

Protected area personnel and ranger numbers are insufficient to deliver global expectations

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The 2020 global spatial targets for protected areas set by the Convention on Biological Diversity have almost been achieved, but management effectiveness remains deficient. Personnel shortages are widely cited as major contributing factors but have not previously been quantified. Using data from 176 countries and territories, we estimate a current maximum of 555,000 terrestrial protected area personnel worldwide (one per 37 km²), including 286,000 rangers (one per 72 km²), far short of published guidance on required densities. Expansion by 2030 to 30% coverage of protected areas and other effective area-based conservation measures is widely agreed as a minimum for safeguarding biodiversity and ecosystem services. We project that effective management of this expanded system will require approximately 3 million personnel (one per 13 km²), including more than 1.5 million rangers or equivalents (one per 26 km²). Parallel improvements in resourcing, working conditions and capacity are required for effective, equitable and sustainable management.

Area-based protection is a cornerstone of global efforts to conserve biodiversity¹ and associated ecosystem services², maintain human health and welfare³ and support unique human cultures⁴. The Convention on Biological Diversity's global spatial targets of 17% (terrestrial) and 10% (marine) coverage of protected areas and areas managed under other effective conservation measures (OECMs) by

2020 ('Aichi target 11')⁵ have been almost met⁶. There has been far less success, however, in achieving the parallel target to manage these areas effectively⁷, with insufficient numbers and capacity of personnel widely recognized as major limiting factors^{8–12}. Recent studies have also highlighted the specific problem of inadequate numbers and poor working conditions among rangers^{13,14}. Global policy is

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now converging around a new target of at least 30% global coverage of effectively managed protected areas and OECMs by 2030^{15,16} (commonly abbreviated to ‘30 by 30’) as a minimum requirement for sustaining biodiversity and essential ecosystem services^{17,18}, for attaining relevant sustainable development goals (SDGs)¹⁹ and for mitigating the impact of climate change²⁰. Without both addressing the current personnel shortages and identifying and meeting the workforce needs associated with the 30-by-30 target, however, effective management of this expanded global protected area system is unlikely to be achieved.

Workforce planning is an approach used in many sectors to guide recruitment, identify skills gaps and capacity needs, calculate investment requirements and improve efficiency²¹. Fundamental stages in workforce planning include analysing the current and required workforces, determining future workforce needs and identifying workforce gaps against those needs²². Within the protected areas sector, however, no review of the global workforce has been published since 1999²³. Furthermore, there have been no global surveys of ranger numbers and few reviews of what constitutes adequate personnel numbers and densities, or of the relationships between personnel numbers and enabling factors associated with their performance, such as training, equipment, and institutional and societal support.

We conceived this study to provide a basis for systematic workforce planning and resourcing that will enable effective management of both the current protected area system and the expanded 30-by-30 system, with the specific aims of (1) determining the current total global numbers and density of protected area personnel and of rangers within entities responsible for managing terrestrial protected areas listed in the United Nations Environment Programme World Conservation Monitoring Centre’s World Database on Protected Areas (WDPA; <https://www.protectedplanet.net/>), (2) quantifying any current shortfalls in protected area personnel numbers and (3) estimating the minimum numbers of personnel and of rangers required for effective management of the 30-by-30 target. For this study, we defined protected area personnel as those spending at least 50% of their work time on protected area-related tasks (based in protected areas or administrative centres). We identified rangers as a subset of protected area personnel using the definition of the International Ranger Federation: ‘(those) involved in the practical protection and preservation of all aspects of wild areas, historical and cultural sites. Rangers provide recreational opportunities and interpretation of sites while providing links between local communities, protected areas and area administration’ (<https://www.internationalrangers.org/>).

We conducted the survey between 2017 and 2021, collating data in varying formats from diverse sources, including questionnaires, published surveys and reports, websites and information provided on request by individuals linked to organizations responsible for protected areas. We did not include data from Antarctica or areas identified in the WDPA as ‘predominantly or entirely marine’ or as ‘polar’ because such remote, large and sparsely inhabited areas are likely to have quite different staffing needs and management models (see Methods for further details).

We encountered considerable challenges in obtaining complete and/or accurate data for many countries for six main reasons: the information was considered sensitive, the data had not been collated or were dispersed among multiple agencies, there were difficulties in differentiating non-protected area and protected area personnel, there were differing definitions of rangers, there were overlaps in staff duties between WDPA-listed and other areas, and there were inconsistencies in the reported number and sizes of protected areas. We made every effort to validate and strengthen our dataset by cross-checking multiple sources, including consulting personal contacts in almost every country (Methods).

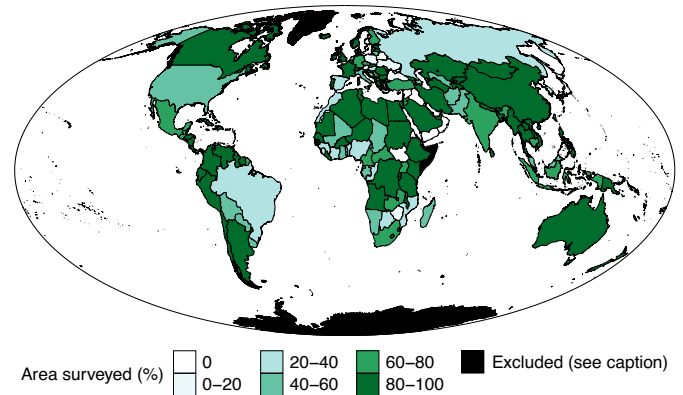


Fig. 1 | Geographical distribution of terrestrial protected areas surveyed. Percentages refer to the relative area of protected areas surveyed within a country/territory. Black areas correspond to countries/territories excluded from the study (Antarctica and countries/territories classified as polar) or with no terrestrial protected areas listed in the WDPA.

Results

Scope of information gathered

From the information collected, we collated the following set of raw data for each country/territory: number of non-ranger personnel (if reported), number of rangers (if reported), total number of on-site and off-site personnel (rangers and non-rangers), total terrestrial area of protected areas managed by the documented personnel (km²), total terrestrial area of protected areas in the country/territory (km²) and year of the data (Supplementary Table 1). The data obtained relate mainly to national and subnational systems of protected areas overseen by central agencies. We could not for practical reasons obtain data for many of the protected areas overseen by local governments, NGOs, private owners, other resource management agencies or Indigenous groups and local communities, except where personnel numbers were centrally collected (for example, in Australia and Kenya). We obtained limited data from Pacific island states where the predominantly traditional systems of protected area governance and management do not readily align with models of staffing used elsewhere in the world²⁴.

Despite these limitations, we obtained data on personnel for 13,244,092 km² of terrestrial WDPA-listed protected areas in 176 countries and territories (Supplementary Table 2), totalling 64.4% of the world’s protected land (Fig. 1). Our statistical modelling accounts for all terrestrial protected areas from which we did not obtain data (Methods).

Estimates of current personnel numbers and densities

To provide a global estimate of the number and density of rangers and other protected area personnel, we (1) imputed the information for unsurveyed protected areas on the basis of information from surveyed protected areas within the same countries/territories and (2) for countries/territories where no information was available on overall personnel numbers and/or ranger numbers, predicted those numbers on the basis of relationships we could establish between available information and candidate predictors in other countries/territories (see Methods for details).

Our resulting estimates for maximum current global and continental totals and mean densities of rangers and of total protected area personnel are shown in Table 1 and Fig. 2 (with further details presented in Extended Data Fig. 1 and Supplementary Tables 1 and 3–5). Both the total numbers of personnel and, as a subset, total numbers of rangers were correlated with the total area of protected areas within a country/territory (Fig. 3), as well as with variables correlated with this metric (Supplementary Table 10). The relationship is allometric,

Table 1 | Estimated current total numbers and mean densities of all terrestrial protected area personnel and of rangers

Continent	Area of terrestrial protected areas (km ²)	All personnel		Rangers	
		Estimated total number	Mean density (area in km ² of WDPA-listed terrestrial protected area per person)	Estimated total number	Mean density (area in km ² of WDPA-listed terrestrial protected area per ranger)
World	20,561,754	555,436	37.0	285,794	71.9
Africa	4,446,610	74,610	59.6	58,832	75.6
Asia	3,699,580	209,979	17.6	119,510	31.0
Europe	3,328,380	122,385	27.2	44,744	74.4
Latin America and Caribbean	4,972,892	37,787	131.6	21,997	226.1
Northern America	2,421,268	98,961	24.5	33,779	71.7
Oceania	1,693,024	11,713	144.5	6,931	244.3

See Supplementary Tables 3–5 for 95% prediction intervals and for estimates under different prediction methods and alternative assumptions for the staffing of unsurveyed protected areas in surveyed countries and territories. Estimates are based on observations, assumptions of staffing of unsurveyed protected areas in surveyed countries and territories, and predictions of numbers in unsurveyed countries and territories. Minor discrepancies may be apparent between aggregated tallies and their constituents due to the rounding of predicted and imputed values into integers. See Methods for details.

with a coefficient that is positive but less than 1. This indicates that in countries and territories with larger total areas under protection, the workforce tends to be bigger, but each individual has on average more land to manage than in countries/territories with smaller protected area systems. The estimated numbers for each continent in Table 1 obscure wide variations in national numbers and densities within continents, as shown in Figs. 2 and 3.

Estimates of current and future personnel requirements

We estimated overall current personnel requirements on the basis that the minimum budget needed to adequately manage the existing protected area system has been estimated as US\$67.6 billion per year, but current annual expenditure is only US\$24.3 billion²⁵. From these figures, we can calculate that resources invested in the current global system of protected areas are approximately 36% of what is required (Methods). Given that public-sector employee compensation globally has remained broadly constant as a proportion of overall public expenditure (<https://ourworldindata.org/government-spending>), we can assume that current protected area personnel numbers are deficient in a similar proportion. On this basis, personnel numbers will need to increase by at least 2.8-fold (1/0.36) to achieve effective management, which would produce a mean required density of one staff member per 13.3 km² and one ranger per 25.9 km².

This estimate is close to most published recommendations for protected area personnel densities (Supplementary Table 6) and indicates that most national protected area systems are severely understaffed (see lines marked ‘average requirement’ in Fig. 2a,b). Using these densities, we can calculate the number of rangers and other personnel required if the global coverage of terrestrial protected areas is increased from 15.7% in our study to the new target of 30% (see Figs. 4 and 5). We therefore project a global requirement for approximately 3 million personnel, including more than 1.5 million rangers, to manage an increase of coverage to 30%.

Discussion

We present here a comprehensive global survey of protected area personnel numbers, the first since 1999²³ and the first specifically to include rangers. Our estimate of the maximum current global protected area personnel density (one per 37 km²) is the same as that reported in 1999⁷, suggesting that overall staffing levels have increased in step with protected area expansion but have not improved per unit area. Our estimated global ranger density of one per 72 km² is far below the coverage recommended at the 2016 International Union for Conservation of Nature (IUCN) World Conservation Congress²⁶ of one

ranger per 5 km² (see line marked ‘Recommended by IUCN’ in Fig. 2b). Other recommended numbers and densities of rangers generally fall between 5 and 50 km² per ranger (Supplementary Table 6). Globally and in all continents, only a small proportion of the total terrestrial area currently under protection is managed at the recommended average density (Fig. 2). In many countries, these low personnel numbers are probably a major contributing factor to documented current deficiencies in management effectiveness and if not addressed will compromise management of the planned 30% coverage of protected areas and OECMs.

We must stress here and throughout this discussion that our definitions of rangers and other protected area personnel encompass a wide range of roles in management, monitoring, protection, resource stewardship, community relations and visitor management, beyond the mainly regulatory functions often associated with protected area management and, in particular, the work of rangers. Our findings show that the expansion, effective management and equitable governance of the global system of protected areas and OECMs requires major increases in numbers of personnel, but achieving the global target of 30% coverage by 2030 (30 by 30) is also likely to require further diversification of those considered as protected area personnel and the ongoing evolution of their functions.

Economic and sectoral considerations

The global shortfall in funding for protected areas (36% of what is required) used for the preceding calculations is close to the funding shortfall (34.4%) from the 1999 global review²³, again suggesting that investment in the past 20 years has merely kept pace with area expansion and has not improved per unit area. These global figures may mask even more serious shortfalls in tropical regions: a review of 2,167 protected areas (biased towards the Neotropics and Afrotropics) found that only 22.4% of protected areas reported having adequate resources in terms of both staffing and budgets⁸, while available funding for protected areas with lions in Africa meets on average only 10–20% of requirements²⁷.

For effective management of 30 by 30, we estimate a requirement for 2.98 million on- and off-site personnel (an increase of 2.43 million from 2021), including 1.53 million rangers (an increase of 1.25 million from 2021). This figure is very low compared with the numbers of persons employed in forests and agricultural land, which cover similar proportions of the global land area (forests: 31%²⁸; agricultural land: 38%²⁹). In 2021, the agricultural and forestry sectors employed over 350 million waged workers³⁰, with a gross value of production of around US\$10,600 a year per agricultural worker³¹ and US\$52,000 per forestry worker³².

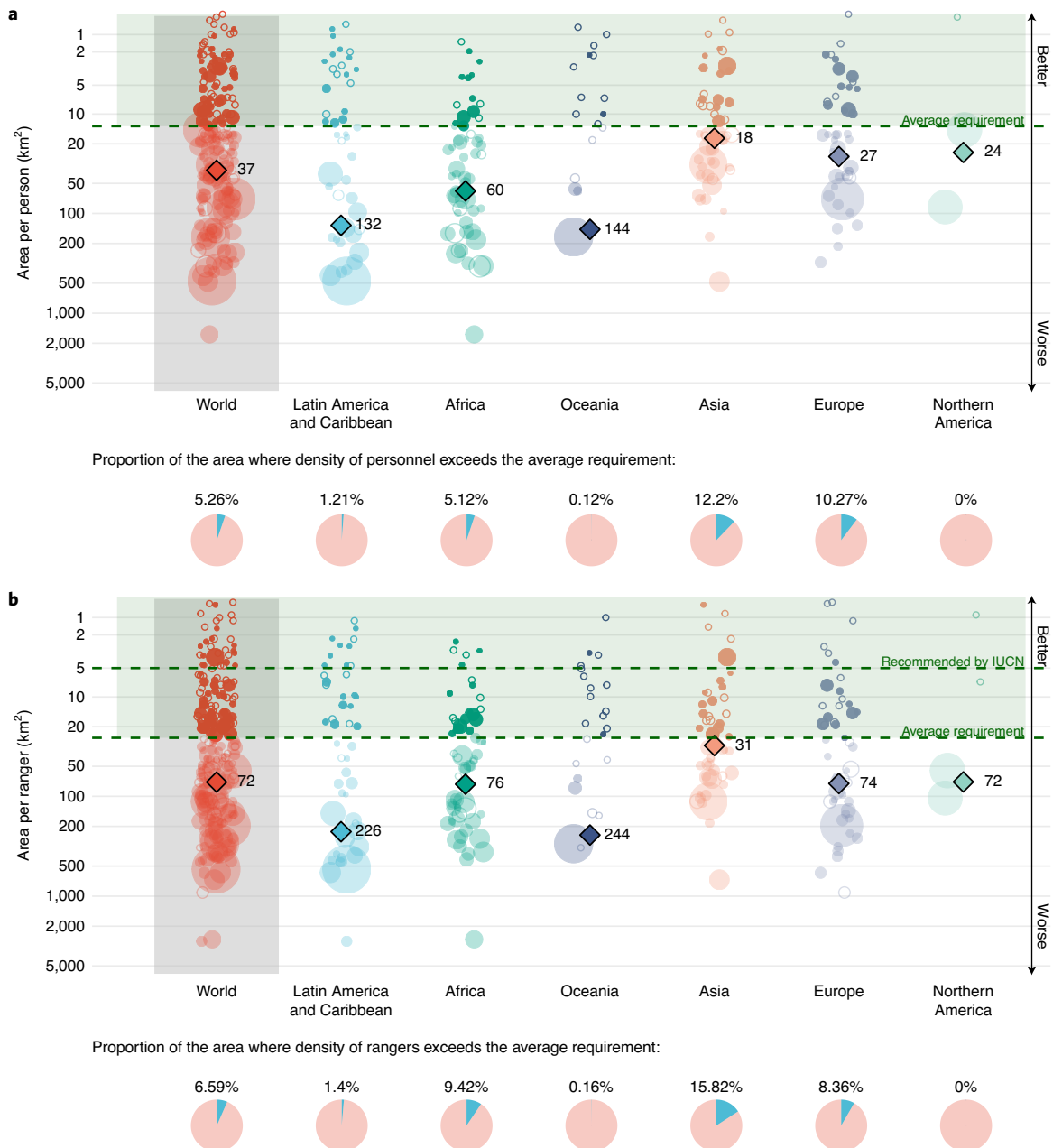


Fig. 2 | Densities of all terrestrial protected area personnel and of rangers only. a, Density of all protected area personnel. **b,** Density of rangers. Filled bubbles depict values for surveyed countries/territories assuming the same density of staff in surveyed and unsurveyed protected areas. Open bubbles depict predictions from linear mixed models for unsurveyed countries/territories. The horizontal dashed green lines represent the recommended

density, assuming current density represents only 36% of what is required (Discussion) and the IUCN-recommended density of 5 km² per ranger. Numbers indicate the current mean density of personnel members for the world and for each continent. Pie charts represent the relative area of protected areas where the density is above (blue) or below (light red) the global mean requirement.

Recent estimates suggest that enlarging the global coverage of protected areas and OECMs to 30% could generate an extra US\$64–454 billion a year in global output by 2050²⁵. Our estimates of personnel requirements, therefore, indicate that each additional personnel member could leverage average annual benefits of at least between US\$28,800 and US\$204,400 (Methods). These should be considered minimum figures as the global output values reflect only selected sectors, refer just to direct outputs and financial revenues and account neither for non-market values nor for wider multiplier effects across the economy. By contrast, the bulk of protected area economic and social benefits do not arise from extractive uses, cash income and

formal markets, but rather come from ecosystem services such as watershed protection, disaster risk reduction, climate adaptation and mitigation, and nature’s contributions to people’s livelihoods, well-being, cultural values, social processes and other non-material aspects. When considered in these terms, the economic contribution of protected area personnel to global, national and local economies is undoubtedly much higher than the preceding figures suggest. Funding numbers of protected area personnel at levels closer to those employed in agriculture and forestry would probably require a wider recognition and prioritization of the broader benefits and values they generate to society and the economy.

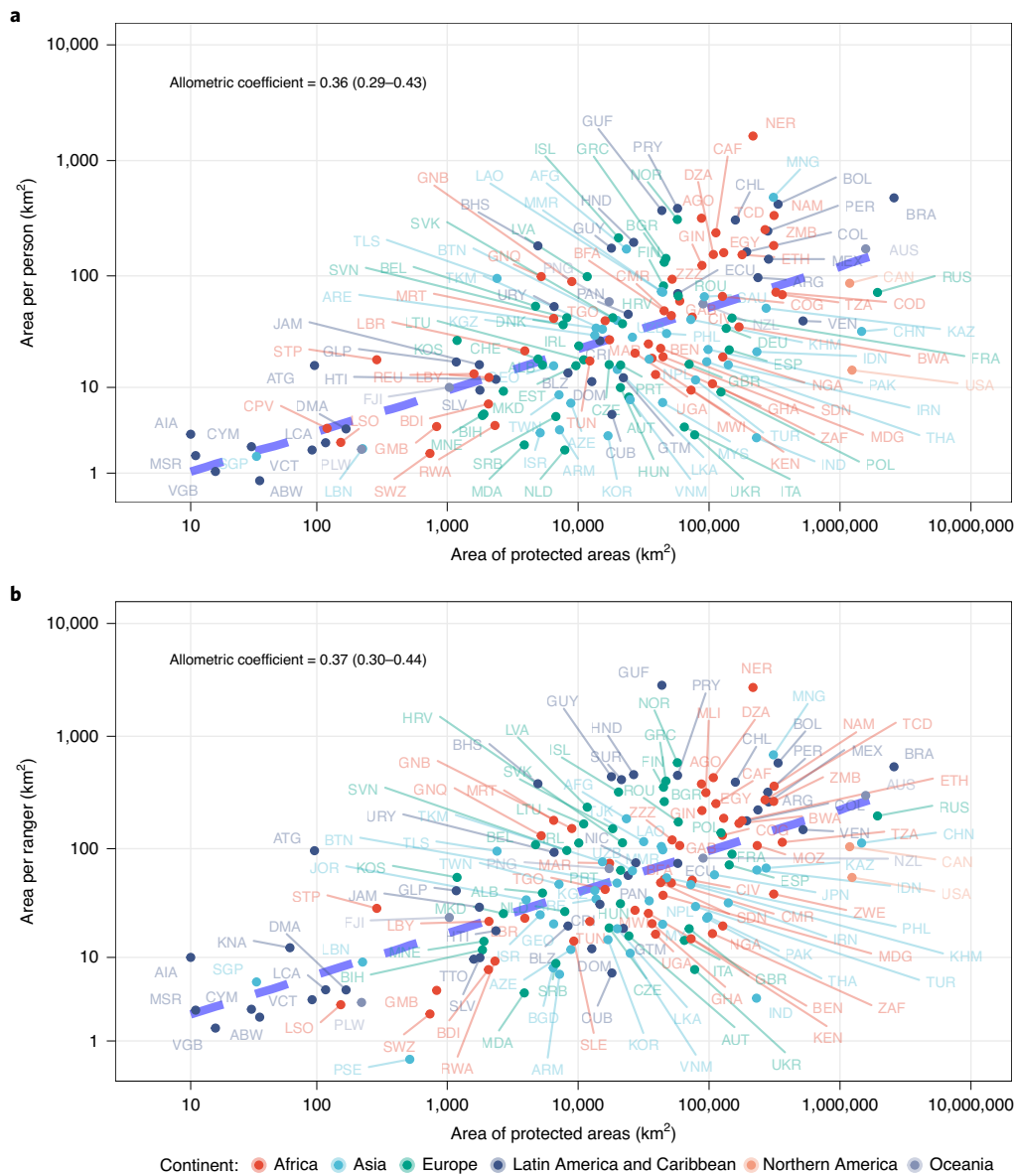


Fig. 3 | Relationship between the total area of terrestrial protected areas in a country/territory and personnel densities. a,b, Personnel densities are shown as the mean area of protected area (km²) covered by each member of protected area staff (a) and each ranger (b). The blue dotted line represents the mean

tendency as approximated by a linear model. Axes have been log-scaled, and the allometric coefficients of the fitted linear relationships are reported within the plots together with their 95% confidence intervals.

Personnel numbers, densities and management effectiveness
 Our recommended densities for protected area personnel of all types (one per 13 km²) and, more specifically, for rangers (one per 26 km²) are global averages; the required numbers and densities of personnel for effective management of specific sites or national systems are bound to vary depending on multiple factors^{33,34}, such as threat levels, site characteristics, management objectives, resourcing and individual capacity. Increasing staff numbers alone, therefore, may not guarantee the improved management effectiveness of the world’s growing network of protected areas and OECMs. Parallel measures are also needed to support and strengthen the workforce, even where personnel and ranger densities are approaching our recommended levels. These measures include staff professionalization (focusing on standards, capacity, resources and working and employment conditions)^{35–38}, deployment of appropriate technologies^{39,40}, adoption of global performance standards (such as the IUCN Green List of Protected and Conserved Areas⁴¹),

increased co-management, improved participation of Indigenous and local communities and recognition of their rights^{42,43}, wider deployment of part-time and volunteer personnel and more equal representation of women in the workforce⁴⁴. Insufficient gender-disaggregated data were available for our survey to draw overall conclusions, but it has been estimated that women represent between 3% and 11% of the global ranger workforce¹³. Further research is required on all these measures, on the relationships between personnel numbers and overall performance, on gender balance in the workforce, on the role of volunteers and on the specific personnel needs of marine protected areas.

Across national protected area systems, economies of scale for staffing may potentially be achieved by improving the spatial efficiency of existing and new protected areas (for example, through enlarging and optimizing perimeter/area ratios) and identifying the most cost-effective potential locations for achieving spatial conservation targets⁴⁵. Expanding the protected area systems may also allow



Fig. 4 | Global terrestrial protected area personnel: estimated numbers and requirements. **a**, Estimated current numbers in existing global terrestrial protected areas (15.7% of land in 2020). **b**, Estimated minimum required numbers to manage existing global terrestrial protected areas. **c**, Estimated minimum numbers required to manage 30% global coverage of terrestrial protected areas. Each figure represents approximately 20,000 personnel; walking figures

represent rangers; standing figures represent other personnel (site based and off site); solid figures represent existing personnel; bold-outline figures represent additional personnel numbers required for management of the current global area of terrestrial protected areas; fine-outline figures represent further required personnel numbers for management of protected and other conserved areas covering 30% of the global terrestrial area.

economies of scale within managing organizations, as suggested by the allometric relationship we have shown between national protected area system sizes and staffing numbers.

Alongside new and extended protected areas, newly recognized areas under OECMs are likely to compose a major proportion of the 30-by-30 target⁴⁵. OECMs are areas whose primary management objective is not necessarily conservation, but whose significant biodiversity values are effectively and equitably conserved by their owners, managers and stewards. These may include private owners, NGOs, resource management agencies and, to a significant extent, Indigenous peoples and local communities⁴⁶ (subject to the free prior and informed consent of customary and traditional landowners). Effective and equitable management of OECMs will still require investment in resources for management and sufficient numbers of individuals with skills and roles analogous to, and at similar average densities to, those working in protected areas. Conventional models of protected area staffing are, however, unlikely to be directly applicable to many of these areas, which may not all require recruitment of new personnel, but rather investment in recognition, capacity building and support for existing personnel and inhabitants so that they can exercise the required effective and equitable management. It will be essential to understand the kinds of support required for managing OECMs, including capacity development, funding mechanisms, appropriate protection mechanisms and wider recognition of the rights of Indigenous peoples.

Planning for 2030

The 30-by-30 target, in the context of the Convention on Biological Diversity post-2020 Biodiversity Framework, the United Nations Framework Convention on Climate Change and the relevant SDGs (SDG 13, SDG 14 and SDG 15), is intended to help secure the long-term future of the world's biodiversity, safeguard the ecosystem services on which society and economies depend and mitigate the impacts of climate change. Our survey has revealed major personnel shortfalls that, if not addressed, will compromise effective management of existing and new protected areas and OECMs, limiting the substantial economic, health, environmental and climate benefits they are expected to deliver.

The difficulties in obtaining data for this study indicate how little information is at present systematically collected and collated about protected area personnel, not only in terms of overall numbers but also related to job roles, gender and traditional links to the area, preventing comprehensive sectoral approaches to workforce planning for 30 by 30. Our estimated global requirements by 2030 for an additional 2.43 million personnel of terrestrial protected areas and OECMs, including 1.25 million rangers (or ranger equivalents), should provide a basis for calculating current and future personnel requirements, refining analyses of protected area costs and benefits, establishing and monitoring management standards and measures of effectiveness, calculating investments and recurrent funding needs and quantifying specific needs of protected area personnel, such as equipment, insurance and capacity development. The recommended average

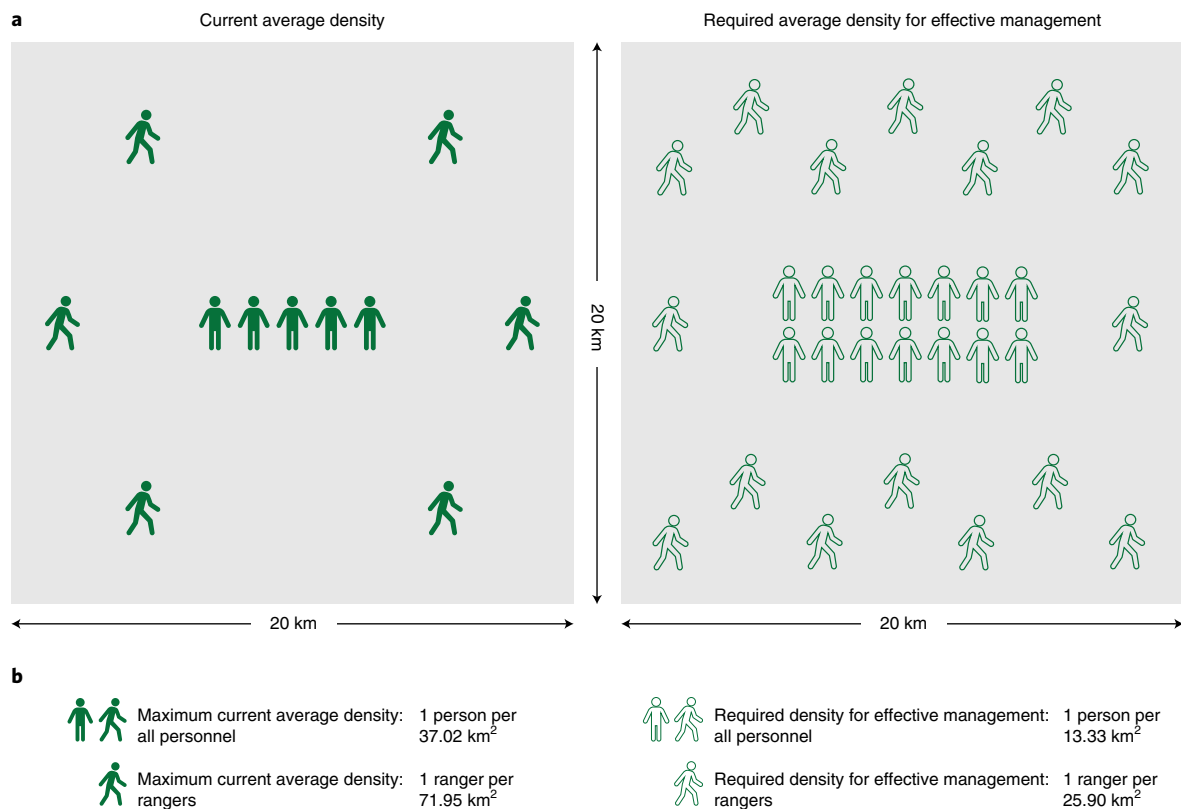


Fig. 5 | Global terrestrial protected area personnel densities. a, Illustrative estimated densities of personnel responsible for 400 km² of terrestrial protected area. Each figure represents approximately one person in an illustrative area of 20 km × 20 km (400 km²); walking figures represent rangers; standing figures

represent other personnel (site based and off site); solid figures represent estimates of existing personnel; outline figures represent estimates of required personnel. **b**, Estimated densities.

densities (particularly for rangers; one per 26 km²) should serve to update and refine current recommendations and guide the recruitment and deployment of site-based personnel at the national level. Quantified workforce data could also support the proposed recognition of the ranger profession by the International Labour Organization¹⁴.

Changes in personnel numbers and densities have the potential to be reliable general indicators of progress towards adequate levels of management effectiveness of protected areas, both within national systems and on broader geographic scales, and provide a baseline for determining the impact of staff increases. To enable accurate workforce monitoring, requirements for providing data on personnel could be included in national planning and reporting requirements for the Convention on Biological Diversity, in monitoring of United Nations Educational, Scientific and Cultural Organization World Heritage Sites, in reporting to the World Databases on Protected Areas and on OECMs, and in protected area management effectiveness assessments. Supported by guidance on data gathering and adaptation to local contexts, national and site-based staffing targets (or acceptable ranges) could, alongside protected area performance standards and norms for employment and welfare conditions, drive measurable improvements in management effectiveness and impact and help to ensure that 30 by 30 and its associated benefits are both achievable and sustainable.

Methods

Data collection

In phase 1 (2017), we first circulated a comprehensive multi-language questionnaire and associated guidelines on protected area personnel numbers to major national protected area agencies, focusing on the

50 countries listed in the WDPA as having the most protected areas. The questionnaire requested information on personnel numbers, type of employers and management levels (from executive to skilled practical workers). Protected area personnel were defined as those spending at least 50% of their work time on protected area-related tasks. The questionnaire also requested information about job titles used for personnel equivalent to rangers. This phase produced usable data for 28 countries/territories.

In phase 2 (2018 onwards), we conducted online searches for published data on protected area personnel numbers in the countries/territories not included in the questionnaire survey or where questionnaire responses were incomplete or unclear. The resulting information came from official organizational reports (10 countries/territories), published external studies, project documents and journal papers (35 countries/territories) and websites of protected area organizations or individual sites (9 countries/territories).

In phase 3 (2018–2021), we directly requested personal contacts to locate or supply information from official sources both for the remaining countries/territories and to improve or verify data from phases 1 and 2. The minimum data requested were the overall number of protected area personnel, the number of those personnel that could be categorized as rangers, the terrestrial area of protected areas managed by the listed personnel and the source of the information. This phase contributed usable data for 68 countries and territories. Data for a further 17 countries/territories were assembled from multiple sources.

The final dataset covered 176 countries/territories: 167 surveyed countries/territories and a further 9 countries/territories that have no WDPA-listed protected areas (Supplementary Table 1), with contributions from more than 150 individuals.

Initial data processing

To assess and, where necessary, improve the reliability of data obtained in a wide range of formats and levels of detail and from multiple sources, we scored the data for each country/territory from 0 to 5 for each of four criteria—detail, accuracy, source and age of the data—with a maximum score of 20 (Supplementary Table 1 and Supplementary Fig. 1). For all low-scoring records (a score of less than 15), we sought more-reliable sources in later phases of the study, rejecting any final scores of less than 10.

On reviewing the data, we excluded from the analysis protected areas identified in the WDPA as predominantly or entirely marine, Antarctica and countries/territories categorized in the WDPA as polar (Greenland, French Southern Territories, Bouvet Island, Heard Island and McDonald Islands, South Georgia and the South Sandwich Islands). These large, remote and/or largely uninhabited areas are likely to have quite different management models and scales of staffing from terrestrial protected areas (although marine protected areas are also widely understaffed¹¹). For example, in 2012 the 972,000 km² of Northeast Greenland Protected Area (categorized by the WDPA as polar) was only periodically visited by six two-person teams of naval personnel⁴⁷, and the 2008 management plan of the 1.51 million km² Papahānaumokuākea Marine National Monument (Hawai'i, USA) specifies just nine personnel, working in conjunction with several other agencies⁴⁸. Data for one country were supplied by officials on the agreement that the country was not specifically identified in publications (the country is given the three-letter code ZZZ in relevant tables and figures).

Because the format, completeness and level of detail of the data varied widely, from comprehensive personnel lists to single figures, we restricted our raw dataset to six variables that could be consistently extracted from data obtained for each country/territory:

1. Total number of non-ranger personnel (if known)
2. Total number of rangers (if known)
3. Total number of protected area personnel (either the sum of 1 and 2 or provided as an undifferentiated total)
4. Terrestrial area of protected areas covered by surveyed personnel (km²)
5. Total terrestrial area of protected areas of the country/territory (km²)
6. Year of the data

We used the WDPA, official publications and websites to determine (or verify) the area of terrestrial protected areas covered by the personnel listed for each country/territory, using WDPA data if there were discrepancies. Total national terrestrial protected area coverage was taken from the WDPA, with the exception of Turkey, where the area officially reported to the WDPA is significantly less than the nationally published area.

The raw data from the survey are shown in Supplementary Table 1.

Candidate predictors

To predict the number of rangers and non-rangers in countries and territories for which we had no data (Statistical analysis), we collected information on the following set of variables, hereafter referred to as candidate predictors:

Location data

The WGS84 latitude and longitude of the centroid of the largest land mass associated with each country/territory (to obtain the polygons defining the land masses, we used the R package `rnatuarearth` version 0.1.0; <https://github.com/ropensci/rnatuarearth>)

2020 data from the World Bank (<https://data.worldbank.org/indicator>).

- Area of the country/territory
- Population density: the mid-year population divided by land area

- Gross domestic product (GDP) in US dollars
- GDP per capita in US dollars (GDP divided by mid-year population)
- Growth rate of GDP
- The proportion of rural inhabitants
- The proportion of unemployed inhabitants
- The forested proportion of the country/territory

2020 data for each country/territory from the WDPA (<https://www.protectedplanet.net/>).

- The total terrestrial area of WDPA-listed protected areas
- The proportion of the terrestrial area of all IUCN-categorized protected areas (Categories I–VI) that falls within protected areas in Category I or II
- The proportion of the terrestrial area of all IUCN-categorized protected areas (Categories I–VI) that falls within protected areas in Categories I–IV

2020 data from the Yale Center for Environmental Law and Policy Environmental Performance Index (<https://epi.yale.edu/>).

- Environmental Performance Index (EPI): a composite index using 32 performance indicators across 11 categories
- Ecosystem Vitality Index (EVI): an indicator of how well countries preserve, protect and enhance ecosystems and the services they provide
- Species Protection Index (SPI): an indicator of the species-level ecological representativeness of each country's/territory's protected area network

Not all this information was available for all countries/territories. Most of the missing data were for small territories that account for only a very small proportion of the total area of protected areas worldwide (Supplementary Table 2c).

Statistical analysis

Our primary objective was to estimate the total number of all personnel engaged in managing all the world's WDPA-listed terrestrial protected areas and the number categorized as rangers. Our raw data collection yielded full, partial or no information on total personnel and ranger numbers for each country/territory (Supplementary Table 1 shows the completeness of all the data collected). Our first task, therefore, was (1) to impute the information for unsurveyed protected areas on the basis of information from surveyed protected areas within the same countries/territories and (2) to predict those numbers for countries/territories where no information was available on overall personnel numbers and/or ranger numbers on the basis of relationships we could establish between available information and candidate predictors in other countries/territories (Supplementary Table 7). A brief description of these two approaches follows, and full details on the analysis are provided in Supplementary Information.

Data imputation

For countries/territories where we had obtained information about numbers of personnel and/or rangers for only some protected areas, our strategy was to populate the unsurveyed protected areas in proportion to the densities of personnel or rangers from the surveyed protected areas of the same countries/territories. For example, for Spain we obtained evidence that there are 619 rangers responsible for protected areas covering 44,328 km², out of a national total protected area system covering 142,573 km². To impute the number of rangers for the remaining 98,245 km², we used the density of rangers in the surveyed area (one ranger per 44,328/619 = 71.6 km²) and applied that to the unsurveyed area, giving a total of 1,991 rangers (619 + (98,245/71.6)). This imputation assumes that unsurveyed areas are staffed at the same

density as surveyed areas, whereas in reality the relative densities are likely to vary in unknown ways within different countries/territories. To study the sensitivity of our results to the assumed proportion, we repeated our analysis using the following proportions of the observed densities: 0, 0.25, 0.50, 0.75 and 1.00. This provided a range of personnel numbers from a minimum (based on a proportion of 0) to a presumed maximum (based on a proportion of 1.00). From the data obtained, it was not possible to calculate the actual proportions, but based on the experience of the practitioners in the author team, the unsurveyed areas are highly unlikely to be staffed at higher densities than surveyed areas and, on average, are very likely to be staffed at lower densities. After all, most survey respondents were national or sub-national agencies responsible for protected areas subject to stronger formal requirements for protection and management and therefore likely to have larger workforces. Unsurveyed protected areas are more likely to be managed by local entities, with fewer resources, less-stringent management obligations and therefore fewer personnel. The range of proportions we considered to populate unsurveyed areas should therefore yield predictions encompassing the actual (unknown) numbers of rangers and non-rangers with a conservative margin of error. In the main text, we have reported the results of imputation assuming a proportion of 1, which is probably the most optimistic assessment of the current workforce in protected areas within the proportions of the observed densities considered. Results using lower proportions are shown in Extended Data Fig. 2 and Supplementary Tables 4 and 5.

Data prediction

Our imputation approach was not possible for countries/territories where (1) zero ranger or personnel data had been obtained and (2) specific data had not been obtained that allowed imputation either for rangers or for total personnel (where only total personnel numbers or only ranger numbers had been obtained). To predict the missing information, we used two different statistical approaches: linear mixed models (LMMs)⁴⁹ and a general implementation of random forests, which we term RF/ETs because it encompasses both random forests sensu stricto (RFs)⁵⁰ and a variant called extremely randomized trees (ETs)⁵¹. LMMs and RFs have been extensively discussed and reviewed in the literature^{49,52,53}. We adopted these approaches because both have proved successful in producing accurate predictions for a wide range of applications and because both are well suited to our data since they both produce predictions from a set of predictors and allow for the consideration of spatial effects^{54,55}. Furthermore, comparing predictions generated through very different methods informs us about the robustness of our results with respect to key statistical assumptions. LMMs come from the 'data modelling culture'⁵⁶ and belong to parametric statistics; RF/ETs come from the 'algorithmic modelling culture' and belong to non-parametric statistics.

We followed the same workflow for both statistical approaches, comprising eight steps: (1) general data preparation; (2) preparation of initial training datasets; (3) selection of predictor variables and of the method used for handling spatial autocorrelation; (4) preparation of final training datasets; (5) fine tuning; (6) final training; (7) preparation of datasets for predictions and simulations; and (8) predictions and simulations (see Supplementary Information for details).

Both approaches yielded very similar results with our data. We chose to present the LMM results in the main text, but we provide and compare the results obtained by both approaches in Supplementary Information.

Software

We performed all the data analyses using the free open-source statistical software R version 4.1⁵⁷. We used the R package spaMM version 3.9.13 to implement LMMs⁵⁸ and the R package ranger version 0.13.1 to implement RF/ETs⁵⁹. To reformat and plot the data, we used the Tidyverse suite of packages⁶⁰. Details are provided in an R package

we specifically developed so that findings presented in this paper can readily be reproduced (see Code availability). Using a workstation with an AMD Ryzen Threadripper 3990 × 64-core processor and 256 GB of RAM, our complete workflow ran in ~3,000 CPU hours.

Estimation of required numbers and densities of personnel

To estimate the numbers of personnel and rangers required for effective management of existing protected areas, we referred to ref.²⁵. This estimates that the minimum budget needed to adequately manage the existing protected area system is US\$67.6 billion per year and that current annual expenditure is US\$24.3 billion. From these figures, we can calculate that resources invested in the current global system of protected areas are approximately 36% of what is required. We consulted data from <https://ourworldindata.org> to determine that the proportion of global public expenditure on employee compensation has remained between 21.01% and 23.33% in the years from 2006 to 2019. We obtained these figures from the 'Government Spending' section of the site, consulting the chart 'Share of employee compensation in public spending, 2002 to 2019' and selecting data for 'World'. On the basis of this broadly constant proportion and the assumption that total employee compensation is an indicator of total employee numbers, we inferred that current numbers of protected area employees are also around 36% of what is required. We therefore multiplied our estimations of personnel and ranger numbers by 1/0.36 and recalculated the densities on this basis (current requirement = 1/0.36 × current estimate).

To estimate staffing requirements for 30% global coverage of protected areas—the global target intended to be reached by 2030—we used the mean personnel and ranger densities calculated as being required at present to 'populate' a global area of terrestrial protected areas if increased from the percentage at the time of our study (15.7%) to 30% (current requirement × (0.300/0.157)).

Economic calculations

We based our calculations on published data from 2020²⁵, which estimate that expanding the protected areas to 30% would generate higher overall output (revenues) than non-expansion (an extra US\$64–454 billion per year by 2050). This figure is only an indicative, partial estimate, generated for the purposes of comparison and to illustrate the substantial return on investment that protected area staff investments imply. Using these figures and our estimates of personnel requirements to ensure effective management of 30% coverage, we calculated the range of sums that each additional protected area staff member has the potential to generate (Supplementary Table 8). For clarity, we rounded these figures to the nearest hundred US dollars in the main text.

Our estimates of the gross value added per worker in forestry and agriculture (sectors responsible for similar proportions of the world as protected areas) are included to provide a point of comparison for the figures showing the economic benefit generated per protected area personnel member (see the preceding). The data for the gross annual value of world agricultural production (US\$3,550,231,736,000) and the number of workers employed in agriculture (343,527,711) come from the Food and Agriculture Organization of the United Nations³⁰, providing an average gross value of annual agricultural production per worker of US\$10,335. We adjusted these 2018 data to 2020 price levels using a deflator based on the US consumer price index (CPI) from the World Economic Outlook database⁶¹ (Supplementary Table 9). This ensures that all the economic value data we present are directly comparable for protected area, agricultural and forestry workers. We calculated the gross value of forest production per worker on the basis of direct contribution of forestry of more than US\$539 billion to world GDP in 2011⁶² and total forest-sector employment of 11.881 million full-time-equivalent jobs in 2010³². These were the most up-to-date global estimates we could locate from credible sources that presented comparable estimates of forest-sector employment and contribution to GDP. This gives an average gross value of forest production

per worker of US\$45,367 per year. We used the same method as for agriculture to bring these figures to 2020 price levels (Supplementary Table 9). These figures are rounded to the nearest hundred US dollars in the main text.

Data availability

The raw data used during this study are available as Supplementary Table 1 (parts A and B). Further details are available within the dedicated R package (see Code availability), as well as from the corresponding author upon reasonable request. Source data are provided with this paper.

Code availability

The code used to support this study is available in the form of a dedicated R package `rangeRinPA`, which can be accessed via GitHub (<https://github.com/courtiol/rangeRinPA>) or Zenodo (<https://doi.org/10.5281/zenodo.7114371>).

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Author contributions

Conceptualization and survey design were by B.L., M.R.A. and J.L.S. Data collection was by L.C.W., M.R.A., J.L.S., J.C.D., M.Á.M., J.R.B., L.d.B., R.C., C.A.J., R.S., E.J.S. and E.G.W. Statistical analysis was by A.C., F.R. and A.T. Economic analysis was by L.E. Draft writing was by M.R.A., A.C., J.C.D., L.E., N.P.H. and E.J.S. All authors contributed to review and editing.

Competing interests

The authors declare no competing interests.

Additional information

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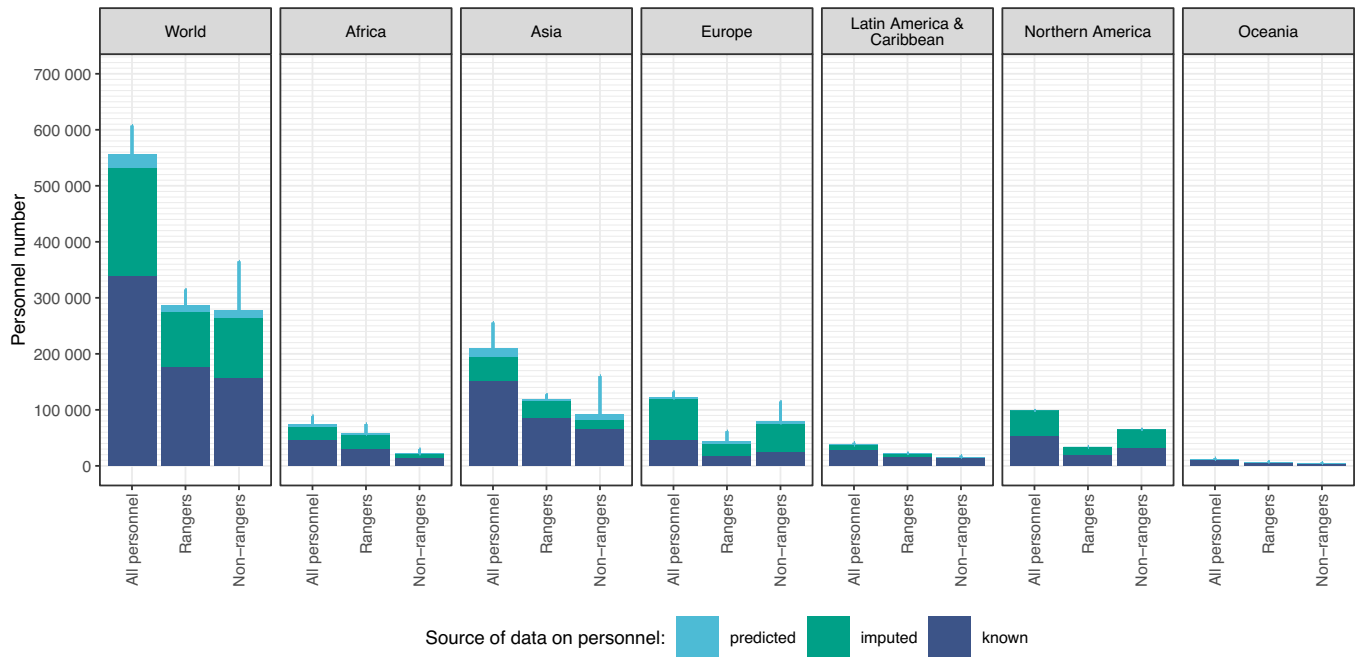
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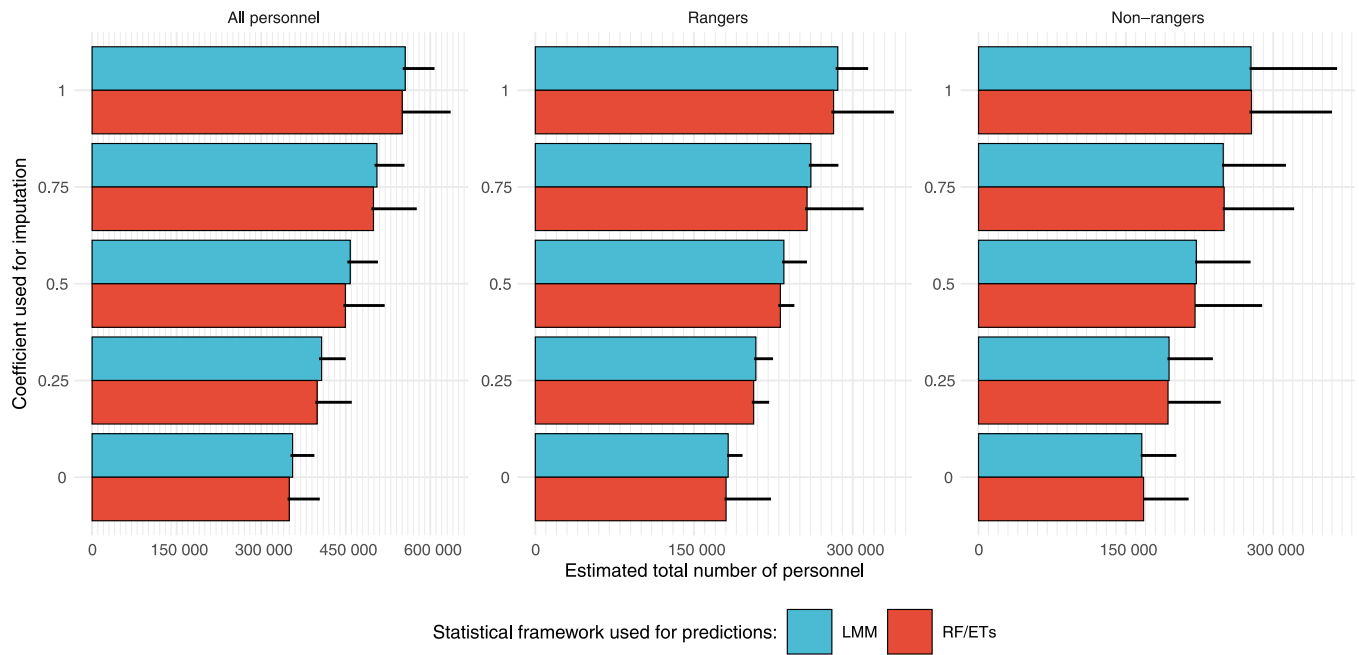
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Extended Data Fig. 1 | Estimated total global numbers of all terrestrial protected area personnel, rangers and non-rangers for the world and for each continent. Each vertical bar shows the breakdown of the totals according to the source of data. Error bars represent 95% prediction intervals.



Extended Data Fig. 2 | Estimated total global numbers of all terrestrial protected area personnel, rangers and non-rangers according to two prediction methods. Methods used are Linear Mixed Models (LMM) and

Random Forests/Extremely Randomised Trees (RF/ETs). Five different values of coefficient are used for the imputation (see Methods). Error bars represent 95% prediction intervals.