $P < 0.001$), Afrotropics ($F = 377$, $P < 0.001$), and in Indomalaya ($F = 220$, $P < 0.001$) had smaller increases in night light densities than the counterfactual (Fig. 2*C*). These patterns were similar when looking at changes across landcover classes, where agriculture increased more inside PAs than in their counterfactuals across most vegetation types, in particular, in grassland, consistent with the subanalysis for forested PAs (*SI Appendix*, Fig. S1). Conversely PAs across all vegetation types were effective at stemming pressure from humans and night lights.

To examine what factors contribute to the performance of PAs, we calculated a relative effectiveness score for each PA, as the difference between the mean change in THPI inside PAs and the mean change in THPI for the counterfactual. We did this both for the full set for which we had contextual variables and

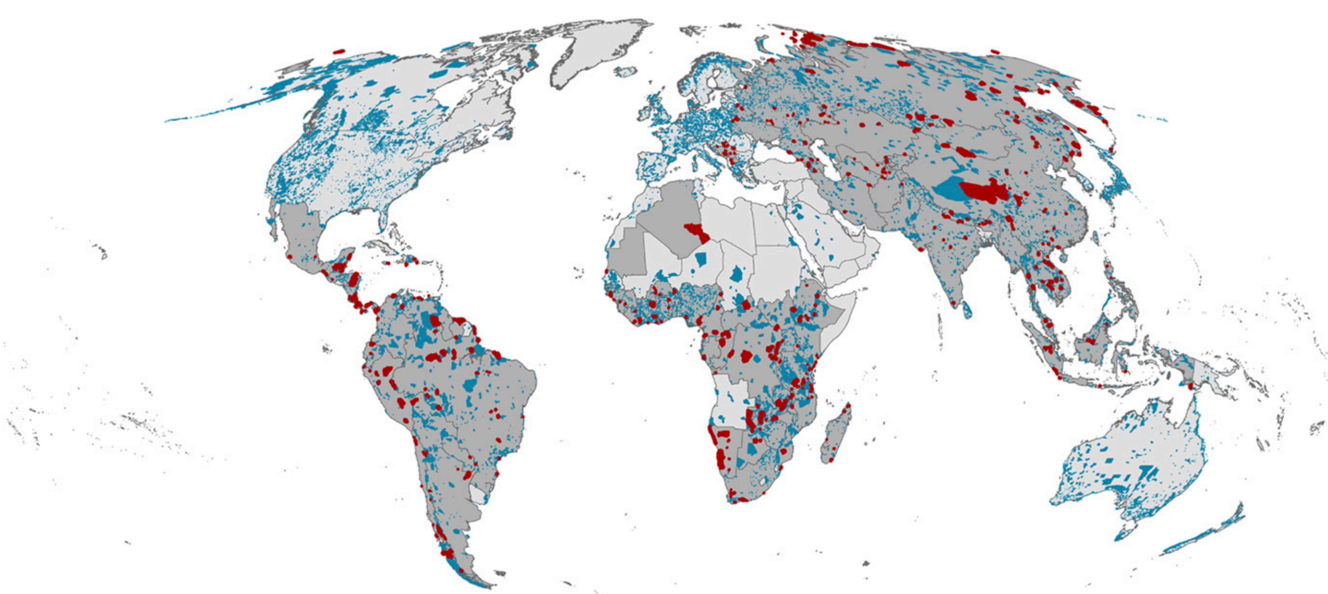

Fig. 1. Map of the 12,315 PAs existing in 1995 (blue) from the 152 countries included in the analysis, across Afrotropic = 2,278, Australasia = 871, Indomalaya = 927, Nearctic = 2,468, Neotropic = 1,033, and Palearctic = 4,738 as well as the 407 PAs for which METT data existed (crimson). Dark gray shows the countries for which we had METT data.

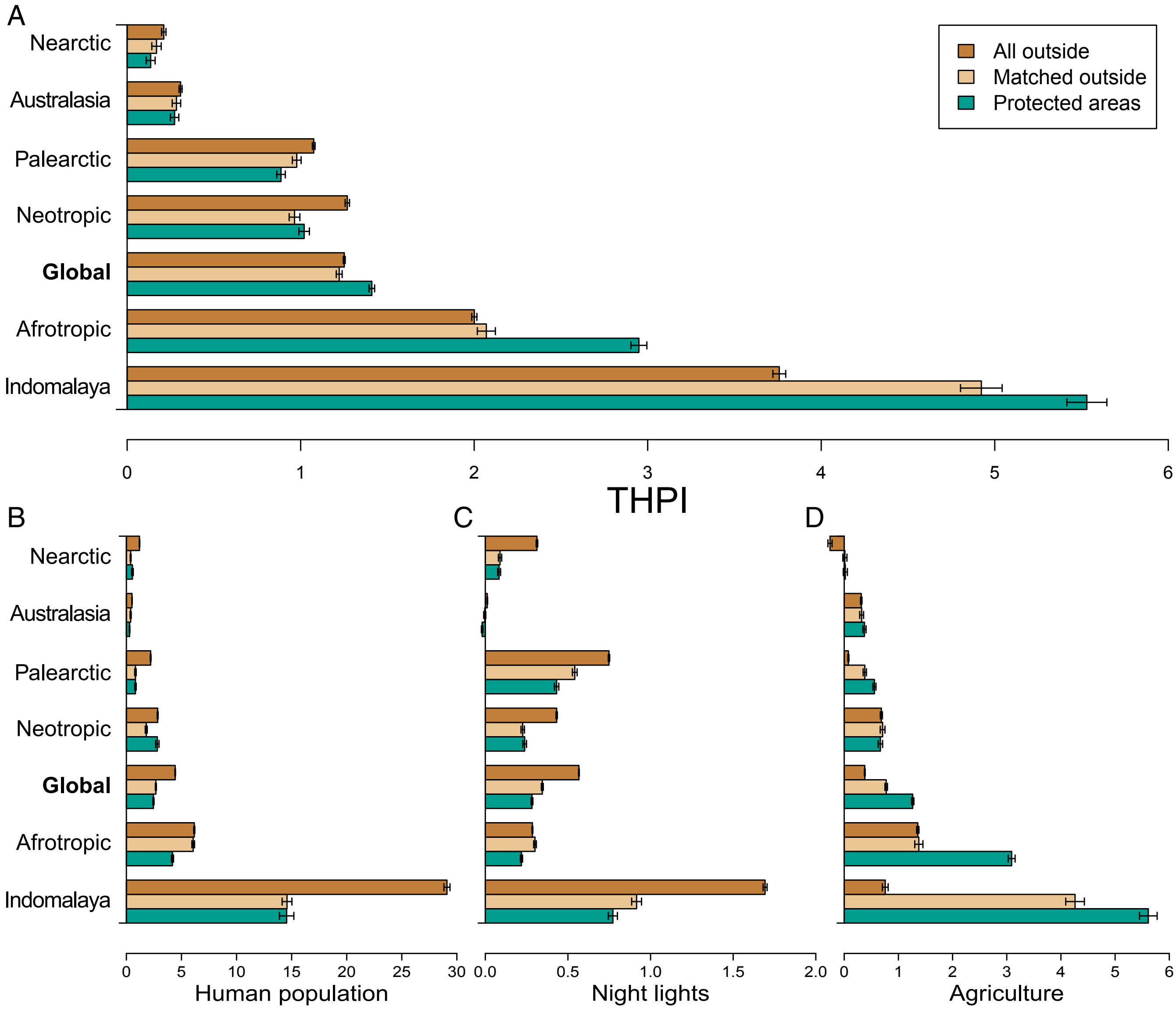

Fig. 2. Mean change in pressure between 1995 and 2010 based on (*A*) the THPI, (*B*) human population density, (*C*) stable night lights, and (*D*) agricultural crop cover for protected area (green), matched outside (light brown), and all unprotected areas in the region (dark brown). Positive values indicate that pressure has increased in the 15 y. Error bars are 1 SE. Scales in *B*–*D* have not been standardized, thus absolute values should only be compared within plots.

the subset for which we in addition had METT assessments. We tested the nonbiome corrected Human Influence Index (HII), elevation, mean road density, travel distance to nearest city, gross domestic product (GDP), national-level Human Development Index (HDI), Transparency International's Corruption Index, mean slope, mean elevation, and PA size as independent variables in our full model and ran all possible model combinations using these variables to select the most parsimonious model based on the Akaike information criterion (AIC). For the global set of PAs (n = 11,491), the best-fit model contained: mean slope (estimate = 0.041, SE = 0.001, t = 4.19), mean road density (estimate = −0.055, SE = 0.011, t = −4.84), HII (estimate = −0.038, SE = 0.011, t = −3.27), and HDI (estimate = −0.056, SE = 0.016, t = 3.55) (Fig. 3*A*). For the METT subset (n = 407) the best-fit model showed a relationship between PA effectiveness and HII (estimate = −0.112, SE = 0.053, P = 0.037) and HDI (estimate = −0.091, SE = 0.053, P = 0.085) (Fig. 3*B*). Thus, PAs experiencing a greater reduction in pressure (relative to the change in the counterfactual) were associated with higher initial human pressure and found in countries with greater human development scores for both the global sample and the METT subset. In addition, for the global sample, PAs with higher density of roads and more even terrain had better relative effectiveness scores. None of the management dimensions were present in the most parsimonious model for the METT subset.

Discussion

This is by far the largest analysis of PA performance investigating the ability of PAs to reduce human pressure. However, despite the THPI using all available global pressure layers for which multiple temporal assessments exist (21), it still lacks many important dimensions of threats to biodiversity (e.g., hunting, climate change, invasive species), and is thus only a partial measure of pressure changes within and around PAs. However, we believe our analysis adds an important piece for 2 reasons. First, except for forest cover, no change metric of biodiversity exists for which counterfactual analysis can be conducted (15, 16). Second, while

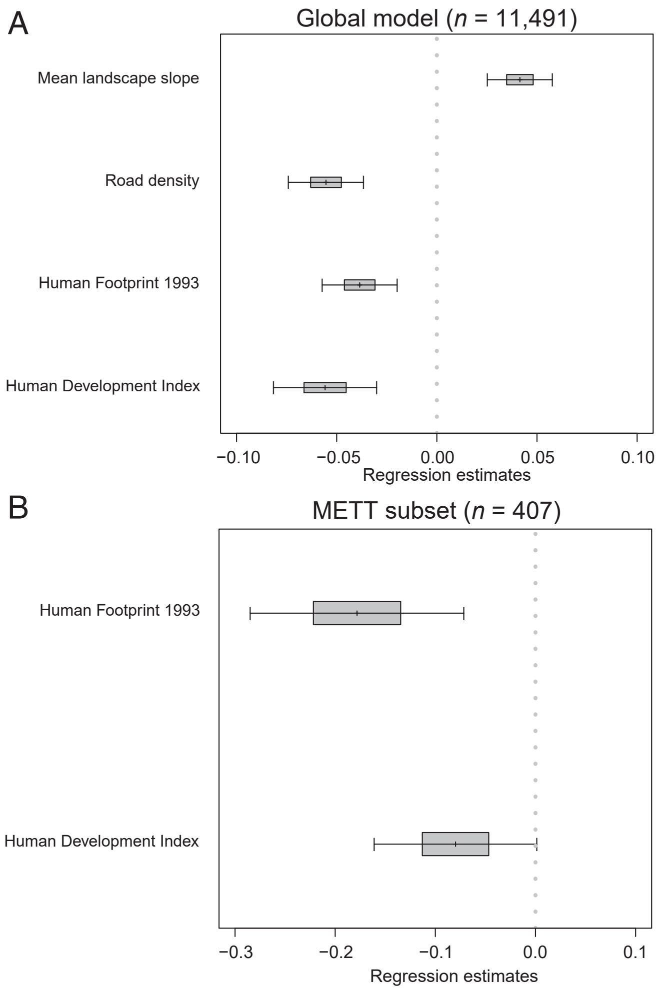

Fig. 3. Standardized parameter estimates for the most parsimonious model, based on AIC for (*A*) the global sample ($n = 11,491$) and (*B*) the subset for which we had METT scores ($n = 407$). Boxes indicate 50% confidence interval; lines indicate 95% confidence interval. The parameter estimates are based on the relative effectiveness score (THPI in PA – THPI in the counterfactual), thus, negative parameter estimates mean that PAs are more effective (i.e., increases are smaller inside PAs than the counterfactual) as explanatory variables increase in value.

the goal of PAs is to conserve biodiversity, pressure reduction is a core element of conservation interventions and in most parts of the world a necessity to achieve improved conditions for biodiversity (22).

Our results show that, on average, human pressures have increased inside PAs, with the greatest changes observed in the tropics, characterized by low HDI and low initial pressure. This makes clear that by their designation alone, PAs are not a panacea. Previous studies have found increased pressure inside PAs, but without relating this to an appropriate control (23, 24). Alarmingly, by comparing pressure changes inside PAs to the counterfactual, our results show that in the tropics pressures have even increased more inside PAs than in their counterfactual. Notably, this was not the case for the subset of forested PAs we tested, where pressure increases were higher in the counterfactual than the PAs. Thus, our results do not suggest that the PAs have failed, and indeed many of the included PAs have seen changes inside that are more positive than in the counterfactual. However, they indicate that establishing a large number of PAs without ensuring an appropriate mechanism and resources to stem human pressure can lead to average negative treatment effects. These ineffective PAs risk displaying limited resources from sites under high pressure and of importance to biodiversity while also diminishing the credibility of one of the most important tools for biodiversity conservation by swamping the many effective PAs. In this light, the last decade's ambition to reach 17% terrestrial coverage could be worrying if not accompanied by enough resources to ensure they decrease pressure and improve ecological conditions. That we find similar patterns to previous analysis that was limited to forests (9–13), confirms that PAs can reduce biodiversity loss. However, that our results are less encouraging for habitats for which no other analysis exists, also indicates that our dependence on available data, restricted to forest loss, might have led to conclusions drawn on a nonrepresentative sample of PAs leading to an overestimation of the average effectiveness of the global PA estate outside forested regions.

While our data and global approach cannot gauge the causal mechanism underlying this pattern, we identify 3 potential causes. First, the establishment of PAs can weaken the tenure rights of indigenous and local communities, eroding their authority to deter outsiders and providing opportunities for other people or companies to enter the reserve. In this way PA designation can spur encroachment rather than prevent it (25). Studies looking at PA downgrading, downsizing, and degazettement (PADDD) have found that many PAs, particularly in the tropics, experience reduced effectiveness inside their boundaries associated with resource extraction and development as well as local land claims (26, 27). Second, formal protection can undermine collective long-term resource-management regimes leading to local communities overexploiting previously sustainably used resources (28). Third, while ensuring the livelihood of local communities in and around PAs is increasingly integrated into PA objectives, protection can lead to loss of economic opportunities resulting in illegal use of resources from within the PA (29). Thus, where PA management is weak and underresourced, tenure rights to nonprotected land might actually offer a stronger deterrent from illegal and unsustainable activities, at least in the short term. Several studies have indeed shown that indigenous and community-managed reserves can reduce forest loss, sometimes more than traditional PAs (9, 13, 30), highlighting the importance of exploring types of protection that better integrate local actors and stakeholders. However, beyond national-level metrics (i.e., HDI), we have not been able to include this in our analysis because of the lack of standardized global data on such governance types at the PA level. This can also have implications for the counterfactuals used in our analysis, which can include areas not formally protected but still under tenure regimes, that include considerations for biodiversity (9).

Our model of predictors of PA performance showed that PAs located in areas of lower initial human pressure and limited human access experienced the highest increase in pressure compared with their counterfactual. This suggests that the most remote PAs that had low human pressure in 1995 have suffered more from increased human pressure than PAs under greater initial pressure. Similar patterns have been observed for changes in wildlife populations (15) and forests (11), and might be because PAs that are out of sight and out of mind are more permeable to illegal and damaging activities, or because of people moving into frontier areas that offer opportunities for farming. Alternatively, our results could indicate that PA planning is effectively targeting areas of disproportionately high pressure, using site-specific knowledge not captured by our available matching variables. That PAs in more remote and wild places are experiencing greater pressure increases is alarming. The remaining wilderness plays an essential and irreplaceable role in maintaining our most rare and threatened biodiversity (31) and, particularly in the tropics, houses a disproportionate amount of the Earth's biodiversity (32). Thus, ensuring that PAs in these regions are effective is a global priority. However, conservation efforts in many of these regions are heavily underfunded (33, 34) and in need of significant additional resources if we are to reverse the current trajectory of pressure increases.

Our finding that human development is correlated to PA performance supports the argument that establishment is not enough (6, 16). Similar relationships between protection and socioeconomic factors have been shown for water birds (35) and vertebrates more broadly (15) as well as for deforestation (36). These PA-level results are also corroborated by the overall differences observed between the developed and the developing worlds, indicating that PAs in regions with lower human development scores have not effectively mitigated recent increases in human pressure. Lower human development scores can be linked to poor PA performance in a variety of ways including through increased corruption (37), weak law enforcement (38), and reduced engagement from stakeholders (39). Our results thus suggest that PA management does not begin at the reserve boundary but requires more systemic changes and that without such processes in place, even well-resourced PAs are unlikely to succeed (14).

Disaggregating the THPI, our results show that increases in human population density and night lights have been smaller inside PAs compared to matched areas outside, throughout the world and vegetation types, except the Neotropics, and across the full range of national HDI scores. Both are potentially significant indicators of environmental degradation and so the evidence that PAs are effective at slowing their growth is encouraging. However, for agriculture the picture is less positive, with cropland increasing more inside PAs over the past 15 y than in matched areas outside PAs in most of the world. This is particularly pronounced in the Afrotropics and seminatural grassland, where the area of cropland inside PAs increased at almost double the rate seen in matched unprotected lands. These results align with results showing extensive contraction of savannah, and conversion to agriculture, across Africa over the past 5 decades due to land-use changes (40), and with the findings of global threat assessments, which show that agriculture is the most commonly reported threat to terrestrial species in the International Union for Conservation of Nature (IUCN) Red List (21) and among the most common reported in PAs (41). The reasons why PAs have failed to prevent agricultural encroachment will likely vary spatially in ways that our data cannot disentangle. However, particularly in the tropics, the combination of rapid and continuing population growth and the fact that most of the easily accessible unprotected land suitable for agriculture was already under that use by 1995 (42), when combined with lower national-level human development scores (43) and higher corruption (44), might have contributed to making PAs more vulnerable to recent agricultural conversion.

We were not able to find any association between PA performance and the management dimensions reported in METT data. We do not take this to mean that management is not important. Indeed, previous studies have shown that capacity and resources are correlated with the persistence of biodiversity in PAs (45) and similar results have been found for conservation spending more broadly (33). Likewise, studies have shown the importance of involving local stakeholders (39), effective enforcement (46), as well as having strong governance and management structures in place (11, 30, 47). There are inherent issues with the management data used in this analysis (48) and previous studies have seen variable, often nonconclusive results when correlating management effectiveness scores to conservation outcomes (49). Thus, our results highlight the importance of improving both the quantity and quality of PA management data as well as the effort to collect and collate these from the PAs. The Aichi targets call for PAs to be "effectively and equitably managed" (4) but understanding to what extent this is the case and, importantly, if effectively managed PAs cost-effectively contribute to the protection of biodiversity are currently severely limited by the paucity of appropriate data.

Our results have significant policy implications as they show that PA designation and management do not occur in a vacuum. Effective PAs are essential in ensuring the delivery of positive conservation outcomes. Our results confirm that focusing only on area-based targets is not enough, and even if we are on track to protect 17% of terrestrial Earth by 2020, we will not have achieved the target 11% unless these areas are effectively and equitably protected. Thus, looking beyond 2020 it will be essential to ensure that future targets are not only ambitious but also measurable across all aspects of what makes PAs effective. Associated with this will be a need for target setting to prescribe and support the collection of data to assess and evaluate future targets.

Methods

We used the THPI (24) which measures change in human pressure over 15 y from 1995 at a resolution of ~77 km^2 across the terrestrial world. These data layers are based on combining data on changes in human population density (from the Gridded Population of the World [GPW], version 3) (50), the density of night-visible infrastructure (Intercalibrated Stable Night Lights, version 4) (51), and the percentage of area under cropland (derived from the History Database of the Global Environment [HYDE], version 3.1) (52), giving equal weight to the values of each variable to generate a composite measure of change in human pressure, scaled between THPI = −100 (maximum decrease in pressure) and THPI = 100 (maximum increase in pressure). The spatial resolution of the THPI was defined by the coarsest dataset (i.e., cropland), and human population density and night-visible infrastructure was rescaled to this resolution [see Geldmann et al. (24) for details]. All 3 layers are developed using independently collected data for the different time steps. While other static representations of human pressure (e.g., the 2009 Human Footprint) (21) have included more components of pressure, their temporal version only includes agriculture, human population density, and stable night lights similar to ours.

We used the January 2017 edition of the World Database on Protected Areas (WDPA) for all spatial analysis (53). All PAs established after 1995 and smaller than the resolution of the THPI were removed, resulting in a final sample of 12,315 PAs while maintaining 81.8% of the land area protected in 1995. After removing PAs smaller than the THPI grain size those in our sample had a mean area of 2,405 km^2, (SE = 666 km^2), which is somewhat larger than that for the total PA estate (mean = 1,996 km^2, SE = 443 km^2).

We used data derived by the METT to measure PA-specific management inputs and processes. The METT is a questionnaire-based assessment covering more than 30 management activities, processes, and capacities which generally involve park managers and other stakeholders and has been applied in more than 2,000 PAs across the world (49), making it the most widely used tool for site-specific management assessments. We used only METT assessments conducted between 2003 and 2010 and with at least 25 of the 30 questions completed. For PAs with multiple assessments over time, we used the first (e.g., oldest) assessment. Applying these quality filters and after removing marine sites and assessments from PAs not established in 1995 the final METT dataset consisted of 407 PAs. We grouped METT responses into 4 dimensions following Geldmann et al. (16): 1) design and planning, 2) capacity and resources, 3) monitoring and enforcement systems, and 4) decision-making arrangements (*SI Appendix*, Table S1). Scores for each dimension were standardized between 0 (absent from the PA) and 100 (fully sufficient to achieve PA objectives).

To account for the nonrandom location of PAs within countries (18), we used propensity score matching (PSM) which, despite some criticism, is the most widely used matching approach. We did so only after also testing coarsened exact matching (CEM) and assessing Mahalanobis distance matching (MDM). Comparing the 3 matching methods showed that PSM in our case was far superior to CEM and that MDM would require exclusion of 21% of the data to run (*SI Appendix*). Matching was based on a suite of variables linked both theoretically and empirically to biases in PA location: 1) elevation, 2) slope, 3) access, 4) temperature, 5) precipitation, 6) initial human footprint, 7) country, 8) land cover, 9) soil type, and 10) nutrient levels (18, 54). Matching was done without replacement using "nearest neighbor" for elevation, slope, access, temperature, precipitation, and initial human footprint, and 0.25 SDs of the propensity scores as a cutoff in line with Stuart (55). We used exact matching for country, land cover, soil type, and nutrient

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levels. This meant that protected pixels were only compared to unprotected pixels in the same country and habitat with the closest match for climate, topography, and initial pressure. Following matching, we discarded any treatment pixel where the distance in propensity scores between treatment and control was >0.1 to remove potential outliers. We then estimated the performance of each PA by calculating the mean THPI for all pixels within each PA relative to the mean THPI for all identified matching control pixels, following Carranza et al. (56). This gave us an estimate for individual PAs that accounted for differences in location and socioeconomic context.

We divided the world into 6 realms, following Olson et al. (57): 1) the Afrotropics, 2) Australasia, 3) Indomalaya, 4) the Nearctic, 5) the Neotropics, and 6) the Palearctic. For each of these 6 realms we calculated the average THPI for the sample of PAs, the matched outside and the entire unprotected landscape. The same procedure was repeated for the 3 individual THPI components (i.e., change in human population density, night light intensity, and cropland cover). For the global set of PAs we used a mixed effects model (generalized linear mixed model [GLMM]) to assess the relationship between PA performance (i.e., the difference between the mean change in THPI inside PAs and in the matched outside) with country as random effect and 1) the mean initial human footprint inside each PA, using the nonbiome corrected version, HII (58); 2) mean elevation; 3) GDP for 2005 (43); 4) national-level HDI for 2000 (43); 5) Transparency International's Corruption Index (44); and 6) PA size (53) as fixed effects. These variables were judged to be the best available proxies for factors expected to affect PA performance (*SI Appendix*, Table S2) (19). For the 407 PAs for which we had management data, we used a general linear model (GLM) with the same explanatory variables as well as the 4 management dimensions. Model selection was based on the AIC after assessing all possible combinations of predictors for each model. For the METT subset, inspection of the residuals of the final model revealed some possible deviations from the assumptions. To confirm the robustness of our conclusions, we reestimated the coefficients using a bootstrap method for GLMs. This bootstrapping of the parameter estimates confirmed that the parameter estimates were robust (*SI Appendix*).

The reported results are based on pixels to reduce the potential influence of smaller PAs for which the resolution of THPI might be more problematic. However, the overall results did not change when aggregated by PAs. Previous studies using matching have been constrained to forested PAs which might explain the observed differences between our average results and those of existing studies. To test our results against previous studies of PA performance, we conducted subset analyses corresponding to published matching studies, using the same geographic and habitat restrictions for the Brazilian Amazon (11, 13), Madagascar (12), and Sumatra (20). Our results show that for all tested subsets, patterns using the THPI corroborate findings using deforestation or fires (*SI Appendix*). This indicate that our results are robust within previously studies habitats (i.e., forest), and that the differences observed in average values in our study are likely due to patterns in PAs where no previous matching studies exist.

Data Availability. METT data related to this paper is available upon request and from https://pame.protectedplanet.net/ (49). THPI data are available from Dryad (https://doi.org/10.5061/dryad.p8cz8w9kf) (24).

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