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Human population behavioural traits matter for explaining terrestrial protected area coverage[☆]

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ABSTRACT

Biodiversity loss demands urgent action, and protected areas are one of the cornerstones of biodiversity conservation measures. While conservation efforts are known to be driven by economic and political factors, there is an absence of literature addressing the potential role played by behavioural traits at the population level. We investigate how population-level behavioural traits are associated with coverage of terrestrial protected areas by using large-scale cross-cultural surveys and geospatial data from 71 countries. We show that behavioural traits explain additional variation in protected area coverage beyond economic indicators alone. Furthermore, trust is negatively associated with protected area coverage at the country level, suggesting that high-trust societies rely more on informal conservation practices. These findings challenge conventional models focused on economic and governance factors and highlight the need for policies that align with population behaviours. Integrating behavioural insights into conservation planning could unlock more effective biodiversity conservation strategies in the era of environmental changes.

1. Introduction

We are entering the era of the sixth mass extinction of biodiversity. The last estimates from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) indicate that approximately one million species worldwide are at risk of extinction in the coming decades due to global environmental changes (Ceballos et al., 2015; IPBES, 2019; Cardinale et al., 2012; Barnosky et al., 2011). In response to this growing threat, the implementation of protected areas has emerged as a strategy to conserve local and global biodiversity. Protected areas are specifically designated geographic regions that are recognised, dedicated, and managed—through legal or other effective means—to achieve the long-term conservation of biodiversity (Dudley, 2008). For this reason, in 2022, 194 countries have adopted the *30 × 30* target aiming to conserve 30% of the Earth's land and sea through the implementation of protected areas and other area-based conservation measures (Dinerstein et al., 2019; Lo and Jang, 2022). Global political awareness of biodiversity protection has grown, as evidenced by the expansion of protected areas from 14.1% to 15.3% of global terrestrial and freshwater environments (excluding Antarctica) and from 2.9% to 7.5% of marine environments between 2010 and 2019 (UNEP-WCMC, 2016; Maxwell et al., 2020). However, despite these advances, the relatively modest increase in global terrestrial protected areas and the ambitious 2030 targets underscore that current efforts remain insufficient to address the biodiversity crisis.

To explain this discrepancy between engagement and final implementation in real conditions, several studies have examined the factors driving countries to establish these areas. A common assumption is that wealthier countries may implement more ecological conservation measures (Heinen, 1996; Amano et al., 2018; Johnson et al., 2023). However, the gross domestic product (GDP) of a country, a common indicator of national wealth, does not consistently explain conservation outcomes across countries (Upton et al., 2008; Kashwan, 2017; Baynham-Herd et al., 2018; Baldi, 2020). Instead, the human development index (HDI), which considers factors such as educational

☆ Ⓡ symbol stands for randomised order of author of the study.

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Table 1
Summary of population behavioural traits, meaning, expected mechanisms and predictions and final results between traits relationship to protected areas coverage.

Behavioural traits	Meaning	Predictions	Supported
Altruism	A concern for the well-being of others, often lead to actions that benefit others at a personal cost.	More altruistic populations are expected to support policies that benefit to the environment. **Prediction:** Positive association with protected areas coverage.	Not supported
Patience	Preference for long-term rewards over immediate gains, reflect inter-temporal decision-making.	More patient populations may favour long-term environmental policies. **Prediction:** Positive association with protected areas coverage.	Not supported
Risk-taking	The willingness to engage in behaviours or decisions that involve uncertainty and potential loss.	Populations with high risk-taking tendencies may be less inclined to implement protected areas due to the ambiguity of climate change impacts. **Prediction:** Negative association with protected areas coverage.	Not supported
Trust	The belief in the reliability and goodwill of others, foster cooperative behaviour.	Higher trust levels is positively associated with higher coverage of protected areas as trust is linked to cooperative behaviour, through Institutional reinforcement mechanism. **Prediction:** Positive association under an institutional reinforcement mechanism Alternatively, higher trust levels might reduce the need for formal conservation measures resulting in lower coverage of protected areas through Non-institutional reinforcement mechanism. **Prediction:** negative association under an Non-institutional reinforcement mechanism.	Supported with Non-institutional reinforcement

attainment, life expectancy, and per capita income, or more globally socio-economics data coupled with environmental data emerged as more robust predictors of protected area coverage (de Araújo et al., 2022; Baldi et al., 2017; Mouillot et al., 2024). In contrast, a country with strong political institutions is a proxy of a government's ability to implement policies (Frank et al., 2000), and a country with high level of education is associated with greater public concern for environmental protection (McDonald and Boucher, 2011). Moreover, evidence shows that patterns of protected area expansion since 2010 cannot be explained solely by differences in countries' wealth or levels of economic and social development (Maxwell et al., 2020; Mouillot et al., 2024). While traditional socio-economic predictors such as GDP and HDI provide valuable insights, they fail to account for the behavioural and cultural factors that shape conservation policies.

Human behaviour is increasingly recognised as a critical factor in implementing policies to mitigate climate change (Beckage et al., 2022; Andre et al., 2024; Stoetzer and Zimmermann, 2024) and biodiversity loss (Amano et al., 2018; Nielsen et al., 2021). For instance, trust is often the foundation of successful community-managed forests, fisheries, and grazing lands, where collective action prevents overexploitation and supports sustainable resources use (Pretty and Ward, 2001; Dietz et al., 2003). Individual behavioural traits also play a role in environmental outcomes. For example, more altruistic individuals have been shown to reduce their consumption of environmentally harmful products (Daube and Ulph, 2016), and a recent research suggests that individuals with greater trust in government are more likely to support the protection of 30% of the Earth (Michaelsen et al., 2024). However, biodiversity conservation challenges does not arise necessarily from individual actions alone but from the interactions of multiple actors across various levels (Nielsen et al., 2021). For example, during the COVID-19 pandemic, populations with higher levels of trust delayed the implementation of restrictive measures and adopted less stringent policies (Dagorn et al., 2024), that could be explained by more responsible behaviour of citizens (Barrios et al., 2021; Bargain and Aminjonov, 2020). Consequently, the aggregation of behavioural traits at the population level offers a framework to explore collective responses to environmental crises, shaping both policy-making and conservation strategies.

Our study examines associations between population-level behavioural traits and terrestrial protected area coverage across 71 countries. We tested whether behavioural traits are associated with variation in protected area coverage, alongside economic and governance factors. The study includes countries from diverse regions of the world, with different levels of protected area coverage and with behavioural traits representing heterogeneous cultural and institutional contexts. We focus on four behavioural traits—trust, altruism, patience, and risk-taking—and take into account economic, social, and political factors. Behavioural traits were obtained from the Global Preferences Survey (Falk et al., 2022), where individuals responses from large-scale cross-cultural surveys were aggregated at the population level. These behavioural traits operate within governance frameworks, influencing whether conservation outcomes stem from top-down policies (e.g U.S. National Parks implemented in 1872, Sellars 2009), or bottom-up initiatives (e.g. Nepal's community forestry programs in the 90's, Agrawal and Ostrom 2001).

Furthermore, several studies highlight the importance of interpersonal trust within communities for the successful implementation of biodiversity conservation policies (Taniguchi and Marshall, 2018). Higher levels of trust can facilitate collective action, reduce transaction costs, and enhance compliance with conservation rules (Olsson et al., 2004; Kulin and Johansson Sevä, 2021). However, high trust may also reduce reliance on formal regulatory instruments if individuals coordinate through informal norms and voluntary cooperation instead (Aghion et al., 2010). Evidence from COVID-19 global pandemic supports this mechanism: societies characterised by higher interpersonal trust exhibited greater voluntary compliance with public health measures, even in the absence of strict enforcement (Barrios et al., 2021; Bargain and Aminjonov, 2020).

By contrast, altruistic preferences can strengthen support for policies that generate collective benefits beyond the individual, while patience increases the weight placed on long-term environmental gains. These altruistic and patient populations may increase political demand for government provision of environmental public goods, including the formal designation of protected areas (Cai et al., 2020; Daube and Ulph, 2016). Conversely, populations with high risk-taking may resist stringent measures due to their tolerance for environmental uncertainty (Zeng et al., 2020) (Table 1), as higher risk tolerance has been associated with weaker perceptions of environmental threats and reduced support for precautionary policies. By integrating behavioural traits into conservation research, our study contributes to a growing interdisciplinary dialogue on how human behaviours are associated to collective responses to global challenges.

2. Material & methods

2.1. Terrestrial protected area coverage

National-level commitment to biodiversity preservation is assessed through the establishment of protected areas (International Union for

Conservation of Nature, 2013). We used the World Database on Protected Areas (UNEP-WCMC 2016, version November 2023) to extract data on the location, boundaries, and year of establishment of protected areas from a total of the 71 countries available in open-source. Our approach is based on the methodology from Maxwell et al. (2020), where we extracted terrestrial protected areas for each country and are categorised with International Union for Conservation of Nature (IUCN) criteria between I, highly restrictive or no-take, and VI least restrictive IUCN category. Among the 71 countries, none reported protected areas in IUCN Category I. We removed protected areas that were *not assigned* and *not reported* categories. The coverage of protected areas may overlap according to their regulation (e.g. regional protected areas overlap international protected areas). We first combined all spatial geometries of all three features, regional, international and national protected areas all together in one large spatial feature (Pebesma et al., 2018). We then extracted terrestrial country boundaries to determine the coverage of terrestrial protected areas for each country by using the Database of Global Administrative Areas (GDAM, https://gadm.org/data.html, Global ADMinistrative Areas (GADM) 2015). For each year since 1948, establishment year of IUCN, we determined the protected area coverage as the percentage of the protected area by dividing the total surface of the terrestrial protected area by the total area of the country. All extraction and cleaning of the protected area was done by using the R package `wdpar` (Hanson, 2022).

2.2. Population's behavioural traits

Population's behavioural traits represent behaviours that are usually observed in laboratory experiments where individuals are faced with monetary trade-offs to elicit their behaviours. Such behavioural traits possess substantial explanatory power as they are associated with observable outcomes at the individual (*e.g.* Kosse and Tincani 2020), and country level (*e.g.* Falk and Hermle 2018). We derived the experimental behavioural traits measures of risk-taking, patience, altruism and interpersonal trust from the Global Preferences Survey (GPS, Falk et al. 2018, 2022) for a total of 71 countries (Table A1). The initial sample of the Global Preferences Survey (n = 76) represents approximately 90% of the world's population and more than 90% of the global Gross Domestic Product in 2012. The Global Preferences Survey initially contained risk-taking, patience, altruism, interpersonal trust, and also positive and negative reciprocity. Altruism is defined as concern for the well-being of others and a willingness to incur personal costs in order to benefit them; Patience is defined as a preference for delayed rewards over immediate gains, reflecting inter-temporal decision-making; Risk-taking describes the willingness to make decisions involving uncertainty and potential losses; And trust is defined as the belief about the reliability and goodwill of others, and is commonly associated with cooperative behaviour (Table 1). We did not use the positive and negative reciprocity traits because of the strong correlation between reciprocity (negative–positive) to other traits (Dagorn et al., 2024). To ensure the internal validity of these measures, the Global Preferences Survey employed a novel validation process that assesses behavioural traits through survey questions linked to incentivised experimental economic games. Falk et al. (2022) implemented in the Global Preferences Survey survey the set of questions that maximise the variance of each preference under scrutiny. By relating these preferences to behaviours observed in controlled lab environments, the approach confirmed that the results are reliable and consistent (internal validity). Furthermore, the survey included a diversity of participants making the population behaviour response more representative of the population (external validity) (see Supplementary Section A). For the measures of behavioural traits, we aggregated observations at the national level and standardised the result at the international level. More details about the behavioural traits database are reported in the Supplementary Section A and in the Refs. Falk et al. (2022), Dagorn et al. (2024). We reported relation among traits in Fig. A-1.

2.3. Economic, political and urban areas

We included a sets of controlling variables, with population's behavioural traits and the coverage of protected areas.

Economic & political variables. We used the Gross Domestic Product (GDP) per capita, population density, Human Development Index (HDI) and Worldwide Governance Indicators as these variable have been documented as main factors related to protected area (Amano et al., 2018; Mouillot et al., 2024). Population density has been extracted from World Bank data (World Bank, 2022). The Human Development Index (HDI), extracted from the United Nations Development Programme, is a composite measure that assesses a country's overall development based on three key dimensions: health (life expectancy at birth), education (mean years of schooling and expected years of schooling), and standard of living (gross national income per capita) (United Nations Development Programme, 2024). Finally, we considered the effectiveness of a government to implement policy using the Worldwide Governance Indicators (Kaufmann and Kraay, 2023) that considered five dimensions of governance: Voice and Accountability, Political Stability, Regulatory Quality, Rule of Law, and Control of Corruption.

Urban areas variable. We chose the total urban areas percentage as a descriptive factor of land availability that cannot be converted as a protected area surface. We extracted this variable from the Organisation for Economic Co-operation and Development (http://stats.oecd.org, version October 2023).

2.4. Analysis

2.4.1. Multivariate analysis to summarise economic–political–urban areas data

In order to take into account the combined effects of economic, political and urban characteristics on protected area coverage, while also addressing the strong correlation among them (Fig. A-2), we undertook a principal component analysis (PCA) to summarise these characteristics at the country level. To do so we included economic and political, and urban area variable previously described. We retained the first two axis representing 82.6% in total dataset inertia (dimension 1 = 66.1%, dimension 2 = 16.5%). The first axis synthesised most predictors related to politics and economy (referred as Governance & Economic axis), whereas the second axis summarised population density and urban areas percentage referred as Population & Urbanisation axis (Fig. A-3). A lower value of PCA1 indicates countries with stronger governance indicators and greater wealth or Human Development Index (HDI), while a higher value of PCA2 suggests a denser population and a larger share of urban areas (see Fig. A-3). These two PCA axis were then included as predictors in the subsequent analysis (Harrell Jr., 2015). We ran the PCA analysis using the R package `ade4` (Dray and Dufour 2007, version 1.7-22).

2.4.2. Relation between protected areas and behavioural traits

We aimed to determine whether population behavioural traits were significantly associated with the percentage of protected areas while accounting for the political, land-use, and economic context of each country. We used a generalised linear mixed model (GLMMs), with the cumulative proportion of terrestrial protected areas as the response variable and population behavioural traits (altruism, trust, patience, and risk-taking) as fixed predictors. We used beta distribution, which is a family of continuous probability distributions defined on the interval (0, 1), with a logit link. We also included the two PCA axis as additional fixed predictors. The two PCA axis are control variables to capture governance, economic, and land-use effects (see Multivariate analysis to summarise economic–political–urban areas data). We tested additional GLMMs that would include the two PCA axis only as fixed predictors. We also tested two more additional models that would include only

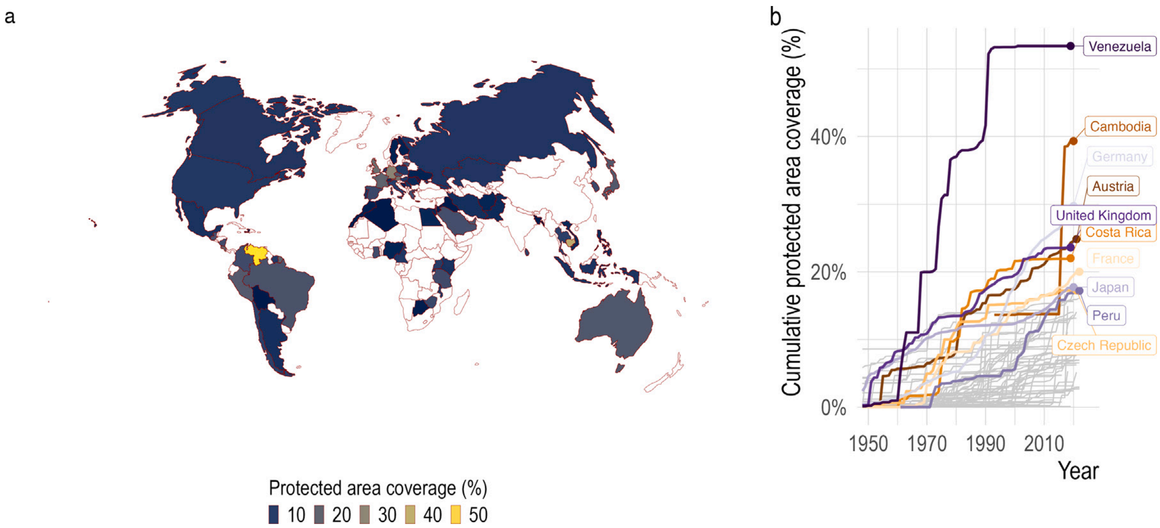

Fig. 1. The 71 countries used in the analysis showing protected area coverage and the increase of protected area coverage over time. (a) Percentage of terrestrial protected areas coverage for the 71 countries studied. The percentage of protected area coverage per country corresponds to the sum of the non-overlapping surface of regional, national, and international terrestrial protected areas over the total terrestrial surface of a main country (from 1948 until 2022, data displayed in Van der Grinten IV projection). Protected areas include sites classified under IUCN categories I–VI. Countries not included in our study are blanked. (b) Cumulative sum over time of protected area coverage (in percentage of total surface country area). Top ten country with largest protected area coverage are reported.

GDP or only HDI as fixed predictors. In all models, we specified country (factor) and year (factor) as random intercepts, as the dataset contains repetitive measurement for both country and year. Model selection was based on Second-order Akaike Information Criterion (AICc) (Bartoń, 2025). Analysis was done with `glmmTMB` (Brooks et al. 2017, version 1.1.9). We assessed the model's diagnostic with the `performance` package (Lüdecke et al., 2021) (version 0.15.0). All the models did not present any modelling issues based on model's diagnostics.

3. Results

The coverage of terrestrial protected areas, as a percentage of each country's total land area, range from ~1% in 1948 to 13% in 2019. The largest increase of percentage of protected areas was recorded in Venezuela going from 0.1 in 1948 to 53% in 2019, followed by Cambodia with 13.6% in 1993 and 39.3% in 2019, and Germany with 0.48% in 1948 and 29.7% in 2019 (Fig. 1). On average, national protected areas account for the greatest coverage with 2.5 ± 5.1%, followed then by international protected areas with 0.7 ± 2.0% and regional protected areas with 0.2 ± 0.3% (Fig. A-4). The average proportion of IUCN categories (II, III, IV, V, VI) remained below 5% (Fig. A-5).

We found that trust is significantly and negatively associated with protected area coverage (standardised slope = −0.43 [CI95% −0.67, −0.20], $p = 0.0002$; Fig. 2 and Table A-2, Table A-3 and Table A-4). In contrast, other behavioural traits—altruism, patience, and risk-taking—showed non-significant relationships with protected area coverage ($p > 0.1$, Table A-4). Results were robust when protected areas of all IUCN categories were considered (Table A-3), which additionally allowed the inclusion of South Africa, India, Croatia, and Turkey countries otherwise absent from the main analysis. Sensitivity analyses showed that the associations between behavioural traits and protected area coverage remained similar when restricting the protected area time series (Fig. A-6). Additionally, Population & Urbanisation axis (PCA axis 2) is positively related to protected area implementation (standardised slope = 0.79 [CI95% 0.05, 1.53], $p = 0.037$), indicating that countries with lower population density and urbanisation tend to have higher protected area coverage (Fig. A-7, A-3c). Model incorporating both behavioural traits in combination to control variable provided better performance than models based only on economic indicators such as Human Development Index or Gross Domestic Product (Table A-5).

4. Discussion

Reversing biodiversity loss requires innovative policies that effectively regulate human activity, with protected areas as a cornerstone. A key challenge is to understand the factors associated with variation in protected area coverage, especially given the persistent gaps in international efforts to establish and maintain them. Previous research has yielded mixed findings on the effect on economic and governance factors on conservation efforts (Opršal et al., 2018; de Araújo et al., 2022; Mouillot et al., 2024). Our findings contribute to this gap of knowledge by highlighting the role of behavioural traits at the population level—such as trust, altruism, patience, and risk preferences—in shaping conservation outcomes.

Our major findings aligns with research highlighting the heterogeneity in terrestrial protected area coverage across countries, often attributed to disparities in socio-economic development (de Araújo et al., 2022; Upton et al., 2008; Mouillot et al., 2024) and governance quality (Amano et al., 2018). While wealthier countries with stronger governance systems tend to have larger coverage of protected area, our results indicate that governance and economy show weaker associations with protected-area coverage than population-level behavioural traits, particularly with trust. We found that a one standard deviation increase in trust is associated with a ~10.6 percentage point decrease in predicted protected area coverage. Trust effect is nearly 43.3 times stronger than Human Development Index or 8.6 times higher than Gross Domestic Product alone.

Behavioural traits might influence conservation outcomes indirectly through societal preferences, political priorities, and institutional governance structures. The Fig. 3 summarises these proposed pathways and their potential policy implications. One possible mechanism is that trust may complement formal governance by fostering cooperation, facilitating conflict resolution, and strengthening community-driven stewardship (Hahn et al., 2006; Mae et al., 2007; Dietsch et al., 2021). In high-trust societies, individuals are more likely to engage in collective action for the common good (Tam and Chan, 2018; Ostrom, 1990, 2010). Interestingly, trust appears to have limited within-country temporal variation, with studies suggesting that it is a relatively stable cultural trait that changes only slowly over generations (Bjørnskov, 2007). Our results suggest that trust may be associated with long-term structural differences in conservation outcomes rather than short-term

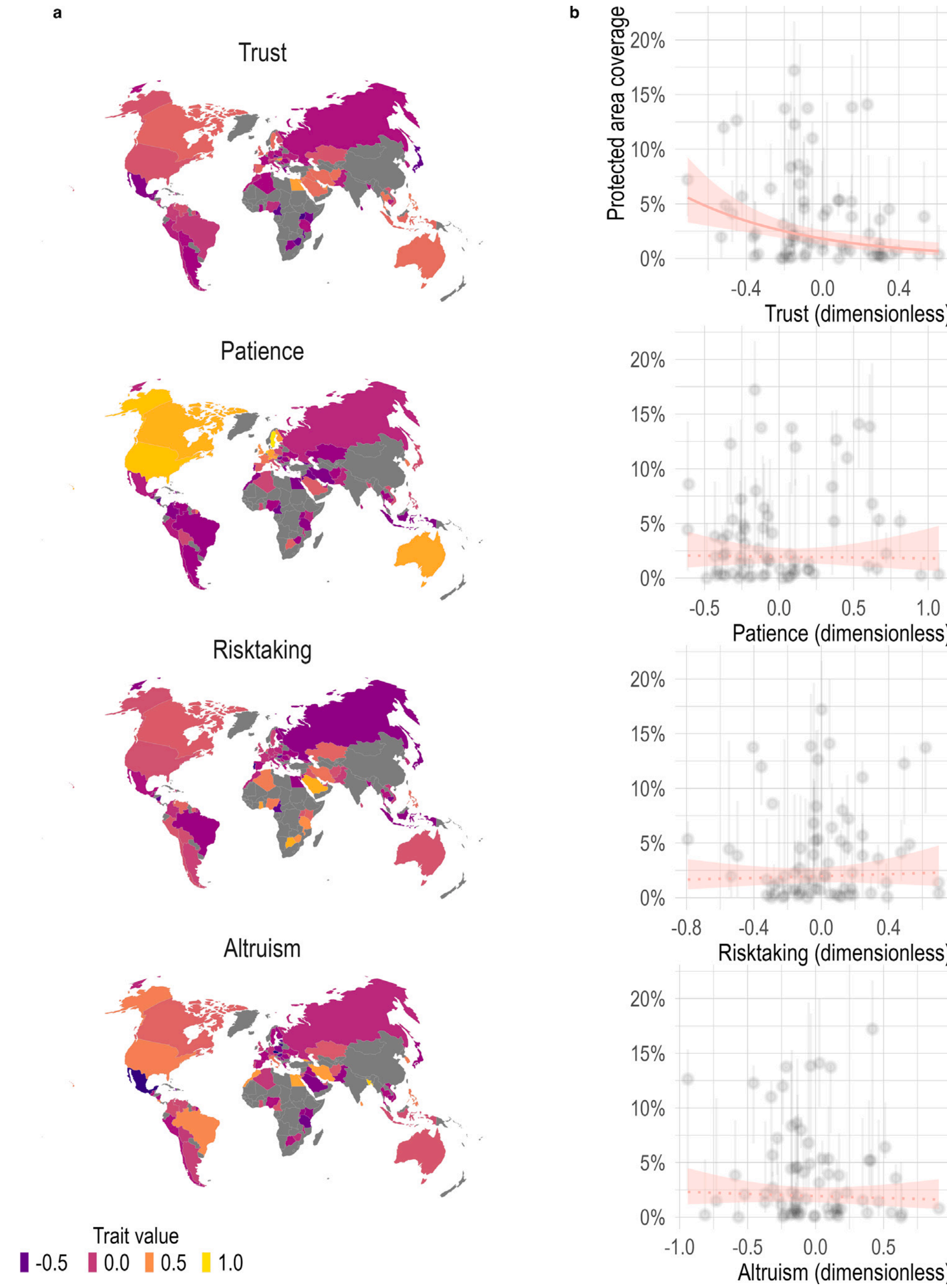

Fig. 2. (a) Maps of population behavioural traits value (trust, patience, risk-taking and altruism) for the 71 countries studied. Behavioural traits are standardised and dimensionless (Falk et al., 2018). Colour gradient is going from low value in purple to high value in yellow. Countries not included in our study are reported in grey. (b) Relationship between the protected area coverage (percentage) and behavioural traits (standardised and dimensionless). Each dots represent country observations (median and inter-quantile range). Predictions from Generalised Linear Mixed Model (GLMM) are reported in pink with the 95% confidence interval. Non significant relationship are dashed. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

responses to policy changes. This may reflect the capacity of governmental institutions to engage in deliberation over competing values and trade-offs, plan over long time horizons, and foster public engagement (Dietz et al., 2003). However, individual countries may diverge from this general patterns due to historical or political factors influencing conservation policies. These interpretations should be viewed as hypotheses that warrant further empirical investigation like including direct measures of informal conservation practices, community-based management, or alternative governance arrangements.

In contrast, the other behavioural traits—altruism, patience, and risk-taking—do not show significant association with protected area coverage. The non-significant relationship with altruism aligns with findings that protected areas often emerge from institutional frameworks and tenure systems rather than altruistic motives (Yagi et al., 2010). Unlike the previous positive relationship observed between patience and climate policy implementation (Cai et al., 2020), we did not observe similar association with patience and protected area coverage. One possible explanation is that climate policies are typically formulated at the national level, requiring long-term commitments and inter-temporal trade-off, which align with patient societies. In comparison, protected areas can be established at different scale, from local to national levels initiatives. Lastly, with risk-taking, the absence of

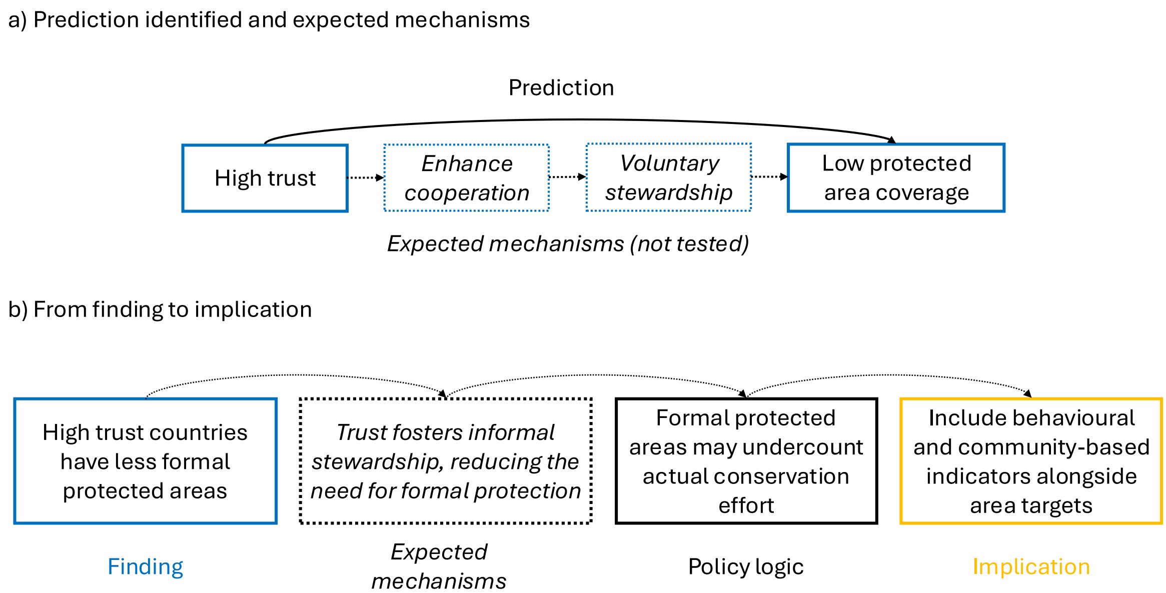

Fig. 3. Proposed mechanism and policy implications of the negative association between trust and protected area coverage. (a) Prediction identified and expected mechanisms. (b) four-step chain linking the empirical finding to a policy implication, conditional on the conjectured mechanism holding. Solid boxes and curved arrow represent the prediction identified whereas dashed boxes and arrows illustrate the potential causal pathway, which is not empirically tested in this study.

statistical significance does not preclude the possibility of its impact on conservation decisions. Risk-taking trait may assume a more significant role during the implementation stage or when modifying conservation measures, rather than in determining the coverage of protected areas (Tam and McDaniels, 2013).

Integrating population-level behavioural traits enhances our understanding of protected area coverage; yet a significant proportion remained unexplained. While our model accounts for approximately 8% of the observed variance, the relatively low value reflects the complexity of conservation dynamics and the influence of additional political, economic, and institutional factors not captured in our analysis. Importantly, a large portion of variance is captured by country and year random intercepts (conditional R2 = 83%), suggesting that national context and temporal policy changes strongly influence protected area coverage. Our dataset spans 71 countries at a single time-point, and geographical coverage is uneven. For example, only 13 of 54 African countries and 19 of 48 Asian countries are included—leaving many regions and their distinct protection approaches unexplored. South Africa, India, Croatia, and Turkey were excluded from the main analysis due to insufficient reliable protected area coverage data under the IUCN category filter, though robustness checks suggest this does not affect our conclusions (see Results). China was absent from the 2023 version of WDPA, as its protected area data has not been publicly available since 2017, representing a notable limitation given its biodiversity significance and governance context. We are aware that protected area coverage does not always reflect conservation effectiveness (Joppa and Pfaff, 2009; Le Saout et al., 2013; Pressey et al., 2015), but still remained a concrete action with standardised rules and lexicon (Dudley, 2008; Salafsky et al., 2024). Incorporating biodiversity indicators such as species richness or conservation status could provide complementary insights into the ecological effectiveness of protected areas. In addition, investigating mechanisms at different spatial and temporal scales—from national measures to local socio-ecological dynamics, as well as historical, cultural, and environmental contexts—is crucial (Chassé et al., 2021). Ideally, such data would be highly granular at the local level to capture the role of populations' behavioural characteristics. For instance, the effectiveness of community-managed conservation areas in Nepal (Agrawal and Ostrom, 2001) and indigenous-led stewardship in the Amazon (Walker et al., 2020) illustrates how governance structures, cultural traditions, and environmental conditions shape conservation outcomes. One potential avenue is to examine the networks of Indigenous and Community Conserved Areas (ICCAs) and Other Effective Area-Based Conservation Measures (OECMs), as these may also reflect societal behavioural characteristics and forms of informal stewardship operating at different governance scales. The maintenance of these protected areas may partly stem from distinct behavioural mechanisms embedded in local institutions and behaviours (Huber et al., 2023). However, datasets documenting these conservation approaches remain limited, which currently constrains cross-country analyses assessing alternative conservation measures in relation to population-level behavioural traits.

Although the primary role of protected areas is to safeguard natural environments, they are also established and managed to conserve ecosystem services (Millennium Ecosystem Assessment, 2005; Watson et al., 2014). Increasingly, protected areas can also become a political tool used to reinforce borders or justify military presence (Lunstrum, 2014), thereby contributing to the construction and reinforcement of national identity (West et al., 2006; Vasilijević et al., 2015). Consequently, the maintenance, creation, or expansion of protected areas may sometimes be driven by political objectives rather than by conservation goals alone. While our results are based on statistical associations, future research could investigate potential causal relationships. Addressing this gap requires the systematic collection of comparable, repeated, and representative behavioural measures at finer geographical scales and over a longer time (Pearl, 2009). The development of more explicit socio-ecological models might also help to clarify underlying mechanisms connecting behavioural traits to conservation (Levin et al., 2013). Such efforts would allow researchers to move beyond coarse national aggregates and better capture the local dynamics that drive conservation outcomes.

The cross-sectional approach of our study limits the ability to capture temporal changes in both behavioural traits and protected area coverage. While conservation policies evolve in response to environmental threats, political shifts, and economic conditions (Le Velly et al., 2024; Hepburn, 2010; Dunlop et al., 2024), behavioural norms also adapt to crises and policy interventions (Casoria et al., 2021). Indeed, trust or patience remained relatively more stable over the time (Falk et al., 2018; EVS/WVS, 2021), contrary to risk taking which is more susceptible to change for example after major crises (Malmendier and Nagel, 2011; Adema et al., 2022).

A natural extension of this work would be to investigate whether population-level behavioural traits have followed similar dynamics over time at a local level. One approach could be first to reduce the range of the study by focusing in one region such as in Europe where repeated behavioural survey have been done, offering higher temporal and spatial resolution (EVS/WVS, 2021). Alternatively, behavioural traits could be inferred by using complementary methods beyond traditional survey. For instance, by applying text analysis to regional and local newspapers or social network, to determinate the main population trait characteristics (Rose and Chang, 2023; Ghermandi et al., 2023). Such approaches would complement our study by offering a temporal perspective on the relationship between population characteristics and protected area development over time.

Our study offers the first large-scale perspective on the relationship between behavioural science and the environment, which has primarily relied on individual-level approaches. We showed that behavioural traits matter and should be explore at finer level to fully exploit their potential. Integrating behavioural insights into conservation planning could unlock more effective and context-specific strategies to safeguard biodiversity in an era of unprecedented environmental change (Nielsen et al., 2021).

CRediT authorship contribution statement

Cathleen Petit-Cailleux: Writing – review & editing, Investigation, Data curation, Conceptualization. **Valentin Journé:** Writing – review & editing, Visualization, Formal analysis, Conceptualization. **Etienne Dagorn:** Writing – review & editing, Writing – original draft, Investigation, Data curation, Conceptualization.

Research ethics

Behavioural trait data were obtained from the Global Preferences Survey, a large-scale, cross-national dataset on economic preferences. The data are aggregated at the country level and anonymised and have been extracted from https://gps.econ.uni-bonn.de/home. All materials provided may only be used for non-profit and academic purposes.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.biocon.2026.111971.

The following references are cited in the supplementary materials: Becker et al. (2012).

Data and code availability

Data and code supporting our results is accessible on GitHub: https://github.com/ValentinJourne/EconomyEcologyPA. All analyses used R software (v4.3.0) and published R packages.

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