Predicted protected area downsizing impedes conservation progress across terrestrial ecoregions in the tropics and subtropics

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Abstract
Protected areas remain a key tool in the fight against biodiversity loss and have expanded rapidly in recent decades. However, protected areas are also increasingly experiencing downsizing events that reduce the total amount of area legally under protection. Here we explore how future predicted protected area expansion and downsizing (by 2045) will impact the ability for countries to meet representation and area-based protection targets, such as those set by the Convention on Biological Diversity. We found that predicted protected area downsizing will likely decrease habitat representation equality and mean area-based target (30% target) achievement by 50% and >80%, respectively, of the 36 countries analyzed across four scenarios (no protection, business as usual, random and optimal protection). Prioritizing protection of underrepresented ecoregions could offset these unfavorable outcomes, increasing representation equality, on average, by >60% and mean target achievement by >30%. We identify countries that are expected to decrease both representation equality and mean target achievement (~50% of countries across scenarios) with predicted downsizing. These countries need to pay particular attention to strategic protected area expansion and policies that prevent downsizing in parks with under-represented habitats. Finally, we identify cases where downsizing events improve protected area metrics, such as India and Nigeria, highlighting the complexities and potential trade-offs of protected area dynamics. A deeper understanding of the influence of protected area downsizing on conservation outcomes is urgently needed to ensure representative and adequate protected area networks.

KEYWORDS
Aichi Target 11, conservation targets, convention on biological diversity, national park, PADDD, protection equality, systematic conservation planning
1 | INTRODUCTION

Protected areas are a pillar of global conservation efforts and are included at the highest levels of global conservation decision making: the United Nation’s Strategic Plan for Biodiversity Aichi Target 11. Aichi Target 11 commits 196 signatory countries to conserving 17% of their terrestrial area in ecologically representative systems by 2020 (Secretariat of the CBD, 2010), with the next 10-year biodiversity plan expected to increase this goal to 30% (CBD, 2020). Protected areas now cover ~15% of global terrestrial area, and representation within ecoregions has been slowly improving as protected areas expand (Kuempel, Chauvenet, & Possingham, 2016; Maxwell et al., 2020). However, inefficiencies and significant gaps in protecting and representing both habitats and species remain (Chauvenet et al., 2020; Maxwell et al., 2020).

The conservation community has drawn attention to the impermanence of protected areas due to downgrading, downsizing, and degazettlement events (PADDD) (Golden Kroner et al., 2019; Mascia & Pailler, 2011; Symes, Rao, Mascia, & Carrasco, 2016). Since the beginning of the 20th century, >2 million km² have been affected by PADDD, even in some of the oldest and most iconic parks such as Yosemite National Park in the United States (Golden Kroner et al., 2019; Golden Kroner, Krithivasan, & Mascia, 2016; Qin et al., 2019). Protected areas that have experienced higher incidents of habitat degradation or fragmentation, or are larger and closer to population centers, have been shown to be at higher risk of PADDD (Golden Kroner et al., 2019; Keles, Delacote, Pfaff, Qin, & Mascia, 2020; Symes et al., 2016; Tesfaw et al., 2018). PADDD events compromise conservation outcomes through the legal loss of protection or amount of area protected, but how decreases in protected area extent will impact progress towards core conservation objectives such as areal-conservation targets and habitat representation across countries has not yet been quantified. This information is needed to help avoid perverse outcomes of PADDD events and is timely as countries negotiate a post-2020 global biodiversity framework (CBD, 2020) and call to acknowledge the risks that PADDD poses to conservation objectives (IUCN World Congress 2020 motion 099 [IUCN, 2020]).

In general, PADDD is seen as a controversial action, with the potential for negative conservation consequences that could move countries further away from area coverage targets if not done in a systematic, transparent and accountable way (Golden Kroner et al., 2019; Mascia et al., 2014). Similarly, the degree of representation of a habitat or species is dependent on the amount of area protected, and thus is influenced by changes in protected area extent. Changes in representation from protected area expansion have been widely studied, revealing significant biases towards steep and/or infertile lands that are least likely to prevent land conversion or protect threatened species (Barr et al., 2011; Joppa & Pfaff, 2009; Pressy, 1994; Venter et al., 2017). We hypothesize that downsizing will decrease ecoregion representation because downsizing events are more likely to occur in locations more suitable for human use, exactly those environments that are poorly conserved in the first place. Understanding where countries are likely to experience the greatest reductions in representation and area-based target achievement can help guide policies and national protection strategies.

We estimate the impacts of predicted protected area expansion and predicted downsizing events on the evenness of habitat representation using the Protection Equality metric (Barr et al., 2011; Chauvenet, Kuempel, McGowan, Beger, & Possingham, 2017) and the achievement of area-based conservation targets using the Mean Target Achievement metric (Jantke, Kuempel, McGowan, Chauvenet, & Possingham, 2018). We considered four future protection scenarios (worst case (i.e., no additional protection), optimal, random, and business as usual (BAU) protection) and simulated expected downsizing events from 2015 to 2045 to identify priority areas where downsizing may be more likely to impede the achievement of conservation objectives.

2 | METHODS

2.1 | Data

We used the World Database on Protected Areas (WDPA, accessed January 2017) to estimate protected area coverage (UNEP-WCMC & IUCN, 2016) and terrestrial ecoregions developed by the World Wildlife Fund to represent broad-scale global biodiversity features (Olson et al., 2001; World Wildlife Fund, 2008). Country and protected area selection followed Symes et al. (2016). All strictly marine protected areas were removed from the WDPA dataset (MARINE = 2), as well as all protected areas designated internationally (i.e., UNESCO biosphere reserves), all those listed as “proposed,” and all privately managed protected areas (Gov_Type = “Individual land owners” OR “non-profit organizations” OR “for-profit organizations”). Privately owned and internationally designated protected areas were excluded because they are subject to different pressures that are not necessarily linked to the national level conditions included in our downsizing model. Only protected areas that had an establishment date of 2015 or earlier were used in our analysis. Missing
establishment year data was imputed following Butchart et al. (2015) by randomly selecting a year (with replacement) from all protected areas within the same country with a known date of establishment. For countries with fewer than five protected areas with known establishment date, a year was randomly selected from all protected areas with a known date of establishment. The random assignment was repeated 1,000 times, and the mean value was assigned to all protected areas within each country that were missing establishment dates.

We further limited our analysis to countries within tropical and subtropical regions (between 40° North and 40° South) that had at least one documented downsizing event enacted between 1980 and 2010. We limited the study to only the tropics and subtropics firstly because these are the areas where most downsizing occurred. Second, because the countries in these regions are similar in context, being predominantly developing economies and thus more likely to have similar pressure on protected area establishment and PADDD dynamics than more developed temperate regions.

To limit inaccuracies in Protection Equality calculations due to small numbers of habitat features and/or inaccurate protected area boundary data (i.e., point data), only countries that (1) had at least 70% of protected areas with delineated boundary data (i.e., polygon), (2) had more than three ecoregions and (3) protected at least 1% of one ecoregion were considered for further analyses. Circular buffers equal to the reported area were used for protected areas that did not have delineated boundary data (i.e., point data). Total ecoregion area (km²) and total area protected (km²) of each ecoregion within each country were calculated based on reported ISO3 codes in the WDPA dataset in ArcGIS 10.5 using Mollweide equal-area projections.

Data on downsizing events was sourced from PADDDTracker.org Data Release Version 1.0 (Conservation International & World Wildlife Fund, 2019). We limited our study to downsizing events because downgrading does not affect the areal representation of habitat features in protected area networks (i.e., there is no loss in area protected), and degazettement events are rare and therefore impossible to meaningfully analyze and predict. In order to ensure our predictions were on a timescale that is policy relevant and to avoid issues with the original temporal assumptions of the modeling approach in Symes et al. (2016), our model only considered downsizing events that took place between 1980 and 2010.

### 2.2 Simulations

To explore how protection and downsizing events may impact representation goals in the future, we developed models to simulate the amount of area protected and the amount of area lost to downsizing across ecoregions in each country between 2015 and 2045. Full details of the models are below.

#### 2.2.1 Protection simulation scenarios

We considered four protection allocation scenarios: (1) no future protection (worst case scenario), (2) protection aiming for optimal ecoregion representation (i.e., maximizing Protection Equality), (3) random protection, and (4) business as usual (BAU). For all scenarios, we calculated the total amount of area protected from 1985 to 2015 and assumed the same amount of area would be protected from 2015 to 2045 within each country.

For the optimal protection scenario, we took a “greedy” approach, meaning that we were solely aiming to maximize Protection Equality without considering the quality of the land for protection (i.e., conversion). We allocated protected area in 1 km² increments to ecoregions within each country, calculated Protection Equality, and always chose to add protected area to the ecoregion that improved Protection Equality in that country the most. This was repeated until area equal to the amount of protection from 1985 to 2015 had been achieved.

For BAU and random simulations, we considered the availability of land for protection by calculating the expected amount of land that would be converted in each country ecoregion from 2015 to 2045. To do this, we used the annual rate of conversion in each country’s ecoregions between 1993 and 2009 based on the Human Footprint dataset (HFP, [Venter et al., 2016] Text S1). Ecoregions were divided into 1 km² raster grids and each cell was assigned to one of three categories: protected, converted, or available in 1993 and 2009. Cells overlapping protected areas were considered to be “protected,” cells that did not overlap with protected areas, but had an HFP value higher than 3 (on a 0–50 scale) were considered “converted” (Di Marco, Venter, Possingham, & Watson, 2018), while all other cells were considered to be “intact” and “available” for future protection (Chauvenet et al., 2020). We ensured that the sum of the amount of area that was available (intact and not protected), converted and protected in each country ecoregion always equaled the total area of that country ecoregion.

Random protection was simulated by randomly selecting ecoregions (with replacement) within each country and adding area equal to the median protected area size in that country until the area protected between 1985 and 2015 was allocated. If simulated protection...
reached the total amount of available intact land within an ecoregion, that ecoregion was removed from potential selection as the simulation progressed. This process of adding protected area to ecoregions randomly, until the equivalent area protected between 1985 and 2015 was allocated, was repeated 1,000 times.

For BAU simulations, we assumed that the rate of protection within each country ecoregion over the next 30 years would be the same as it had been for the past 30 years. If the amount of area to be protected from 2015 to 2045 was greater than the amount of land available in an ecoregion due to conversion, only the amount of available land was protected. To test the sensitivity of our results to this assumption we redistributed unallocated protected area from ecoregions that were too converted to ecoregions that had available area to protect across three allocation strategies: (1) to the most highly converted ecoregions (% converted), (2) to the least protected ecoregions and (3) randomly across ecoregions with available area to protect (see Text S2).

Protection scenarios were first run without considering downsizing events to explore how representation may change as a result of future protection, and then with downsizing events (described below) to predict the impacts of downsizing on future protection scenarios.

### 2.2.2 Protected area downsizing simulations

We constructed generalized linear mixed effects models (GLMM) with a random intercept for country to determine the probability of a downsizing event occurring within a given protected area as in Symes et al. (2016). We modeled the probability of downsizing in a given protected area as a function of protected area size, accessibility, altitude, local population density, spatially explicit gross domestic product (GDP) and potential agricultural rents (Symes et al. (2016)) (see model regression table in Table S1). The resulting model predicted the probability of a downsize event taking place in a protected area in a given 30-year period. Systematic biases in the PADDDTracker data were deemed to be sufficiently accounted for through the model random effects, as shown by a sensitivity analysis in Symes et al. (2016). We calculated the Area Under the Curve (AUC) and plotted the Receiver Operating Characteristic (ROC) curve for the model to check for over prediction of downsizing events. The AUC is a measure of how well a model can distinguish between prediction classes, with higher values indicating better predictive performance. The ROC curve shows the relationship between true positive and false positive prediction rates of the downsizing model. We also constructed prediction intervals (analogous to confidence intervals) for the predicted probability of downsizing to assess uncertainty. We used the predictInterval function from the merTools package in R (Knowles, Frederick, & Whitworth, 2020) to calculate the prediction intervals. This function estimates prediction intervals by calculating the range of fitted values across the sampling distribution of the fixed and random effects in the model, and thus takes into account all of the variation present in the model except for variation in the covariance parameters.

We used a Monte Carlo simulation approach to determine the chance of a protected area undergoing a downsizing event in a given simulation run, which was dependent on the country-level probability threshold for downsizing and the protected area-level probability of downsizing. We assumed that the probability threshold of a downsizing event in each simulation run at the country level was random, because we wanted to test the response of Protection Equality to the full range of possible downsizing futures. To do this, we randomly generated the probability of downsizing events by sampling from a uniform distribution between 0 and 1 for each simulation. The probability of an individual protected area undergoing downsizing was calculated from the model described above. If the probability of downsizing within a given protected area (generated from the model) was greater than the country-level probability threshold generated as a random number, then the protected area was considered to have undergone a downsizing event. The extent of downsizing events was based on the proportion of protected areas lost in observed downsizing events within each country between 1980 and 2010 for which we had data, and randomly sampled from that distribution. The distribution of downsizing extents in our simulations are, therefore, identical to the actual distribution of downsizes extents observed at the country scale.

In some cases, a single protected area encompasses several different ecoregion types, with some ecoregions potentially having a higher probability of downsizing than others. However, since we do not currently know how downsizing dynamics vary at the ecoregion scale within a single protected area, we took a conservative approach and equally downsized each ecoregion within a protected area predicted to experience a downsizing event. For example, if a protected area underwent a downsizing event that removed 20% of its area and contained three ecoregions, the area of each ecoregion in that protected area was reduced by 20%. It is important to note that ecoregions that did not have any protection as of 2015 had not undergone downsizing events and, therefore, were not predicted to experience downsizing events in the future but may experience future protection in random and optimal scenarios.
2.3  Evaluating conservation objectives

We evaluated how protected area downsizing is likely to impact two conservation objectives: representation of ecoregions and area-based protection targets. We used the Protection Equality metric to evaluate the impact of downsizing and protection simulations on the evenness of ecoregional representation within protected area networks at the country-level (Chauvenet, Kuempel, McGowan, et al., 2017). Protection Equality is a measure of the evenness of protection of conservation features (i.e., representation) within a given protected area network based on the Gini coefficient, with a value of 1 representing perfect equality (i.e., evenness) and a value of 0 representing perfect inequality (i.e., unevenness) of protection. Protection Equality (proportional) is calculated using the equation:

\[
PE_p = \frac{1}{N} \times \left( \frac{1}{2} \sum_{i=1}^{N} \frac{p_i}{a_i} + \sum_{i=1}^{N-1} \frac{p_i}{a_i} \times (N-i) \right),
\]

where \( N \) is the number of conservation features (e.g., ecoregions) in the area of interest (e.g., country), \( a_i \) is the total area of conservation feature \( i \) inside the region of interest, and \( p_i \) is the total amount of area protected of conservation feature \( i \) in the region of interest. Protection Equality was calculated using the ProtectEqual package in R v3.4.4 including a correction factor for small sample size (Chauvenet, Kuempel, McGowan, et al., 2017; Chauvenet, Kuempel, & Possingham, 2017).

We calculated Protection Equality before and after predicted losses in area from downsizing events to evaluate the impacts of downsizing on the equality of representation of ecoregions within each country. Protection Equality before downsizing events was based on the amount of area protected within ecoregions in each protection scenario (worst case, optimal, random and BAU). In the random protection scenario, the average Protection Equality across each of the 1,000 random protection simulations was used at the 2045 timestep. To determine Protection Equality after downsizing, we subtracted the predicted area lost to downsizing from each of the 1,000 downsizing simulations from the predicted amount of area protected in each protection scenario and calculated Protection Equality. We then calculated the mean Protection Equality value for each protection scenario across downsizing simulations. To evaluate relative changes in Protection Equality, we calculated the ratio between Protection Equality after downsizing and Protection Equality before downsizing in each country across protection scenarios (hereafter the Protection Equality ratio). The relationship between the Protection Equality ratio and downsizing was investigated using Pearson’s correlation analyses.

To evaluate how downsizing may affect the ability for countries to meet area-based targets across ecoregions, we used the Mean Target Achievement metric with an area-based target of 30% (Jantke et al., 2018). Mean Target Achievement calculates the degree of conservation target achievement (e.g., 30% of each ecoregion protected) for all biodiversity features of interest within a given country or system. A value of 1 signifies that all biodiversity features (e.g., ecoregions) have met the specified target, whereas a value of 0 indicates that no biodiversity features have met the specified target. The Mean Target Achievement analyses followed the same methodologies as described above for Protection Equality. We then calculated the ratio between Mean Target Achievement after downsizing and before downsizing in each country across scenarios (hereafter Mean Target Achievement ratio).

3  RESULTS

3.1  Simulations

Our selection criteria resulted in the inclusion of 36 countries in the analysis (Table S2). All countries were predicted to experience some level of protected area expansion from 2015 to 2045, and all but two countries were predicted to experience some level of protected area downsizing. The average predicted decrease in area protected from downsizing events ranged from no loss in Ghana and South Africa to 14,308.64 km² in Brazil. Uganda was predicted to lose the most area relative to 2015 protection levels (~11%) followed by Kenya, Mali and Congo, while 26 (72%) countries were predicted to lose <1% (Figure S1). Bhutan was predicted to expand protection across the greatest proportion of area (protected area expansion of ~49%) and Madagascar was expected to protect the least (~2.6%, Figure S2). Twenty-three (64%) countries are expected to have >50% of their area converted by 2045, with some up to >99% (e.g., Guinea and Madagascar, Figure S3).

3.2  Evaluating conservation objectives

3.2.1  Future protection without downsizing

In 2015, Protection Equality (0 = perfect inequality, 1 = perfect equality of representation) ranged from 0.089
in Mali to 0.734 in Gabon (mean = 0.45, SD = 0.16 across countries, Figure 1a, Figure S4). The majority of countries (N = 23, 64%) had relatively high Protection Equality scores (>0.4), and experienced an increase in Protection Equality with an increase in area protected across the optimal (N = 36, 100%), random (N = 29, 80.6%) and BAU (N = 23, 64%) protection scenarios (Figure 2a). However, in some cases, BAU and random protection resulted in reserve networks that decreased the equality of representation compared to if there was no new protection at all. Protection Equality decreased in Botswana, Kenya, Indonesia, Zambia, Congo, Cote d’Ivoire, Cambodia, Tanzania, Venezuela, Rwanda and Ghana under BAU protection (N = 11) and Congo, Indonesia, South Africa, Cote d’Ivoire, Cambodia, Nigeria, and Rwanda with randomly allocated protection (N = 7). Twenty-nine (~81%) countries had lower Protection Equality scores (worse representation) under BAU scenarios than under random protection.

As expected, optimal protection scenarios always produced the greatest Protection Equality values. Guatemala achieved the greatest increase in Protection Equality from 0.19 to 0.88 and Gabon nearly reached perfect Protection Equality of 0.99. On average, countries increased equality of ecoregion protection by ~1.6 times under optimal scenarios compared to the BAU scenario.

Mean Target Achievement (30% conservation target across ecoregions) ranged from 0.10 in Mali to 0.93 in Bhutan in 2015 (mean = 0.48, SD = 0.23 across countries, Figure 1b, Figure S5). The majority of countries (N = 21, 58%) had a Mean Target Achievement value >0.4. Mean Target Achievement increased across all countries in the optimal scenario, with an average increase of 0.24 (min increase = 0.004 in Dominican Republic, max increase = 0.72 in Guatemala, Figure 2b) and the random protection scenario, with an average increase of 0.14. Eight countries, including Guatemala, Bolivia, Brazil, Belize, Tanzania, Cambodia, Namibia and Bhutan achieved the 30% target across all ecoregions under the optimal protection scenario (i.e., Mean Target Achievement equal to 1). Similar results were seen in the BAU protection scenario with 94% of countries increasing Mean Target Achievement (N = 34, average increase = 0.06) and two having no change in Mean Target Achievement from 2015 levels (Turkmenistan and Guinea).

3.2.2 | Future protection with downsizing

Our analyses of uncertainty in our downsizing models had an AUC of 0.91, indicating the model is not over-predicting downsizing events (Figure S6). The estimated probability of downsizing with prediction intervals can be found in Figure S7. When downsizing events were considered, the majority of countries (>52%) decreased Protection Equality across all protection scenarios (Protection Equality ratios < 1, Figure 2c), showing how, overall, downsizing negatively impacts representation. Downsizing combined with random future protection resulted in the most countries decreasing Protection Equality (69%, N = 25), followed by the optimal and no future protection scenarios (58%, N = 21) and BAU protection (53%, N = 19) (Figure 2c). Several countries experienced increases in Protection Equality with predicted downsizing, with varying patterns across scenarios. Rwanda and Mali had the highest increases in Protection Equality across the BAU and worst-case scenarios, while Rwanda and Uganda had the highest increases in Protection Equality in the random scenario and Mali and Vietnam had the highest increases in the optimal scenario. Rwanda and Bhutan had the highest decreases in Protection Equality in the optimal scenario, Congo—Brazzaville and Gabon in the worst-case scenario, Kenya and Congo-Brazzaville in the BAU scenario, and Congo-Brazzaville and Mali in the random scenario. Further evaluation of these patterns across Rwanda and Mali can

FIGURE 1 Map of (a) Protection Equality and (b) Mean Target Achievement (30% protection target) across countries included in our analysis as of 2015 (before protection and downsizing scenarios)
be found in Text S3. Importantly, countries that decreased Protection Equality in optimal scenarios, but not across the other scenarios, the optimal scenarios with downsizing still resulted in higher predicted Protection Equality values. Given predicted downsizing, optimal protection still resulted in a similar average ~1.6-fold increase in Protection Equality compared to BAU protection. Further, in all countries analyzed, BAU protection resulted in worse Protection Equality than random scenarios with or without considering downsizing.

Based on the distribution of the data (Figure S8), Rwanda, Bhutan, Congo, Uganda, Thailand, Kenya, Gabon and Mali were common outliers across all scenarios. There were an additional four outliers for the optimal scenario (Cambodia, Ecuador, Vietnam and Brazil). These outliers were removed from the Protection Equality ratio analyses. For the random scenario, as the proportion of area lost to downsizing increased the Protection Equality ratio significantly decreased ($r = -0.66, p = .0001$, outliers removed, Figure 3a). The worst-case, optimal and BAU scenarios were not significantly correlated ($r = -0.2, p = .36, r = -0.39, p = .06$ and $r = -0.28, p = .17$, respectively). When outlier countries were included, there was no significant relationship between downsizing and the Protection Equality ratio for any scenario (Text S3, Figure S9A). For a more detailed look at factors driving patterns in “outlier” countries see Text S3 and Figure S10.
Protected area downsizing resulted in a decrease in Mean Target Achievement for the majority of countries, across all scenarios: 94% \((N = 34)\) for worst-case, 89% \((N = 32)\) for the BAU, 83% \((N = 30)\) for the optimal, and 86% \((N = 31)\) for the random scenario (Figure 2d). The remaining countries had no change in Mean Target Achievement with downsizing. These countries included Ghana and South Africa for the worst-case scenario, with the addition of Belize and Dominican Republic for the BAU scenario, and the further addition of Tanzania for the random scenario and Namibia and Guatemala for the optimal scenario. The largest decreases were seen in Uganda, Rwanda, Kenya, Congo-Brazzaville and Mali across all scenarios. On average Mean Target Achievement decreased by <0.7% across all scenarios. Optimal protection resulted in an average of ~1.3 times greater

![Figure 3](image_url)

**Figure 3** The relationship between (a) the Protection Equality ratio and the average proportion of area lost from 2015 protection levels and (b) the Mean Target Achievement ratio and the average proportion of area lost from 2015 protection levels in each country across protection scenarios (worst, business as usual (BAU), random, and optimal). Identified outliers were removed from this analysis for both Protection Equality and Mean Target Achievement metrics (Figure S6). For results with outliers, see Figure S7. Values greater than 1.00 (horizontal line) in both plots depict an increase in Protection Equality or Mean Target Achievement after considering protected area downsizing, while a value less than 1.00 indicate a decrease. The trend line represents the relationship between the Protection Equality ratio (a) or Mean Target Achievement (b) and the average proportion of area lost from 2015 protection levels. Statistics describing these relationships are noted above each plot. In panel A, points are labeled by country ISO3 code if the Protection Equality ratio is between 0.9997 and 1.0003, and in panel B if the Mean Target Achievement ratio is less than 0.998
Mean Target Achievement compared to BAU protection, whether downsizing was considered or not. BAU protection resulted in worse Mean Target Achievement values than random in all countries, with or without considering downsizing.

Based on the distribution of the data (Figure S8B), Congo, Mali, Kenya, Uganda, and Rwanda were outliers across all scenarios, with the addition of Vietnam for the optimal scenario. These outliers were removed when evaluating the relationship between Mean Target Achievement and the proportion of area lost to downsizing; however, significant patterns persisted regardless of the inclusion or exclusion of outliers. We found that as the proportion of area lost to downsizing increased, the Mean Target Achievement ratio significantly decreased across all scenarios (BAU: \( r = -0.82, p \leq 0.0001 \), optimal: \( r = -0.56, p = 0.001 \), random: \( r = -0.79, p \leq 0.0001 \), worst-case: \( r = -0.86, p \leq 0.0001 \), outliers removed, Figure 3b).

The majority of countries in the worst-case (58%, \( N = 21 \)) and random scenarios (61%, \( N = 22 \)), and half the countries (\( N = 18 \)) in the optimal and BAU scenarios, decrease both Protection Equality and Mean Target Achievement with predicted downsizing (lower left corner Figure 4). Thirteen of these countries exhibited these decreases across all scenarios (Bhutan, Congo-Kinshasa, Congo-Brazzaville, Ecuador, Egypt, Gabon, Guinea, Indonesia, Cambodia, Mozambique, Turkmenistan, Venezuela, Zambia). A further 12, 14, 13, and 8 countries in the optimal, BAU, worst-case and random scenarios, respectively, increase Protection Equality but decrease Mean Target Achievement (lower right corner, Figure 4). The remaining countries have no change in Mean Target Achievement but either increase Protection Equality (Guatemala), decrease Protection Equality (Belize, Dominican Republic, Namibia, Tanzania) or have no change in Protection Equality (South Africa, Ghana) across scenarios (Figure 4). For results including outliers see Figure S11.

4 | DISCUSSION

We quantified the predicted impacts of future protected area expansion and downsizing events on achieving representation and area-based conservation targets. We found that future protected area downsizing decreased Protection Equality (a measure of conservation representation) in the majority of countries studied across all scenarios, but the relationship between the amount of area downsized and changes in Protection Equality was not statistically significant. Future protection scenarios show promise in achieving area-based targets, even under aspirational goals of 30% of each ecoregion. However, downsizing is likely to negate this progress in many countries that we analyzed.

We did not find clear, statistically significant relationships between the degree of downsizing and changes in equality of habitat representation in the countries we analyzed. However, across all scenarios, >52% of countries suffered reduced Protection Equality with predicted downsizing events. Protected area downsizing will often

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**Figure 4** The relationship between the Mean Target Achievement Ratio and the Protection Equality ratio within countries. Countries that fall in the lower left corner of the plot (Mean Target Achievement ratio < 1 and Protection Equality ratio < 1) are at-risk of decreasing both area-based target achievement and representation with future protected area downsizing. Countries that fall in the lower right corner of the plot (Mean Target Achievement ratio < 1 and Protection Equality ratio > 1) achieve more even representation across ecoregions given downsizing, but reduce progress towards area-based protection targets. Countries with a Mean Target Achievement ratio less than 0.995 are labeled by their country ISO3 code. Downsizing should be strongly avoided and very carefully considered in countries that decrease progress towards conservation goals. Outliers were removed. For results with outliers included see Figure S11.
exacerbate poor representation. The proximate causes of PADDD events have been linked to industrial scale resource extraction and development, infrastructure, local land pressures and claims, higher historical deforestation rates, and larger protected areas that are closer to population centers (de Marques & Peres, 2015; Golden Kroner et al., 2016; Symes et al., 2016; Tesfaw et al., 2018). At the local scale, this suggests that downsizing events occur in places that are already over-exploited or under high human pressure and emphasizes the need to continue to monitor and evaluate how protected area downsizing impacts vulnerable and underrepresented ecoregions in the future.

Given the complex nature of both protected area establishment and downsizing, varying patterns in their impacts within countries is perhaps unsurprising but deserves further exploration. For example, Mali and Congo-Brazzaville were consistent outliers across all scenarios—both lost significant portions of their protected area estate to downsizing. However, they exhibited varying patterns of change in Protection Equality from downsizing events (Text S3, Figure S10) with Congo-Brazzaville experiencing a small decrease and Mali experiencing an increase in Protection Equality. Importantly, predicted downsizing resulted in very little protected area remaining in Mali, begging the question of whether a higher Protection Equality value is necessarily better or worse if very little protection remains. In this case, even though Protection Equality increased, Mean Target Achievement decreased by 3–6% across scenarios, emphasizing the need to consider a suite of metrics when evaluating impacts of downsizing on conservation outcomes (Barr et al., 2011).

Unsurprisingly, Mean Target Achievement decreased for nearly all countries when future protected area downsizing was considered, with a clear negative relationship with the amount of area lost to downsizing. Only a handful of countries experienced no change in Mean Target Achievement because the 30% target was predicted to be adequately met across all ecoregions, even when downsizing was considered (e.g., Belize and Dominican Republic). In two of these countries, Ghana and South Africa, this is explained because there was no downsizing predicted. On the other hand, the majority of countries ($N = 28, 78\%$) did not achieve the 30% target across ecoregions with optimal protection, which is then exacerbated when downsizing is considered. Greater Mean Target Achievement values could likely be obtained by protecting ecoregions closest to the conservation target (Chauvenet et al., 2020), but it is unclear how this would impact Protection Equality. In any case, achieving better outcomes than if protection was allocated randomly, which is currently the case, needs to be a priority in post-2020 conservation targets and investments.

Our results highlight several countries where downsizing could negatively impact both representation and area-based conservation goals. The thirteen countries that experience these reductions across all scenarios (Bhutan, Congo-Kinshasa, Congo-Brazzaville, Ecuador, Egypt, Gabon, Guinea, Indonesia, Cambodia, Mozambique, Turkmenistan, Venezuela, Zambia) are likely more susceptible to perverse impacts of downsizing on these conservation metrics regardless of the protection approach employed. Even countries that did improve the equality of habitat representation with downsizing events but still decreased Mean Target Achievement, need to prioritize avoiding downsizing to meet international conservation targets. There is a need to invest in management and create policies that reinforce legal protections in these areas. Globally, the protected area network is underfunded (Watson, Dudley, Segan, & Hockings, 2014), and expanding coverage to “30% of the planet” will require a significant increase in annual conservation funding (Waldron et al., 2020). Expanding protection without a large increase in investment will increase pressure within protected area networks given potential trade-offs between protected area expansion and management (Adams, Iacona, & Possingham, 2019; Kuempel, Adams, Possingham, & Bode, 2018). Countries should renew their efforts to protect underrepresented ecoregions that are more vulnerable to downsizing, and more likely to impede conservation progress if they wish to achieve area-based conservation and representation objectives.

Importantly, the resulting impacts on biodiversity from downsizing are unclear, but should be approached with caution. For example, Indonesia and Ecuador both decreased Mean Target Achievement and Protection Equality across both scenarios. However, insight from historical PADDD events shows potential differences in outcomes for biodiversity. In Indonesia, recent policy reforms allow for conversion of conserved and protected forests for commercial uses, such as mining and oil palm plantations (Mascia & Pailler, 2011), likely leading to perverse impacts on biodiversity. On the other hand, PADDD events in Ecuador have returned land to local communities, who were not consulted in the original planning process (Mascia & Pailler, 2011), and could have positive conservation outcomes. Further exploring the conservation implications of these dynamics, as well as ensuring area-based targets do not mask achievement of other objectives (Kuempel et al., 2016; Visconti et al., 2019), is urgently needed. This case-by-case nature of conservation implications from PADDD events was recently recognized by an approved motion at the IUCN World Conservation Congress 2020 (motion 099). These areas may still contribute to conservation goals through other effective conservation measures (OECMs) and indigenous and community management (Maxwell et al., 2020). Future work should aim...
to expand the knowledge base around OECMs and their patterns of expansion, downsizing, and subsequent conservation outcomes, given their important role in biodiversity conservation.

Predicting PADDD events is very challenging due to the complex socio-economic interactions that drive decisions about PADDD and the many uncertainties surrounding future protected area expansion and downsizing dynamics. We detail several assumptions that may influence our results in Text S2. Our results should be viewed as an approximation of an unknown future state that will likely be more accurate in some countries and contexts than others given the systematic biases in the PADDD dataset. Further, while broad drivers of PADDD events globally may be generalizable, the ways these drivers manifest in individual protected area sites are likely to be highly variable. For these reasons, we believe our results provide reasonable and useful insights into the impacts of downsizing on protected area systems at a generic level. Results for specific countries should be treated with caution as further fine scale analyses are required to better understand these complex dynamics.

Increasing social and economic pressures call for protected areas that can be resilient and robust to change through time (Cumming et al., 2015; Lee & Jetz, 2008). Understanding the drivers of downsizing events and determining their influence on network level objectives (e.g., representation) is critical for developing sustainable protected area networks that contribute to conservation outcomes in the future. Given the relative success of countries in meeting the 17% coverage target, there is pressure for a similar, increased percentage target (currently 30%) (CBD, 2020) in the post-2020 biodiversity framework. However, our results show that simply extending protected area coverage is unlikely to provide the kind of impacts required to “bend the curve” on biodiversity loss (Mace et al., 2018). Failing to consider the impact of downsizing, and PADDD more generally, can undermine conservation gains, even with optimal reserve selection. It is therefore crucial that any new protected area targets in the post-2020 framework consider ecological representation, area-based target achievement and PADDD in a more strategic and quantitative manner. These measures along with policies that promote protected area resilience and/or require the justification and evaluation of downsizing events on quantitative and qualitative protected area objectives, are needed as downsizing becomes increasingly part of the conservation landscape.

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CONFLICT OF INTEREST
The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS
All authors contributed to the conception of the analyses. William S. Symes completed the downsizing modeling while Caitlin D. Kuempel ran protection scenarios and calculated the conservation metrics. Caitlin D. Kuempel interpreted results and led the drafting of the article. All authors contributed to writing and editing.

DATA AVAILABILITY STATEMENT
All datasets used in the analyses are publicly available as described in the text. For further information on modeling approaches please contact Caitlin D. Kuempel.

ETHICS STATEMENT
No ethics review for animal handling or human subjects was necessary for the analyses reported in the article.

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