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RESEARCH ARTICLE

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The global exposure of species ranges and protected areas to forest management

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Abstract

Aim: Many vertebrate species globally are dependent on forests, most of which require active protection to safeguard global biodiversity. Forests, however, are increasingly either being disturbed, planted or managed in the form of timber or food plantations. Because of a lack of spatial data, forest management has commonly been ignored in previous conservation assessments.

Location: Global.

Methods: We combine a new global map of forest management types created solely from remote sensing imagery with spatially explicit information on the distribution of forest-associated vertebrate species and protected areas globally. Using Bayesian logistic regressions, we explore whether the amount of forested habitat available to a species as well as information on species-specific threats can explain differences in IUCN extinction risk categories.

Results: We show that disturbed and human-managed forests dominate the distributional ranges of most forest-associated species. Species considered as non-threatened had on average larger amounts of non-managed forests within their range. A greater amount of planted forests did not decrease the probability of species being threatened by extinction. Even more worrying, protected areas are increasingly being established in areas dominated by disturbed forests.

Conclusion: Our results imply that species extinction risk and habitat assessments might have been overly optimistic with forest management practices being largely ignored so far. With forest restoration being at the centre of climate and conservation policies in this decade, we caution that policy makers should explicitly consider forest management in global and regional assessments.

KEYWORDS
extinction risk, forest management, forest restoration, forest specialism, plantations, species distribution, threat mapping, vertebrate diversity

1 | INTRODUCTION

Forests cover approximately 27% of the earth's land surface (Buchhorn et al., 2020; Jung et al., 2020). They are the exclusive habitat of 54.5% of terrestrial vertebrate and many other plant, fungi and invertebrate species (Gibson et al., 2011; Hill et al., 2019; IUCN, 2012), and can directly or indirectly benefit humankind through ecosystem services through food or water provision, something particularly relevant for the over 1.6 billion living within close proximity of a forest (Newton et al., 2020). Increases in human population and demand for food, non-timber and timber products, are resulting in forests worldwide being increasingly disturbed, modified or removed by humans (Fritz et al., 2022; Lewis et al., 2015). Changes in forest use and management can affect the structural integrity of forests (Ghazoul et al., 2015; Lewis et al., 2015), ultimately reducing the size and connectivity of forest patches (Haddad et al., 2015) and affecting forest biodiversity (Hill et al., 2019). Yet, while a loss in forest cover can reduce local species richness (Melo et al., 2018) and increase the extinction risk of many species (Santini et al., 2019; Tracewski et al., 2016), it is not fully understood to what extent biodiversity is exposed to forest disturbances and management globally.

Most forests globally are anthropogenically disturbed and managed, which can prove challenging for conservation as linkages with biodiversity can be complex (Lewis et al., 2015; Müller et al., 2019; Thom & Seidl, 2016). Forest disturbances can be caused by both natural causes (Thom & Seidl, 2016), such as wildfires or insect outbreaks, and anthropogenic causes, such as selective logging and edge effects (Dantas de Paula et al., 2016; Matricardi et al., 2020), both of which can drive a forest to a 'degraded' state (Chazdon et al., 2016; Ghazoul et al., 2015). Increasingly disturbed and degraded forests have become the focus of policy attention (Hansen et al., 2020; Newton et al., 2020). In addition to forest disturbances, many forests across the world are anthropogenically managed, for instance by active planting of forests for production of timber and non-timber products (Chazdon et al., 2016). Anthropogenically managed trees and timber plantations cover most of western Europe, Southern China, Japan and America (Jung et al., 2020), and agroforestry has long been recognized as a traditional form of land management, often using many native tree species (Zomer et al., 2016). Yet, the potential global impacts of disturbed and managed forests on biodiversity have so far not been comprehensively investigated.

Owing to the reduction and simplification of structural complexity, disturbed and planted forests often have considerably altered biodiversity (Barlow et al., 2016; Chazdon et al., 2016). Disturbances are commonly identified as a key driver of worsening conditions in protected areas (Laurance et al., 2012). Nevertheless, responses of forest-associated species to disturbances can be highly context-specific and in many managed forests also promote biodiversity (Barlow et al., 2016; Thom & Seidl, 2016), thus biodiversity conservation policies need to address not only intact but also disturbed forests (Grantham et al., 2020; Müller et al., 2019). And while (even exotic) forest plantations can potentially connect or form a tree-covered buffer around natural forest patches (Brockerhoff et al., 2008; Pellikka et al., 2009), there is mounting evidence that especially monoculture plantations, such as pine or oil palm plantations, provide little or only reduced benefits for biodiversity (Farwig et al., 2008; Newbold et al., 2015), although impacts can differ depending on the species and landscape in question and the successional stage of plantation (Betts et al., 2013). Although mixed, traditional management forms such as agroforestry can provide critical habitat (Bhagwat et al., 2008; Hemp, 2006) and maintain a comparable high level of biodiversity (Jung et al., 2017; Norfolk et al., 2017), they also commonly have an altered species composition (Harvey & González Villalobos, 2007). Yet, most current global forest pressure maps (Grantham et al., 2020; Lewis et al., 2015; Malhi et al., 2014) or frameworks for conservation or restoration assessments have ignored managed forests (Grantham et al., 2020; Hansen et al., 2020), or included them only for a limited number of countries (Hill et al., 2019), presumably because of a lack of spatial data.

Remote sensing can assist in reliably identifying forest disturbances and management types. Fine-scale differences in remote sensing observations combined with visual evidence of selective logging or human structures nearby allow the separation of (visually) undisturbed from disturbed forests (Curtis et al., 2018; Dantas de Paula et al., 2016; Fritz et al., 2022). Similarly, trees that were planted in regular spacing, such as timber or fruit plantations can be identified and delineated from high-resolution satellite imagery. Here previous studies have used single or multiple satellite observations to map the world's intact forest landscapes (Potapov et al., 2008), small-scale disturbances caused by selective logging (DeVries et al., 2015) or regional gradients of different management (Pfeifer et al., 2016). Yet, until recently, no global remote-sensing derived maps of forest management types existed, with earlier attempts instead relying on several environmental predictors, little independent training or validation data (Schulze et al., 2019), or only being available at coarse scales (Curtis et al., 2018). Recently a new global map of forest management types has become available (Lesiv et al., 2022), that describes at high-resolution not only undisturbed and disturbed forests, but also several types of forest management identifiable from remote sensing.

In this study, we investigate the exposure of forest-associated biodiversity to different types of forest management globally. Specifically, we combine estimates of the distribution of forest-associated vertebrate species with a novel, remote-sensing derived global map of forest management for the year 2015 (Figure 1, (Lesiv et al., 2022). Under the assumption that disturbed and managed forests cover large tracts of the Earth, we expect that (i) the distributional range of forest-associated species is to a large degree covered by forests that are either disturbed or under some form of forest management, (ii) species threatened by extinction or threats associated with disturbances or forest extraction are disproportionately affected by parts of their range covered by disturbed or managed forests and that (iii) protected areas are increasingly established in forests that cannot be considered undisturbed. Collectively, these expectations would suggest

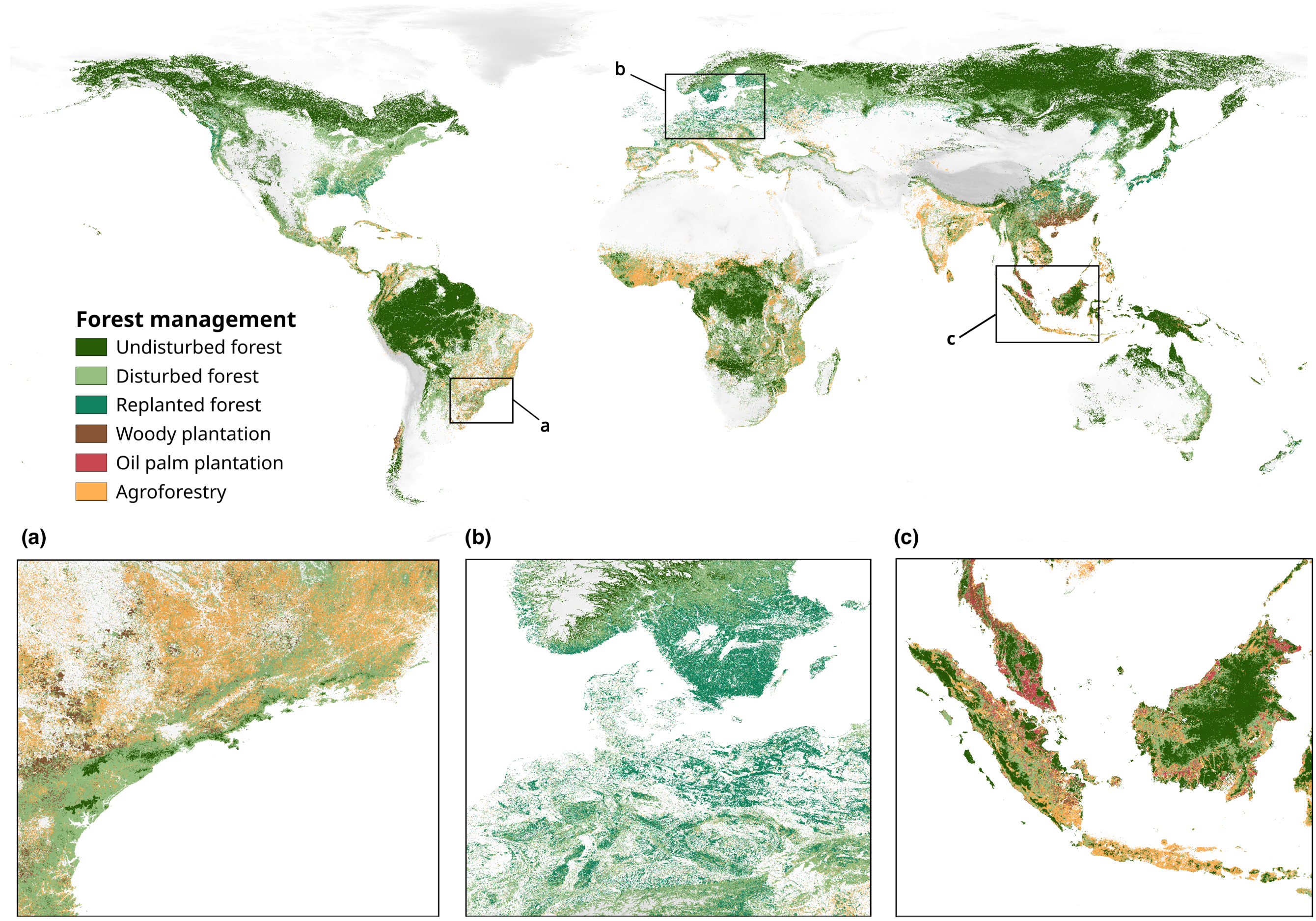

FIGURE 1 Global map of forest management types at ~100 m resolution. Insets highlight the (a) remaining undisturbed forest in the Atlantic Forest region, (b) planted forests in central and northern Europe and (c) undisturbed forest amid palm oil and other fruit plantations in Malaysia and Indonesia. Background shows a half-transparent digital elevation model

that several forest-associated species are confined to marginal intact habitats and addressing the management of these forests is critical to revert global biodiversity declines and improve the ecological state of forests globally.

2 | METHODS

Data on disturbed and planted forests came from a novel global forest management layer produced for the year 2015 at 100-m resolution (Lesiv et al., 2022). The global forest management layer has in total six different classes, namely undisturbed (no visual signs of human impact), disturbed (visual impacts such as selective logging, clear cuts or built-up roads and human structures) and planted forest (with a rotation period longer than 20 years), as well as woody plantations (with a rotation period of up to 15 years) and oil palm plantations, and agroforestry (which includes fruit tree plantations, shelterbelts or isolated trees on tropical pastures). Full definitions of each class can be found in the supplementary information (Table S1). We stress that the identification of managed forests was limited to those forms that are visually identifiable and can be mapped by remote sensing, which in this case was imagery from the PROBA-Vegetation satellite (Buchhorn et al., 2020). The forest management layer was created entirely from remote sensing, combining high-resolution training data, satellite time series and machine learning and shows overall good total accuracy (82%) with independent validation data using a random stratified sampling design. The reference data, layer and validation approach is described in full in Lesiv et al. (2022) with the used classification algorithm and predictors being identical to the Copernicus data pre-processing workflow (Buchhorn et al., 2020).

From the forest management layer, we only considered plantations that had at least 10% tree cover fraction according to the global Copernicus Land cover product (Buchhorn et al., 2020) to follow more closely FAO definitions of forest (FAO, 2020). Opposed to other products of human impact on forests (Grantham et al., 2020), the forest management layer does not depend on any 'scores', stacking of land-use layers or thresholds of 'intactness', but instead identifies forest management and disturbances directly from remote sensing and machine-learning techniques. While this makes the mapped classes in our opinion more transparent, robust and replicable, we acknowledge that many forms of fine-scale forest disturbances and logging events cannot reliably be detected from satellite imagery alone (Peres et al., 2006), which makes any estimates presented conservative.

For data on forest-associated vertebrate species distribution, we used spatial data on the ranges of amphibians (5547), birds (8434), reptiles (4369, although we stress that not all reptiles globally have been assessed yet) and mammals (4032) from the global IUCN Red List (ver 2019-2, [IUCN, 2019]). We filtered the IUCN provided range data using standard criteria, for example, by selecting only those parts of a species' range where (i) it is extant or possibly extinct, (ii) where it is native or reintroduced and (iii) where the species is seasonally resident, breeding, non-breeding, migratory or where the seasonal occurrence is uncertain. We limited our analyses only to those species that are 'forest-associated', which we define as any species for which 'Forest' is listed as known habitat preference according to IUCN. Lastly, we obtained data on the threat status (e.g. CR, EN, VU, NT, LC, DD) of all selected species. We adopted the IUCN definition of 'threatened' species (CR, EN or VU) and considered all other species as 'non-threatened'. Where available we also collated data on IUCN listed threat types, such as '2.2 Wood & Pulp Plantations' or '5.1 Hunting & trapping terrestrial animals', which we broadly grouped into threat groups (See Table S2) and those with medium or high impact on a species.

In addition to data on the potential distribution of forest-associated vertebrate species, we also extracted the amount of total forested area (in ha) for each management type in all protected areas designated in or after 1995 available through the World Database on Protected Areas (IUCN & UNEP-WCMC, 2020) from Google Earth Engine. Only protected areas from 1995 onwards were selected as a compromise between the potential time of establishment of a managed forest and the reference year (2015) of the forest management layer. We only selected established protected areas and furthermore excluded UNESCO-MAB Biosphere Reserves, following WDPA guidelines (Bingham et al., 2019).

We then summarized for each forest-associated species and protected area the amount of forest area (in ha) under each form of forest management. Dominant forest management types were determined per species range. Protected areas which had no forest cover within their boundary were excluded from the analyses. To test whether the available forest area, in interaction with management type, differed among threatened and non-threatened species, we used a logistic regression model fitted in a Bayesian framework using default uninformative priors (Bürkner, 2017). Based on IUCN criteria B2 we thus assumed that species with smaller amounts of forest area are more likely to be threatened. Posteriors were estimated through 8000 iterations and 2000 burn-in samples across four chains. Conditional model estimates were derived by summarizing the posterior in a mean estimate and 95% credible interval. We investigated model convergence by assessing the rhat statistic (all ~1.0) and the Markov chain Monte Carlo (MCMC) chains visually (Figure S2). All data extractions and preprocessing were conducted on Google Earth Engine (Gorelick et al., 2017) and visualized in R (R Core Team, 2019; Wickham, 2016).

3 | RESULTS

About 55% of the world's forests were disturbed or under some form of management up until 2015. We found that 12,293 forest-associated vertebrate species (or 55.5% of all considered species) had disturbed or human-managed forests as the most common type of forest within their range (Figure 2, Table S3), and among reptiles, twice as many forest-associated species had most of their range now occupied by disturbed or planted forests (Figure 2). Forests within the ranges of 1122 forest-associated species were predominantly of woody and oil-palm plantation and agroforestry type (Figure S1, Table S1).

The amount of forest under different management types covering the distribution of forest-associated species differs depending on whether the species are threatened by extinction. While forest-associated species were more likely to be threatened if the amount of forest within their range was low (Figure S2), this relationship was strongest only for species with a greater amount of undisturbed, disturbed and agroforestry forested areas in their range (Figure 3a). In contrast, species whose range was more covered by planted forest, woody and oil palm plantations were less likely to be categorized as threatened (Figure 3a). Species classified as non-threatened had overall larger amounts of undisturbed and disturbed forest within their range as well as a greater proportion of planted small forest fragments present than for comparable threatened species (Figures 3b and S3). The amount of forest area under different management types for data-deficient species mirrored that of threatened species (Figure 3b).

Furthermore, we found that, for species with available threat information, disturbed forests were the most common forest management type (Figure S4). Agroforestry tended to be more often the dominant type of forest management within the range of species threatened by wood harvesting, persecution and subsistence farming (Figure S4). Interestingly, many species which—according to IUCN—are strongly impacted by wood harvesting, did not have significantly more woody or fruit plantations in their ranges than the other forest management types.

Forests in terrestrial protected areas were under differing management types. Globally, protected areas contained 301 million ha of undisturbed forest (11.7% of all undisturbed forest), 121 million ha disturbed forest (5.6% of all disturbed forest) as well as 36.1 million ha of planted or managed forest (3.57% of all managed forest). Yet, irrespective of any IUCN assigned category of protection, the dominant forest management type within protected areas was disturbed forest, followed by planted and then undisturbed forests (Figure 4a). Interestingly, the majority of new protected areas designated between the years 2000 and 2010 are dominated by disturbed and planted forest in the year 2015 (Figure 4b), while few protected areas predominantly contain undisturbed forest. Few protected areas were established over predominantly woody or fruit plantations, indicating that protection measures are mainly aimed at conserving forest that is not under intensive use by humans.

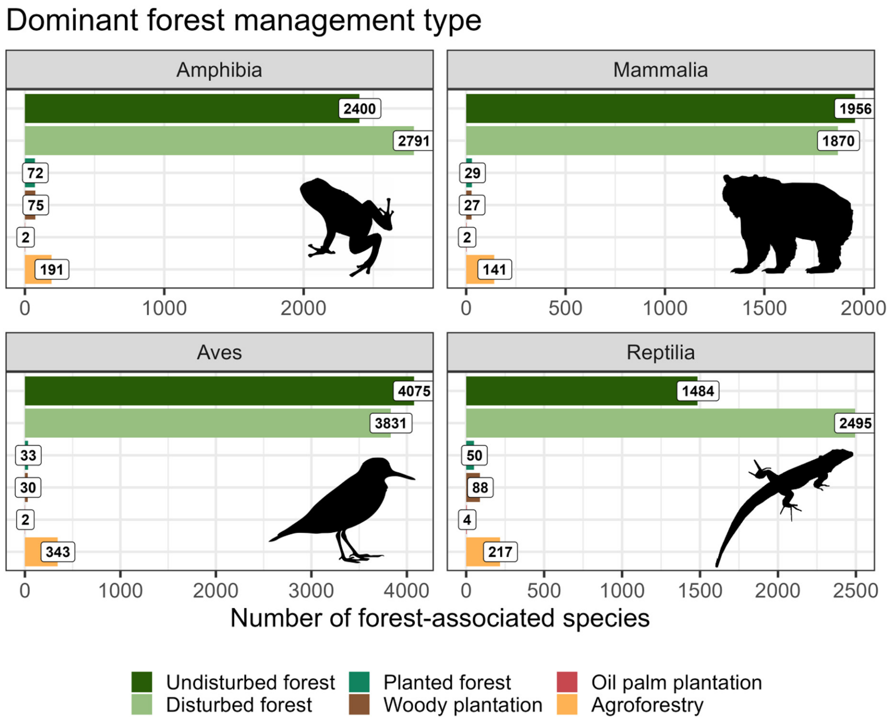

FIGURE 2 Dominant forest management type across all forested areas within each vertebrate species range. Numbered labels and x-axis show the total number of species. Colours and legend as in Figure 1. Icons are public domain from phylopic.org

4 | DISCUSSION

Humans have altered the majority of forests across the world, with 55% of forests being either disturbed or managed by humans. Our results show that over half of the ranges of forest-associated vertebrate species across the world are covered by either disturbed or human-managed forests (Figure 2), with the amount being particularly high for species threatened by extinction according to IUCN (Figure 3). Furthermore, we show that many designated protected areas are already dominated by disturbed and planted forests (Figure 4), highlighting both the value of past forest restoration measures as well as the need to step up protection of remaining undisturbed forests.

Replanting forest is considered to be one of many key primary targets for restoring forested landscapes. Interestingly, our results indicate that increasing or decreasing the amount of planted forest within forest-associated species ranges has little influence on whether the species is currently classified as threatened by extinction (Figure 3). This could indicate that most previous forest restoration efforts have either not yet explicitly benefitted forest-associated vertebrate species, or the presence of lag effects due to outdated IUCN assessments or past land-use change affect the conservation status (Chazdon et al., 2009; Jung et al., 2019; Veldman et al., 2019). For example, areas previously covered by native tree species in Kenya have been increasingly reforested using exotic pine trees, often with little benefit for native species (Farwig et al., 2008; Pellikka et al., 2009). Human planted forests are not necessarily bad for biodiversity (Carnus et al., 2006), they are in fact essential if we are to subject large tracts of previously forested land to habitat restoration (Chazdon, 2008; Chazdon et al., 2009) and climate mitigation efforts. Yet those planted forests need to be established in places where they do not displace natural habitats, such as forests or savannas (Veldman et al., 2019), or native tree species, and do not negatively impact the livelihood of local communities particularly in developing countries (Malkamäki et al., 2018). Thus, further afforestation and reforestation efforts should be carefully evaluated with regards to local contexts and their potential benefits for biodiversity conservation.

Our results also have important implications for conservation applications that use species habitat preferences and land-cover maps to refine species ranges to Area of Habitat (AOH) maps (Brooks et al., 2019). Because, most existing AOH use exclusively land cover products (Ficetola et al., 2015; Rondinini et al., 2011), thus ignoring forest management, it follows that AOH might be grossly overestimated if populations of forest-associated species are not able to persist in disturbed or managed forests. If the amount of unmanaged, disturbed and managed forests in a species range is any indication of the risk of being threatened (Figure 3b), this suggests that forest-associated and data-deficient vertebrate species are, on average, more likely to be at high risk of extinction than not. Novel hybrid maps have been developed that alleviate some of these issues by accounting for both land cover and land use (Jung et al., 2020); however, these maps do not thematically consider all possible forms of management that might be relevant for ecological or conservation studies.

Indeed, we stress that our work only quantifies the exposure of species within their range to different types of forest management, and cannot be used to infer species impacts or sensitivity towards forest management. Previous work has shown that the impact of different types of forest management on species populations can depend on management intensity, species traits and landscape factors (Betts

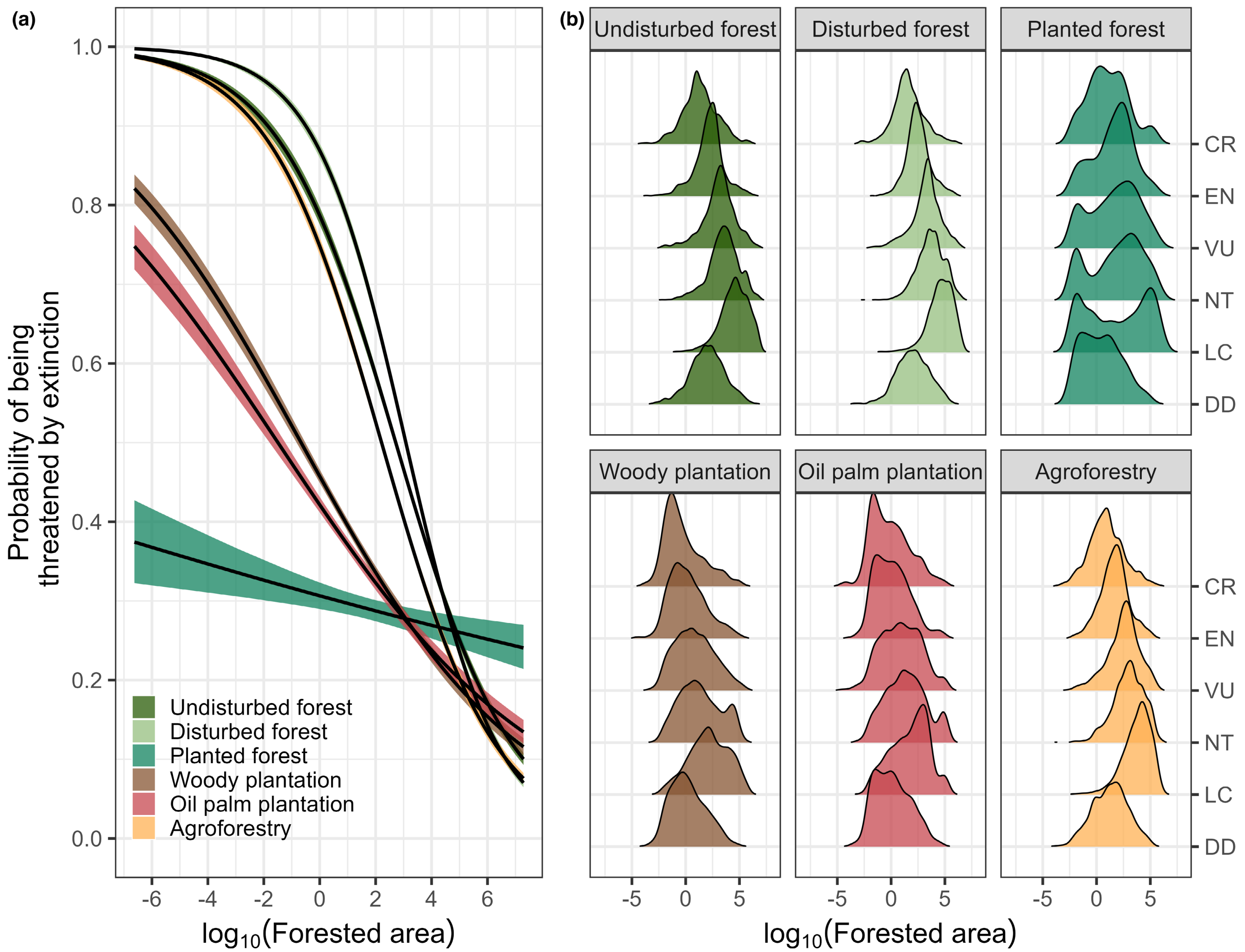

FIGURE 3 Marginal effect of an increase in forest area (log-transformed) on extinction risk probability, that is the probability that a species is classified as threatened according to IUCN. (a) Differences in forest management affect the benefit of increasing potentially suitable forested area. Lines are mean estimates sampled from the model posterior with uncertainty bands showing the 95% credible interval. Figure S2a contains the model results where forest management is ignored. (b) Species classified as non-threatened have on average larger amounts of non-managed forests. Distribution of log10-transformed forested area estimates across species with different threat statuses according to IUCN. Colours as in Figure 1

et al., 2013; Chazdon et al., 2016; Kroll et al., 2017). Although some types of forest management (e.g. oil palm plantations) have resulted in increased extinction risk for many species (Meijaard et al., 2020), we emphasize that on-the-ground work and population assessments are usually necessary to identify whether species populations are able to persist in managed forests. Given the scarcity and declining extent of undisturbed and primary forests (Sabatini et al., 2020), our finding that protected area expansion predominantly covers disturbed or managed forests, is hardly surprising. We suggest that more evidence is needed on the persistence of forest-associated species in disturbed and managed forests to ensure that maps of habitat-based refinements are fit for purpose and protected areas are effective.

While the global forest management map used here is the most detailed spatially explicit quantification to date, we acknowledge that not all forms of anthropogenic disturbances can be detected from remote sensing (Peres et al., 2006), thus our estimates will likely be an underestimate. This is exemplified by the fact that although many forest-associated species are known to be sensitive to anthropogenic threats (Maxwell et al., 2016), we found few differences between species threatened by disturbances or wood harvesting (Figure S4). We also cannot rule out that some types of forests have been misclassified, which can impact our analyses (Estes et al., 2018; Sexton et al., 2016). Furthermore, we also highlight that our analysis does not take into account species occurrence and relative abundance across forest management types (we performed only range overlaps) and many—particularly disturbance sensitive—species do not necessarily inhabit all forests everywhere (Pfeifer et al., 2017). More work is needed on the impact of disturbances and wood harvesting on species local occurrence, population density and persistence and their sensitivity to management practices (such as the tree planting density, thinning rate, age of plantations), as well as more detailed mapping of forest management types at national and regional scales.

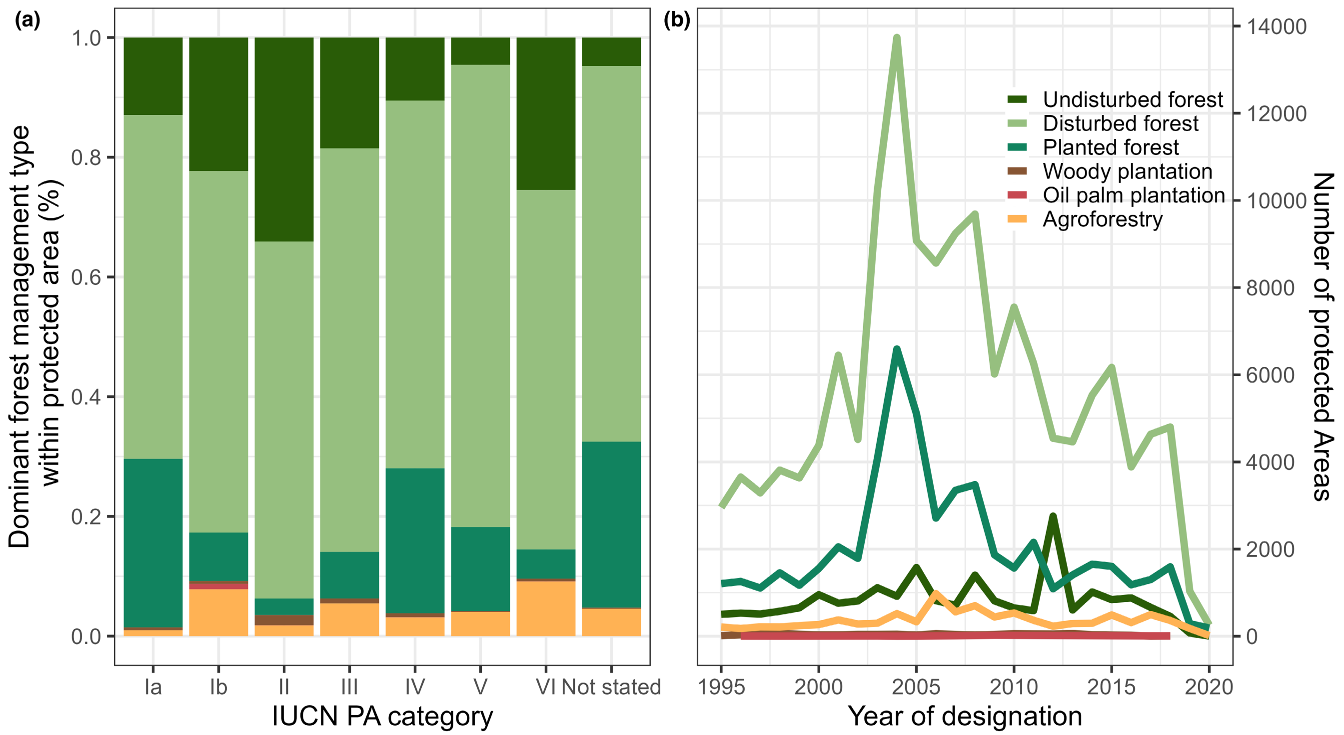

FIGURE 4 Dominant forest management type across (a) protected areas with different IUCN categorization and (b) number of newly designated protected areas in the last 25 years grouped by dominant forest management type. Colours as in Figure 1

As we move into a decade of ecosystem restoration, we urge conservationists and policy makers to consider the type of forest management. Critically, ignoring forest management and focussing on forest cover alone, can give the misleading impression of stable habitats when in fact native, undisturbed forests are being replaced by woody plantations or getting disturbed (Tropek et al., 2014). The increasing emergence of remotely sensed differentiations of forest management types allows the specific consideration of this habitat in global and regional species extinction risk assessments and protected area placements. With an increasing proportion of the Earth's forests being disturbed or managed, we need to better account for and investigate the impact of forest management on the persistence of species populations and the effectiveness of conservation efforts.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The raw global forest management layer has been made openly available as part of Lesiv et al. (2022). Data on the distribution of vertebrate species and protected areas can be requested from the respective data providers, namely IUCN and Birdlife International. Data on threats status and existing threats are available from the IUCN Red List. Extracted data for each species are made available in SI Table 3 and the code repository.

CODE AVAILABILITY

Code used for the analysis and extracted intermediate data has been made openly available (https://doi.org/10.6084/m9.figshare.13968071.v1).

IMPACT STATEMENT

Global conservation and restoration assessments need to recognize forest management as an important factor for biodiversity.

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BIOSKETCH

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SUPPORTING INFORMATION

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