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Mapping biases, gaps, and trends in climate-change research on Brazilian biodiversity

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Abstract

Brazil hosts exceptional biodiversity, but research on climate-change impacts is unevenly distributed across biomes, taxonomic groups, and regions. We characterized a deliberately bounded *corpus* of peer-reviewed literature retrieved from the Web of Science (1945–2023) using a Topic search combining "climate change," "global change," or "global warming" with "biodiversity" and "Brazil." After screening 633 records, 111 articles met the inclusion criteria for coding. We extracted bibliometric metadata and classified studies by biome, Brazilian region, taxonomic group, climatic and ecological dimensions, co-occurring pressures, and reported effects. Within this *corpus*, publication output increased sharply after 2010 and concentrated in the Atlantic Forest and the Southeast and Northeast regions; plants, insects, and other invertebrates were represented more frequently than reptiles, amphibians, and fish. Reported effects were predominantly negative. Generalized linear mixed models identified marked differences in publication counts among biomes, regions, and taxonomic groups. These results reveal spatial, taxonomic, institutional, and thematic asymmetries in the retrieved evidence base, while also showing an unusually strong representation of insects and other invertebrates relative to broader conservation-literature patterns. We identify priorities for broader evidence coverage, particularly for underrepresented biomes, aquatic systems, and taxa, and discuss implications for research planning and climate-biodiversity policy in Brazil.

INTRODUCTION

As the world nears the Paris climate targets of 1.5 to < 2.0°C above pre-industrial levels, there is growing acknowledgment of humanity's urgent need to prepare for climate change's adverse impacts [1]. The 2023–2024 El Niño Southern Oscillation cycle, intensified by global warming, wreaked havoc across various regions, including heatwaves, wildfires, hurricanes, heavy rainfall, flooding, and disruptions to marine ecosystems [2]. Addressing this challenge necessitates bolstering resilience and adaptability to climate impacts, establishing early warning systems, and safeguarding vulnerable communities. However, alleviating the effects of climate change on biodiversity is paramount. These impacts can profoundly affect human societies by disrupting trophic relationships and the energy flow, and by endangering species and populations, with consequences for ecosystem structure, function, and environmental services [3].

Species respond diversely to temperature, humidity, and seasonal shifts, rendering some more susceptible to extinction as temperatures and seasons change [4]. Anthropogenic disturbances and carbon emissions exacerbate these effects, potentially leading to synergistic impacts, particularly in dynamic regions like Amazonia and Central America. These impacts can cascade and be amplified by CO_2 emission overshoots [5]. Climate change exacerbates the biodiversity crisis, which could mirror major extinction events in the history of life [6]. Brazil's vast biodiversity is highly vulnerable to declines driven by global warming, particularly in land and freshwater habitats, with projections indicating alarming biodiversity loss in certain regions.

Brazil is especially vulnerable to biodiversity loss under climate change because it harbors a large share of global biodiversity and includes many tropical species living close to their critical climatic limits [7–9]. Rapid environmental change may therefore lead to severe population declines, local isolation, and an increased risk of extinction [10]. This vulnerability is amplified by Brazil's continental extent, environmental heterogeneity, and the difficulty of reconciling development and sustainability across regions. Climate change can also disrupt ecosystem balance, food production, and natural resource use, while effective mitigation and adaptation remain constrained by limited technical knowledge on impacts across biomes, taxonomic groups, and interacting drivers [11, 12].

Beyond ecological vulnerability, Brazil exhibits substantial inequalities in the distribution of scientific capacity and attention across its territory. Research infrastructure, postgraduate training, and public biodiversity funding are unevenly distributed among regions, with particularly important constraints in Amazonia [13, 14]. Ecological coverage is likewise uneven: the Atlantic Forest and Amazonia feature prominently in recent syntheses, whereas the Pantanal, Pampa, Caatinga, and marine environments remain less consistently represented [13, 15, 16]. Malecha et al. documented strong spatial and taxonomic imbalances in studies projecting climate-change impacts on Brazilian biodiversity, including limited information for the Pantanal, Pampa, marine environments, and several taxonomic groups [16]. Taxonomic biases are also well established in conservation research, although their direction varies among research domains: plants and charismatic vertebrates often receive disproportionate attention, whereas many invertebrates, amphibians, and reptiles remain less studied [17–19]. These asymmetries can shape the evidence available for conservation decisions and motivate an explicit examination of how climate-biodiversity research effort is distributed across ecological, taxonomic, and institutional dimensions.

In this context, we use a systematic bibliometric and evidence-mapping approach to characterize patterns within a clearly defined Web of Science corpus of climate-change and biodiversity studies focused explicitly on Brazil. Rather than synthesizing study-level effect sizes, we identify, screen, and code publications to quantify where research has been conducted, which taxa and ecological levels have been emphasized, which climatic drivers and co-occurring pressures have been examined, and how research output has changed through time. We then model publication counts to evaluate variation across biomes, taxonomic groups, and geopolitical regions. The ecological and geopolitical dimensions are complementary rather than independent: biomes represent environmentally defined units of biodiversity and conservation relevance, whereas political regions provide a distinct lens on the distribution of institutions, postgraduate training, and research capacity. This approach complements formal meta-analyses by describing the structure of an evidence base that can support subsequent effect-size syntheses [20, 21]. Recent work has quantified projected climate-change risks to Brazilian biodiversity using effect-size-based analyses [16]; our objective is different, focusing on how scientific attention and research capacity are distributed. Because our search deliberately required explicit reference to both biodiversity and Brazil in Web of Science Topic fields, our inference is restricted to the literature retrieved under this reproducible search strategy rather than to an exhaustive census of all Brazilian climate-biodiversity research.

Here, we analyze the resulting literature corpus to address three related questions. First, how has climate-biodiversity research effort changed through time and across Brazilian biomes, political regions, and taxonomic groups? Second, how is publication effort associated with ecological information (including numbers of species evaluated for extinction risk and threatened species) and with a proxy for regional scientific capacity? Third, which ecological levels, climatic drivers, biodiversity responses, ecosystem types, and additional environmental or anthropogenic pressures are most frequently represented? By focusing on scientific production rather than projected biodiversity effect sizes, our study complements recent quantitative syntheses of climate-change risk in Brazil [16]. We also examine institutional participation and international collaboration to place geographic patterns of publication output in the context of the Brazilian research system.

We evaluated three a priori expectations. (1) Biome allocation: publication effort would be uneven among Brazilian biomes, with greater representation of highly visible and species-rich systems such as the Atlantic Forest and Amazonia. (2) Regional research capacity: publication output would differ among political regions and would be greater where biodiversity postgraduate capacity is more concentrated; this analysis treats political regions as institutional units and does not assume independence from biome geography. (3) Taxonomic allocation: publication effort would be uneven among major taxonomic groups, reflecting established taxonomic biases in biodiversity and conservation research [18, 19]. We treated other coded dimensions—climatic drivers, biological responses, ecological levels, ecosystem types, study coverage, reported effects, and co-occurring pressures—as exploratory descriptors of the thematic structure of the retrieved literature rather than as a single confirmatory hypothesis.

METHODS

Following the PRISMA 2020 reporting recommendations for systematic reviews [22], we conducted the study in four sequential stages: literature search, article screening, predictive classification, and structured data extraction. We searched the Web of Science (WoS) Core Collection using the Topic query TS = ((“climate change” OR “global change” OR “global warming”) AND “biodiversity” AND “Brazil”), covering the Science Citation Index Expanded for all years from 1945 to 2023. The Topic field included title, abstract, author keywords, and Keywords Plus [23]. We selected WoS for its standardized metadata, rigorous indexing, broad coverage of environmental journals, and widespread use in evidence synthesis and bibliometric studies [20, 24, 25]. The search was intentionally conservative: requiring explicit reference to “Brazil” and “biodiversity” increased geographic specificity and reproducibility but reduced recall, so studies referring only to a biome name, Brazilian locality, or the adjective “Brazilian” without the term “Brazil” may not have been retrieved. Accordingly, we treat the resulting dataset as a bounded, reproducible WoS corpus rather than an exhaustive census of all climate-biodiversity research conducted in Brazil. We applied structured inclusion and exclusion criteria (Table 1) using a review framework adapted to our question [26]. We interpreted biodiversity broadly to encompass taxonomic, functional, phylogenetic, and genetic diversity across populations, communities, and ecosystems, including fauna, flora, and associated ecosystem components. The search returned 633 records, which underwent an initial eligibility assessment followed by validation. Trained evaluators classified records

as eligible or ineligible, and experienced researchers subsequently checked those decisions; thus, each record passed through both screening and validation stages before final inclusion. To assist prioritization, we assembled a balanced training subset of 50 eligible and 50 ineligible articles and used it to develop a multinomial Naïve Bayes text-classification model in R [27, 28]. We evaluated model performance by cross-validation using accuracy, precision, recall, and F1 score. The classifier supported screening but did not determine final eligibility; we ultimately reviewed and validated all 633 records and included all eligible articles in the bibliometric dataset for structured data extraction (Fig. 1).

Table 1
Inclusion and exclusion criteria used for article screening, structured according to our adapted PICO organizing framework in the evidence-mapping and bibliometric analyses of climate change impacts on Brazilian biodiversity.

Criterion Type	Inclusion Criteria	Exclusion Criteria
Population (P)	Studies addressing Brazilian biodiversity (any biome, region, or taxon)	Studies not clearly referring to Brazil or Brazilian biodiversity
Intervention (I)	Studies evaluating the effects of climate change drivers (e.g., temperature, rainfall)	Studies addressing only other drivers (e.g., pollution, land use, without climate)
Comparison (C)	Studies allowing comparison across regions, biomes, or taxonomic groups	Studies without any spatial/taxonomic breakdown
Outcomes (O)	Studies reporting impacts on biodiversity, including distribution and richness.	Articles lacking biological outcomes (e.g., economic-only, policy-only analyses)
Study Type	Primary empirical research articles (field, modeling, or observational data)	Reviews, meta-analyses, theoretical essays, or methodological notes
Language	Articles written in English or Portuguese	Other languages without accessible translation
Publication Type	Peer-reviewed journal articles	Conference abstracts, theses, reports, grey literature

We coded variables representing ecological allocation, institutional geography, taxonomic allocation, and thematic content. For biome-level analyses, we recorded Amazonia, Atlantic Forest, Cerrado, Caatinga, Pantanal, Pampa, and the Coastal-Marine System [29]. For regional analyses, we recorded the five Brazilian political regions (North, Northeast, South, Southeast, and Central-West) [30]. We used these spatial classifications for different purposes: biomes represent ecological units, whereas political regions provide an institutional and administrative perspective on research capacity. As a simple, nationally standardized proxy for regional scientific capacity, we compiled the number of biodiversity-related postgraduate programs in each political region from CAPES [31]. We selected this metric because postgraduate programs concentrate researchers, students, infrastructure, and training opportunities that contribute directly to scientific production; we recognize that it does not capture all

dimensions of research capacity, such as total funding or numbers of resident researchers. To explore whether publication effort tracked the amount of available conservation information, we also compiled from IBGE the number of species evaluated for extinction risk and the number classified as threatened, by biome and taxonomic group [32]; we did not treat these quantities as estimates of total known species richness. For taxonomic analyses, we grouped the focal biota into broad categories that retained biologically interpretable groups while maintaining sufficient replication for comparison: plants, insects, other invertebrates, birds, mammals, reptiles, amphibians, and fish. We retained “ecosystems” and “socio-biodiversity” as separate non-taxonomic analytical categories for studies centered on landscapes, ecosystems, or biodiversity-linked production systems. This grouping was intended to characterize broad research allocation rather than fine-scale taxonomy and is consistent with the literature documenting taxonomic biases in conservation research [18, 19]. We additionally coded climatic drivers (precipitation, temperature, humidity, and other climatic variables), biological responses (richness, distribution, habitat suitability, diversity, extinction risk, demography, and other responses), geographic coverage, ecological level, ecosystem type, reported effect (negative, positive, or neutral), and environmental or anthropogenic pressures examined together with climate change, including agriculture/livestock, land-use/cover change, habitat loss/fragmentation, fire, aridity/drought, and other anthropogenic disturbance. Because climate change was a search criterion, we expected it to appear frequently as an “impact” and did not interpret this as evidence that it was more important than the additional pressures; instead, we used these categories primarily to describe which co-occurring pressures were investigated alongside climate change. We also extracted annual scientific output, prominent terms, Brazilian institutional affiliations, international collaboration, and publication output by country. Categories were not mutually exclusive because a single article could address multiple biomes, regions, taxa, pressures, or biodiversity responses.

We first used the Boruta algorithm with random forest to identify variables contributing information to subsequent count-based analyses, using the Boruta package [33]. We then used generalized linear mixed models (GLMMs) to examine temporal variation in publication counts. The response variable was the number of publications per category and year. We evaluated four global model sets that combined biome or political region with taxonomic group, and reported effects with either co-occurring pressure categories or taxonomic group. We fitted Bayesian models with brms [34] when more complex model structures did not converge well under the frequentist framework. We compared candidate model structures using the leave-one-out cross-validation information criterion (LOOIC), calculated with the loo package [35]. For each explanatory variable analyzed separately, we fitted additional GLMMs with publication year included as a random effect using glmmTMB [36]. These simpler frequentist models converged satisfactorily and were used to compare publication counts among levels of each factor. Model support was evaluated with Akaike’s Information Criterion (AIC).

For all model sets, we compared candidate count distributions, including Poisson, negative binomial, zero-inflated Poisson, and zero-inflated negative binomial distributions, before comparing model structure. Candidate structures included interaction, additive, single-predictor, and null models as applicable, with publication year retained as a random effect. For frequentist models, we obtained post

hoc Tukey-adjusted pairwise comparisons with emmeans when appropriate [37]. For Bayesian models, we based inference on posterior estimates and 95% credible intervals rather than *p*-values. We conducted all statistical analyses in R [38].

RESULTS

The WoS search retrieved 633 records up to November 30, 2023. The text classifier identified 169 potentially eligible records (accuracy = 0.85, precision = 1.00, recall = 0.78, F1 = 0.87); however, we determined final eligibility through review and validation, yielding 111 articles for analysis (Supplementary Material). The earliest included publications appeared around 2004, and publication output increased markedly after 2010 and especially after 2018 (Fig. S1a). A word cloud summarized the most frequent abstract terms (Fig. S1b). The Boruta analysis identified the coded explanatory variables as informative for publication counts (Table S1, Fig. S2). Despite the many zero counts across category-year combinations, model comparison favored the Poisson distribution for the retained GLMMs (Table S2). For the four global model sets, additive models received greater support than interaction models, indicating that the main factors contributed independently within the fitted models. All results below refer specifically to the 111 publications retrieved and retained under our predefined WoS search and eligibility criteria.

Biomes

Within the retrieved *corpus*, publication counts differed among biomes and taxonomic groups over time, with no supported interaction between these factors (Table S3). The Atlantic Forest had the highest publication count, followed by the Cerrado and Caatinga; Amazonia, Pampa, Pantanal, and the Coastal-Marine System were represented less frequently (Fig. 2a). Publications increased through time across biomes, while their relative representation remained broadly similar (Fig. 2b). Pairwise comparisons distinguished several of the more frequently represented biomes (Atlantic Forest, Cerrado, and Caatinga) from the least represented (Pampa, Pantanal, and Coastal-Marine), whereas Amazonia did not differ clearly from Cerrado, Caatinga, or Pampa (Fig. 3b, Fig. S3). Publication counts were positively associated with the number of species evaluated for extinction risk and, particularly, the number classified as threatened within biomes (Table S3). These patterns support uneven ecological allocation of research effort within this bounded evidence corpus, with especially high representation of the Atlantic Forest and Cerrado.

Brazilian geographic regions

Publication counts also differed among political regions and taxonomic groups, with the additive model favored over an interaction model (Table S2). The Northeast and Southeast accounted for the largest numbers of included publications, followed by the South, North, and Central-West (Fig. 2c), and publication output increased through time in all five regions (Fig. 2d). Pairwise comparisons indicated

higher counts in the Northeast and Southeast than in the North and Central-West, while the South did not differ clearly from the other regions (Fig. 3c, Fig. S4). Regional publication counts were positively associated with the number of biodiversity-related postgraduate programs (Table S3), consistent with the use of this variable as a proxy for scientific capacity. Because political regions overlap geographically with several biomes, we interpret these results as an institutional-geographic perspective on research production rather than an independent ecological pattern.

Taxonomic groups

Publication counts varied strongly among taxonomic categories. Plants were the most frequently represented group, followed by insects, other invertebrates, birds, mammals, and ecosystem-level studies, whereas reptiles, amphibians, socio-biodiversity, and fish were represented least often (Fig. 3a). Pairwise comparisons showed substantially more plant-focused articles than articles in most other categories, and insects and birds were more frequently represented than reptiles (Fig. S5). Publication counts across taxonomic groups were associated with the numbers of species evaluated for extinction risk and classified as threatened (Tables S3-S4). The additive models indicated broadly consistent differences among taxonomic groups across biomes and political regions (Fig. 3b-c, Figs. S5-S6). Notably, the relatively high representation of insects and other invertebrates contrasts with the vertebrate-dominated pattern often reported for conservation research, making this a distinctive feature of the climate-biodiversity corpus analyzed here.

Ecological and climatic aspects

Exploratory thematic analyses showed that reported biodiversity effects were predominantly negative, followed by positive and neutral effects (Fig. 4a, Fig. S8). Because the search strategy required climate change, its high frequency as an impact category was expected and was not interpreted comparatively. Instead, we focused on additional pressures examined together with climate change. Anthropogenic disturbance was the most frequently coded co-occurring pressure, followed by land-use/cover change, habitat loss/fragmentation, agriculture/livestock, aridity/drought, and fire (Fig. 4b). Negative reported effects predominated across the different pressure categories (Fig. 4c).

Reported effects also varied among taxonomic groups, but the selected additive model provided no evidence that the distribution of effect classes depended strongly on taxonomic group (Table S2). Negative effects predominated in most groups, whereas plants and insects showed a somewhat larger proportion of positive effects than other categories (Fig. 4d; Figs. S9-S10). These results describe the composition of the retrieved literature and should not be interpreted as pooled biological effect sizes.

Most included articles focused on Brazil, with fewer studies covering South America, the Pan-American region, the Neotropics, or global extents (Fig. 5a; Tables S4-S5). Terrestrial environments were represented more frequently than aquatic or marine environments (Fig. 5b), and community- and

population-level studies were more frequent than ecosystem- and socio-environmental studies (Fig. 5c). Temperature and precipitation dominated the climatic drivers coded from the literature, whereas humidity and other climatic variables occurred less often (Fig. 5d). Among biological responses, distribution was most frequent, followed by richness, diversity, habitat suitability, extinction risk, demography, and other responses (Fig. 5e). These exploratory patterns identify thematic dimensions that are relatively well represented or comparatively sparse within the retrieved corpus.

Leading institutions and collaborations between countries

Institutional and collaboration patterns provided additional context for the regional distribution of research capacity. Universidade de São Paulo was the most frequently represented Brazilian institution, followed by Universidade Federal de Goiás, Universidade Federal de Pernambuco, Universidade Federal de Santa Catarina, and Universidade Estadual de Campinas (Fig. S11a). International collaborations most frequently involved the United States, United Kingdom, Portugal, Argentina, Germany, and Australia (Fig. S11b), while publication output by country also reflected contributions from other South American countries, Mexico, the United States, and Europe (Fig. S11c). These patterns align with the concentration of scientific infrastructure and postgraduate training in particular Brazilian regions, although they do not establish causation.

DISCUSSION

Our analysis reveals marked spatial, taxonomic, institutional, and thematic structure within a deliberately bounded WoS corpus of climate-change and biodiversity research focused explicitly on Brazil. Publication output increased strongly over the last two decades, reported effects were predominantly negative, and research effort was unevenly distributed among biomes, regions, and taxa. The Atlantic Forest and Cerrado were most strongly represented in our corpus, whereas the Pantanal, Pampa, and Coastal-Marine System were less represented. This ranking differs from Malecha et al. [16], who found particularly strong representation of the Atlantic Forest and Amazonia. The difference is important rather than contradictory: Malecha et al. searched multiple databases with a broader geographic query including biome names and several Brazil-related terms, whereas our search required explicit reference to both “Brazil” and “biodiversity” in WoS Topic fields. Our results therefore characterize patterns within this reproducible evidence subset and should not be interpreted as an exhaustive census of all Brazilian climate-biodiversity research. Within that scope, the analyses provide a detailed view of how scientific attention is allocated across ecological and institutional dimensions.

The regional analysis adds an institutional perspective that differs from, though is geographically correlated with, the biome analysis. The Southeast and Northeast had the largest publication counts, while the North and Central-West were less represented. These differences are consistent with longstanding inequalities in Brazilian scientific capacity and public biodiversity investment [14]. The positive association between publication counts and biodiversity-related postgraduate programs supports the view that training and institutional capacity shape the geography of scientific production.

We use postgraduate programs only as a standardized proxy: funding, numbers of resident researchers, institutional age, and accessibility also influence research output but were not available in a directly comparable form for our analysis. The regional and biome analyses should therefore not be read as independent spatial tests; rather, they provide complementary institutional and ecological views of where climate-biodiversity research has been produced.

Taxonomic allocation showed both familiar and unexpected patterns. Plants were the most frequently represented group, but insects and other invertebrates also ranked ahead of birds and mammals, whereas reptiles, amphibians, and fish were comparatively scarce. This differs from the vertebrate-heavy bias commonly documented in conservation research [18, 19] and from Malecha et al. [16], whose quantitative risk projections were dominated by plants and terrestrial vertebrates. The relatively strong representation of insects and other invertebrates in our corpus may reflect climate-change-specific research themes, including pollination, crop interactions, invasive species, and ecosystem services, as well as the particular search and eligibility criteria used here. Because our design cannot separate these mechanisms, we interpret this difference cautiously, but it indicates that taxonomic bias in climate-biodiversity research need not mirror the broader conservation literature. Conversely, the limited representation of reptiles, amphibians, fish, and aquatic biota remains a clear gap within the retrieved evidence base [39–41].

The exploratory thematic analyses further show that publication effort is concentrated on particular climatic and ecological dimensions. Temperature and precipitation were the dominant climatic drivers, while distribution, richness, diversity, and habitat suitability were among the most frequently evaluated biological responses. Terrestrial systems and community- or population-level studies were much more common than aquatic, marine, ecosystem, or socio-environmental research. Because climate change was a mandatory search term, its high frequency cannot be interpreted as evidence of greater importance relative to other pressures. More informative is the pattern of co-occurring pressures: anthropogenic disturbance, land-use change, habitat loss and fragmentation, and agriculture/livestock were repeatedly considered alongside climate change. This emphasis is ecologically relevant because habitat transformation and other anthropogenic pressures can constrain climate-driven range shifts and population responses [42, 43].

Our study also illustrates both the value and the limitations of computational support for literature synthesis. Large bibliographic datasets require substantial screening effort [44], and text-classification algorithms can help prioritize records without replacing expert eligibility assessment [45]. In our workflow, the Naïve Bayes classifier accelerated screening, but all records ultimately underwent researcher review and validation. A more important limitation concerns evidence retrieval itself. Restricting the search to WoS and requiring the exact terms “Brazil” and “biodiversity” improved reproducibility and geographic specificity but inevitably reduced recall. Consequently, relative frequencies - particularly biome rankings - may differ from broader syntheses using multiple databases or biome-specific search terms. The strength of our design lies in transparently characterizing this defined *corpus*, not in claiming exhaustive coverage of every relevant Brazilian publication. Future

bibliometric comparisons could explicitly test how database choice and geographic search syntax alter apparent research gaps.

Implications for conservation

Within the retrieved *corpus*, climate-biodiversity research increased markedly from the early 2000s onward, particularly after 2018. This trajectory parallels the growing scientific and policy prominence of climate change and the expansion of climate projections and species-distribution modeling [46, 47]. The literature analyzed here focuses mainly on community richness and diversity, species distributions, and habitat suitability, while ecosystem services and socio-biodiversity remain emerging components [48]. For research planning, the key implication is not simply that some categories have fewer publications, but that uneven evidence coverage can constrain the ability to compare climate risks and design adaptation strategies across ecosystems, taxa, and regions.

Priorities should therefore be interpreted in relation to the scope of the retrieved evidence rather than as an exhaustive national ranking. The Pantanal, Pampa, Coastal-Marine System, aquatic environments, reptiles, amphibians, and fish were all sparsely represented in our corpus, and independent syntheses likewise identify important information gaps in several of these systems [16, 49]. At the same time, Amazonia deserves sustained investment because of its extraordinary biodiversity, climatic exposure, and documented inequalities in research funding and infrastructure [14, 50]. More balanced research support should combine ecological need with institutional capacity building, including postgraduate training, long-term monitoring, data infrastructure, and collaboration networks. Such measures are directly relevant to climate adaptation, biodiversity conservation, and the Sustainable Development Goals, particularly Climate Action, Life Below Water, and Life on Land.

Global Implications

Although our analysis is nationally focused, the underlying problem is broader: scientific evidence on climate-change impacts is produced unevenly across space, taxa, ecosystems, and institutions. Similar asymmetries can occur in other megadiverse tropical countries where biodiversity value, accessibility, research infrastructure, and funding are spatially mismatched [51–53]. Our workflow demonstrates how a transparent, bounded bibliographic corpus can be combined with systematic coding, machine-learning-assisted screening, and count-based models to diagnose those asymmetries. The results are particularly relevant to environmental research planning because apparent knowledge gaps should be interpreted jointly with the search design that generated the evidence base. This combination of methodological transparency and explicit scope of inference can support more defensible prioritization of future climate-biodiversity research.

Conclusion

Our systematic bibliometric analysis identifies substantial asymmetries within a reproducible WoS corpus of research on climate change and Brazilian biodiversity. Publications increased strongly after the early 2000s, but their distribution remained uneven across biomes, political regions, taxa, ecosystem types, and thematic dimensions. The Atlantic Forest and Cerrado were strongly represented within this corpus, while the Pantanal, Pampa, and Coastal-Marine System were less represented; the Southeast and Northeast accounted for much of the regional output, whereas the North and Central-West had fewer publications. Plants were the most frequently studied taxonomic group, but the comparatively high representation of insects and other invertebrates - relative to birds and mammals - distinguishes this climate-biodiversity corpus from the vertebrate-dominated pattern often reported in conservation research. Reptiles, amphibians, fish, aquatic systems, and several ecosystem-level dimensions remained comparatively sparse. These patterns should be interpreted within the limits of our deliberately conservative search, which prioritized geographic specificity and reproducibility over exhaustive retrieval. Even with that limitation, the study demonstrates how uneven scientific capacity and ecological coverage can shape the evidence available for environmental decision-making. More balanced investment in research infrastructure, long-term monitoring, understudied systems, and open, standardized evidence can strengthen the basis for climate adaptation and biodiversity conservation in Brazil.

Declarations

Supplementary Information

Supplementary material related to this article is provided with the submission. The underlying coded dataset has been deposited in the Dryad Digital Repository and will be made publicly available upon acceptance; we will add the final DOI when available.

Ethics approval:

Not applicable.

Consent to Participate:

Not applicable.

Consent to Publish:

Not applicable.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

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Author Contribution

Tarcísio L. S. Abreu: Conceptualization, Methodology, Data curation, Formal analysis, Visualization, Writing – original draft, Project administration, Writing – review & editing. Vitor H. G. L. Cavalcante: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. Ana Luiza A. Ferreira: Data curation, Investigation, Writing – review & editing. Júlia W. R. Nacif: Data curation, Investigation, Writing – review & editing. Almir De Paula: Data curation, Writing – original draft, Writing – review & editing. Hernani F. M. Oliveira: Conceptualization, Methodology, Formal analysis, Writing – review & editing. Geraldo W. Fernandes: Writing – review & editing, Supervision. Cecília R. Vieira: Project administration, Supervision, Writing – review & editing. Guarino R. Colli: Conceptualization, Supervision, Validation, Writing – original draft, Writing – review & editing, Funding acquisition.

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DATA AVAILABILITY

Not applicable.

References

1. Sanson A, Masten A. Climate change and resilience: Developmental science perspectives. Int J Behav Dev. 2024;48(2):93–102.
2. Jiang N, et al. Enhanced risk of record-breaking regional temperatures during the 2023-24 El Niño. Sci Rep. 2024;14(2521):1–10.
3. Price J, et al. Assessing the potential risks of climate change on the natural capital of six countries resulting from global warming of 1.5 to 4°C above pre-industrial levels. Clim Change. 2024;177(3):1–20.
4. Arruda V, et al. Assessing four decades of fire behavior dynamics in the Cerrado biome (1985 to 2022). Fire Ecol. 2024;20(1):1–20.

5. Wunderling N, et al. Global warming overshoots increase risks of climate tipping cascades in a network model. Nat Clim Change. 2023;13(1):75–.
6. Pörtner HO, et al. Overcoming the coupled climate and biodiversity crises and their societal impacts. Science. 2023;380(6642):1–11.
7. Core W, Team H, Lee, Romero J. Climate Change 2023. Synthesis Report: Summary for Policymakers. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC; 2023. pp. 1–34.
8. Deutsch CA, et al. Impacts of climate warming on terrestrial ectotherms across latitude. Proc Natl Acad Sci USA. 2008;105(18):6668–72.
9. Huey RB, et al. Predicting organismal vulnerability to climate warming: roles of behaviour, physiology and adaptation. Philosophical Trans Royal Soc B-Biological Sci. 2012;367(1596):1665–79.
10. Chowdhury S, et al. Insects as bioindicator: A hidden gem for environmental monitoring. Front Environ Sci. 2023;11(1146052):1–16.
11. Hagen I, et al. Climate change-related risks and adaptation potential in Central and South America during the 21st century. Environ Res Lett. 2022;17(3):1–26.
12. Moura FR, Silva FMR Jr. 2030 Agenda: Discussion on Brazilian priorities facing air pollution and climate change challenges. Environmental Science and Pollution Research, 2022. 30(3): pp. 8376–8390.
13. Chiquetto JB, Nolasco MA. New insights on climate change and adaptation research in Brazil: A bibliometric and bibliographic review. Discover Environ. 2024;2(36):1–15.
14. Stegmann L, et al. Brazilian public funding for biodiversity research in the Amazon. Perspect Ecol Conserv. 2024;22(1):1–7.
15. Tourinho L, et al. Projected impacts of climate change on ecosystem services provided by terrestrial mammals in Brazil. Ecosyst Serv. 2025;71:1–13.
16. Malecha A, Manes S, Vale M. Climate change and biodiversity in Brazil: What we know, what we don't, and Paris Agreement's risk reduction potential. Perspect Ecol Conserv. 2025;23(2):77–84.
17. Teixido A et al. Major biases and knowledge gaps on fragmentation research in Brazil: Implications for conservation. Biol Conserv, 2020. 251.
18. Di Marco M, et al. Changing trends and persisting biases in three decades of conservation science. Global Ecol Conserv. 2017;10:32–42.
19. Winter M, et al. Patterns and biases in climate change research on amphibians and reptiles: A systematic review. Royal Soc Open Sci. 2016;3(9):16.
20. Gurevitch J, et al. Meta-analysis and the science of research synthesis. Nature. 2018;555(7695):175–82.
21. Paul J, Barari M. Meta-analysis and traditional systematic literature reviews—What, why, when, where, and how? Volume 39. Psychology & Marketing; 2022. pp. 1099–115. 6.

22. Page M et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, 2021. 372.
23. Boudry C, Baudouin C, Mouriaux F. International publication trends in dry eye disease research: A bibliometric analysis. Ocular Surf. 2018;16(1):173–9.
24. Grames E, et al. An automated approach to identifying search terms for systematic reviews using keyword co-occurrence networks. Methods Ecol Evol. 2019;10(10):1645–54.
25. Haddaway N, Westgate M. Predicting the time needed for environmental systematic reviews and systematic maps. Conserv Biol. 2019;33(2):434–43.
26. Nishikawa-Pacher A. Research questions with PICO: A universal mnemonic. Publications, 2022. 10(3).
27. Benoit K, et al. quanteda: An R package for the quantitative analysis of textual data. J Open Source Softw. 2018;3(30):1–4.
28. Rubenstein M et al. Climate change and the global redistribution of biodiversity: Substantial variation in empirical support for expected range shifts. Environ Evid, 2023. 12(1).
29. IBGE - Coordenação de Recursos Naturais e Estudos Ambientais. Biomas e Sistema Costeiro-marinho do Brasil: Compatível com a Escala 1:250 000. Rio de Janeiro: IBGE; 2019. p. 164.
30. IBGE, *Atlas Geográfico Escolar*. 9a Edição ed. 2023, Rio de Janeiro: IBGE, Centro de Documentação e Disseminação de Informações.
31. CAPES, *Cursos Recomendados / Reconhecidos.* https://www.gov.br/capes/pt-br/acesso-a-informacao/acoes-e-programas/avaliacao/sistema-nacional-de-pos-graduacao-snpg/dados-do-snpg/cursos-recomendados-reconhecidos. 2024.
32. IBGE. *Contas de Espécies Ameaçadas. Tabela 9625 - Número de espécies da fauna e da flora brasileira avaliadas quanto ao risco de extinção, por grupos taxonômicos, hábito ou forma de vida, tipo de ambiente, biomas e Sistema Costeiro-Marinho e categorias de risco.* https://sidra.ibge.gov.br/tabela/9625#notas-tabela. 2024.
33. Kursa MB, Rudnicki WR. Feature selection with the Boruta package. J Stat Softw. 2010;36(11):1–13.
34. Bürkner P. brms: An R package for Bayesian multilevel models Using Stan. J Stat Softw. 2017;80(1):1–28.
35. Vehtari A, Gelman A, Gabry J. Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. Stat Comput. 2017;27(5):1413–32.
36. Brooks ME, et al. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R J. 2017;9(2):378–400.
37. Lenth R. *emmeans: Estimated marginal means, aka least-squares means. R package version 2.0.3.* 2026.
38. Core Team R. *R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.* https://www.R-project.org/. 2026.

39. de Oliveira AG, Pelaez O, Agostinho AA. The effectiveness of protected areas in the Paraná-Paraguay basin in preserving multiple facets of freshwater fish diversity under climate change. Neotropical Ichthyol. 2021;19(3):1–20.
40. Biber MF, Voskamp A, Hof C. Potential effects of future climate change on global reptile distributions and diversity. Glob Ecol Biogeogr. 2023;32(4):519–34.
41. Magris RA, et al. A blueprint for securing Brazil's marine biodiversity and supporting the achievement of global conservation goals. Divers Distrib. 2021;27(2):198–215.
42. Cardillo M, Skeels A, Dinnage R. Priorities for conserving the world's terrestrial mammals based on over-the-horizon extinction risk. Curr Biol. 2023;33(7):1381–9.
43. Velazco SJE, et al. A dark scenario for Cerrado plant species: Effects of future climate, land use and protected areas ineffectiveness. Divers Distrib. 2019;25(4):660–73.
44. Foo YZ, et al. A practical guide to question formation, systematic searching and study screening for literature reviews in ecology and evolution. Methods Ecol Evol. 2021;12(9):1705–20.
45. Kowsari K, et al. Text classification algorithms: A survey. Information. 2019;10(4):1–68.
46. Howe PD, et al. How will climate change shape climate opinion? Environ Res Lett. 2019;14(11):1–17.
47. Fick S, Hijmans R. WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. Int J Climatol. 2017;37(12):4302–15.
48. Estevo MdO, et al. Understanding multidirectional climate change impacts on local livelihoods through the lens of local ecological knowledge: A study in western Amazonia. Volume 36. Society & Natural Resources; 2023. pp. 1–18. 3.
49. Schoeman DS, Bolin JA, Cooley SR. *Quantifying the ecological consequences of climate change in coastal ecosystems.* Cambridge Prisms: Coastal Futures, 2023. 1(e39): pp. 1–18.
50. Nóbrega R, et al. Co-developing pathways to protect nature, land, territory, and well-being in Amazonia. Commun Earth Environ. 2023;4(364):1–5.
51. Nunez S, et al. Assessing the impacts of climate change on biodiversity: Is below 2°C enough? Clim Change. 2019;154(3–4):351–65.
52. IPBES. In: Brondizio ES, et al. editors. Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Bonn, Germany: IPBES Secretariat; 2019. p. 1148.
53. Bastazini V, et al. The impact of climate warming on species diversity across scales: Lessons from experimental meta-ecosystems. Glob Ecol Biogeogr. 2021;30(7):1545–54.

Figures

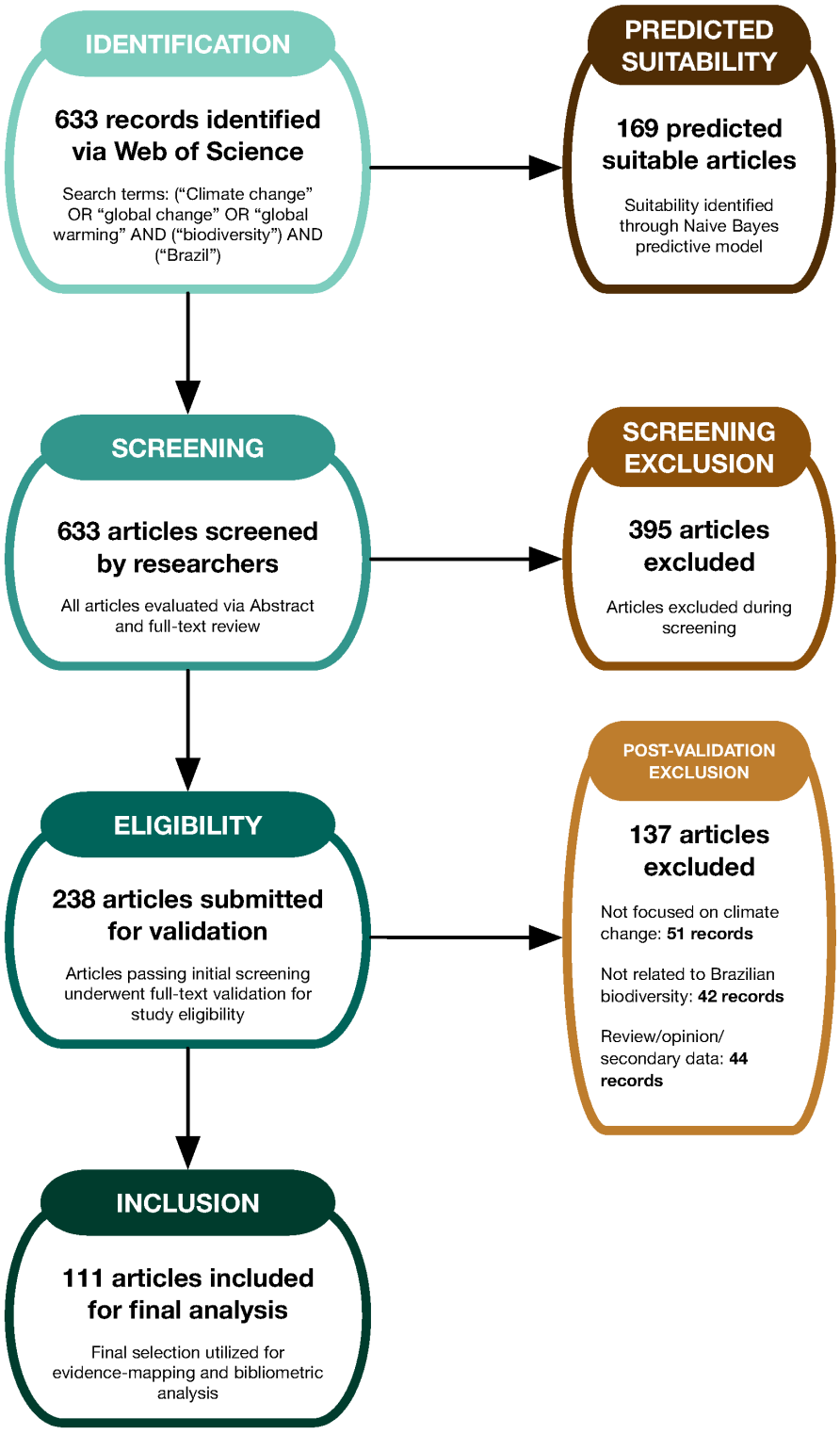


Figure 1

Workflow diagram of article identification, screening, predictive classification, eligibility assessment, and inclusion in the evidence-mapping and bibliometric analyses, following PRISMA 2020 reporting recommendations. The diagram summarizes the Web of Science search, researcher-based screening, Naïve Bayes predictive classification, full-text validation, and final inclusion of studies on the impacts of

climate change on Brazilian biodiversity. Numbers indicate records retained or excluded at each stage, including exclusions during initial screening and post-validation.

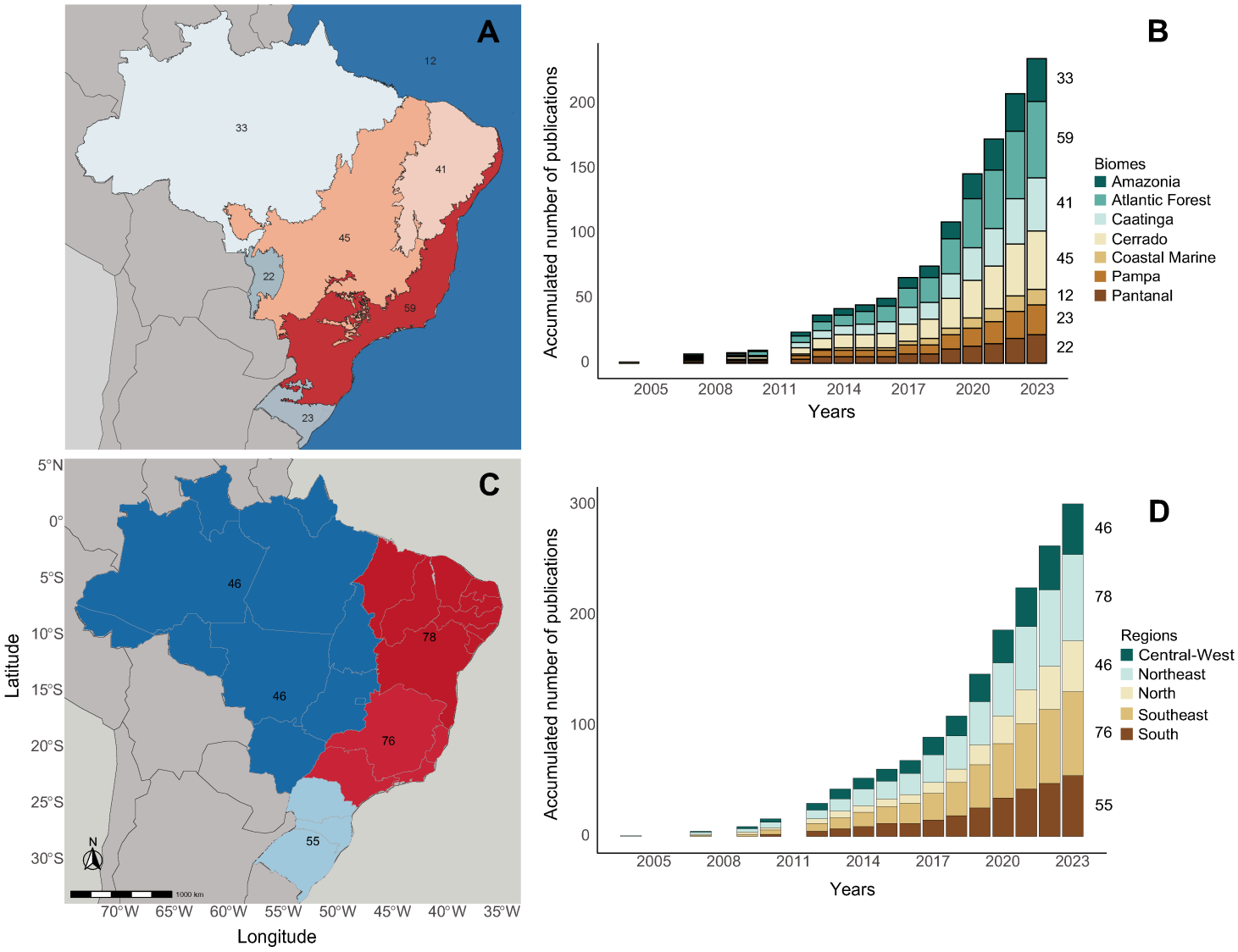


Figure 2

Spatial and temporal distribution of publication counts on climate change and biodiversity in Brazil. (A) Heat map showing total publications by Brazilian biome: Atlantic Forest (59), Cerrado (45), Caatinga (41), Amazonia (33), Pampa (23), Pantanal (22), and Coastal-Marine (12). (B) Annual publication counts for each Brazilian biome. (C) Heat map showing the total number of publications by Brazilian geographic region: Northeast (78), Southeast (76), South (55), Central-West (46), and North (46). (D) Annual publication counts for each Brazilian geographic region.

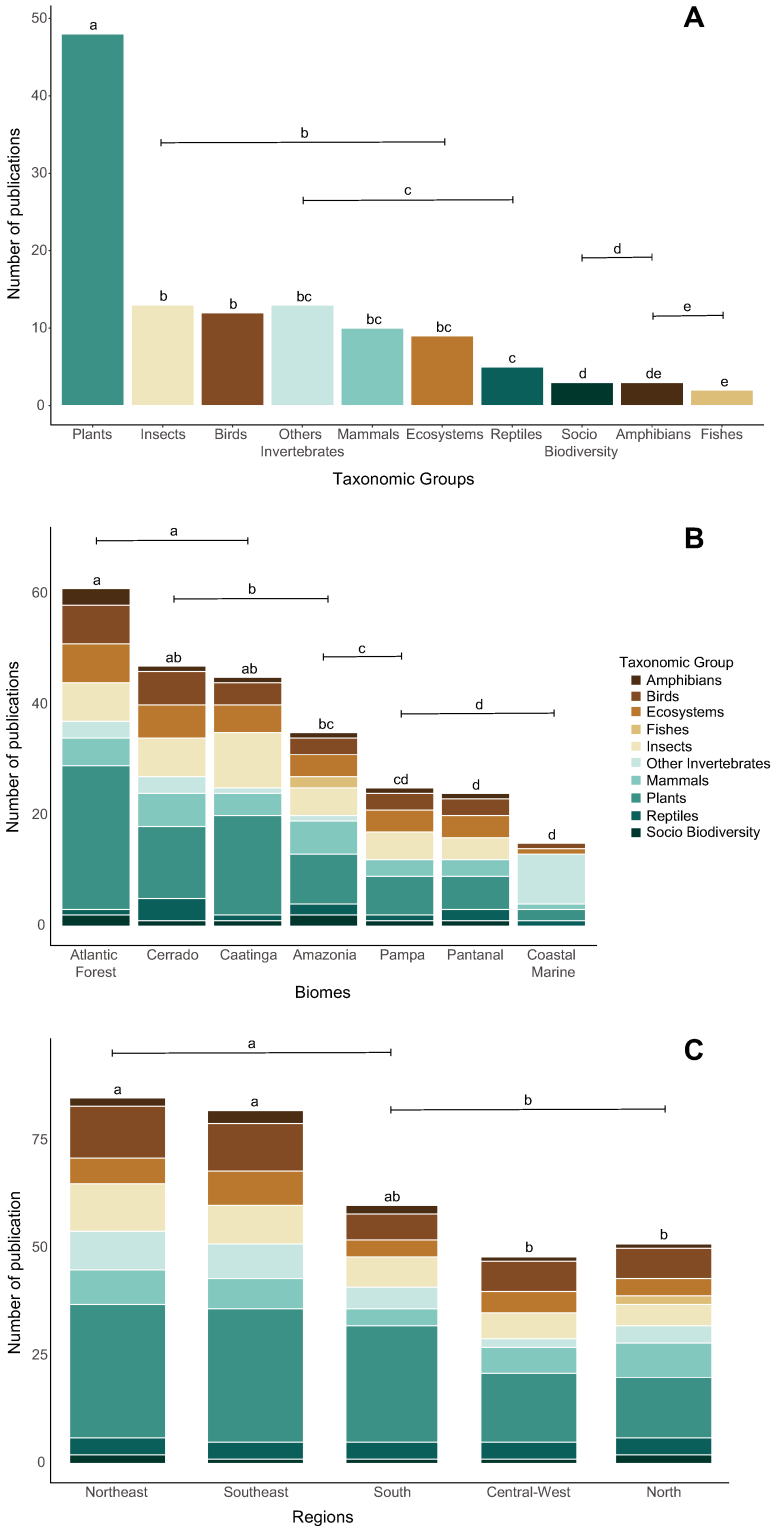


Figure 3

Modeled publication counts across taxonomic groups, biomes, and geographic regions based on the additive brms model. (A) Estimated publication counts by taxonomic group. (B) Estimated publication counts for the combination of Brazilian biomes and taxonomic groups, obtained from the best-fitting additive model. (C) Estimated publication counts for the combination of Brazilian geographic regions and taxonomic groups, obtained from the additive model. Letters above bars indicate groups that differ

according to posterior contrasts from the Bayesian model; groups sharing the same letter are not clearly differentiated by the model. Letters are ordered from higher to lower estimated publication counts (a > b > c > d > e).

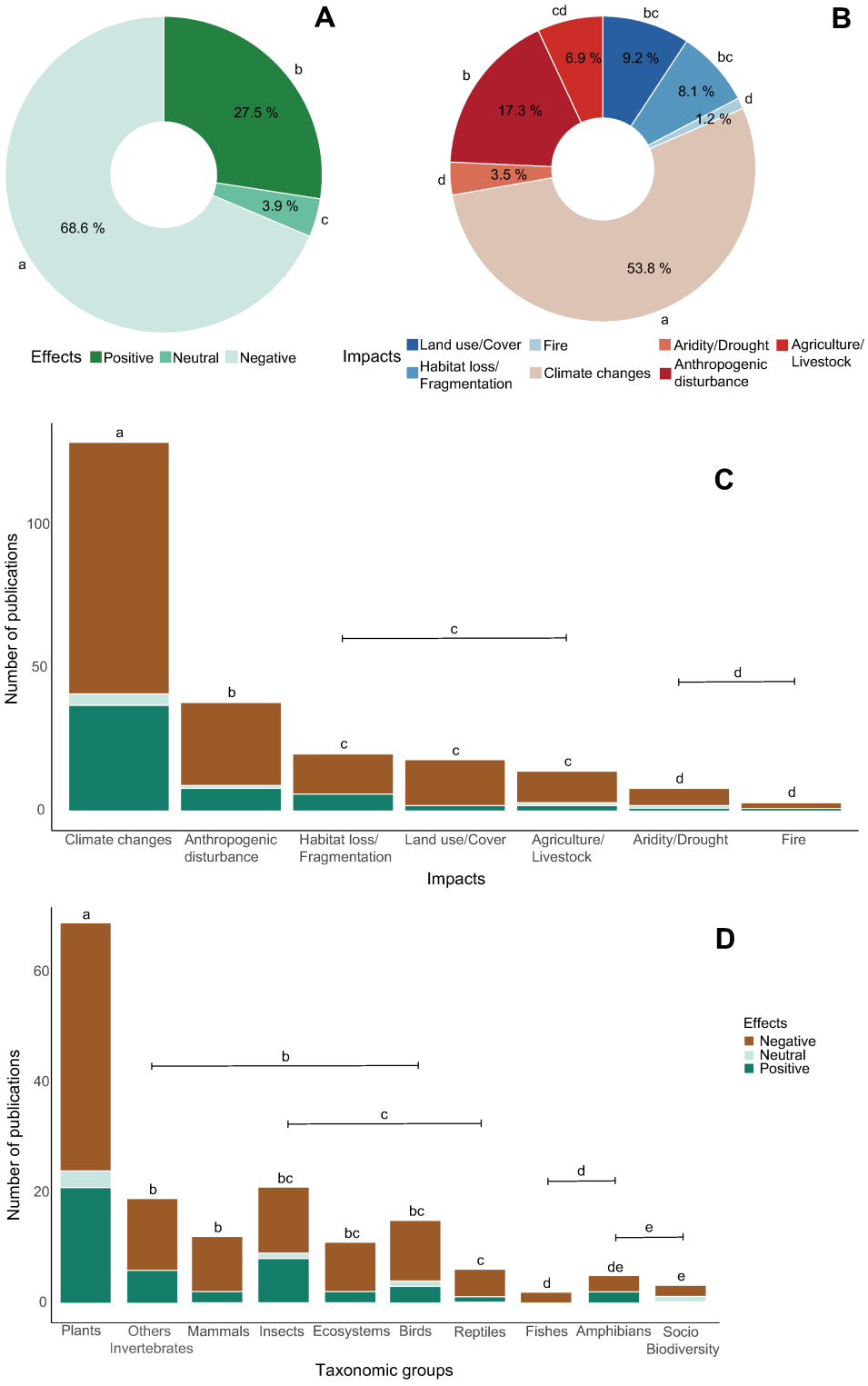


Figure 4

Reported effects and environmental or anthropogenic pressures coded in studies of climate change and Brazilian biodiversity. (A) Percentage of reported effects on biodiversity, classified as negative (N = 105), positive (N = 42), or neutral (N = 6). (B) Percentage of coded pressure categories, including climate change (96), anthropogenic disturbance (30), land-use and cover change (16), habitat loss and fragmentation (14), agriculture and livestock (12), aridity and drought (6), and fire (2). Because climate change was a search criterion, its frequency is descriptive and is not interpreted comparatively. (C) Estimated publication counts for combinations of pressure categories and reported effects. (D) Estimated publication counts for combinations of taxonomic groups and reported effects. Letters above bars in panels C and D indicate groups that differ according to posterior contrasts from the additive Bayesian brms models; groups sharing the same letter are not clearly differentiated by the model. Letters are ordered from higher to lower estimated values (a > b > c > d).

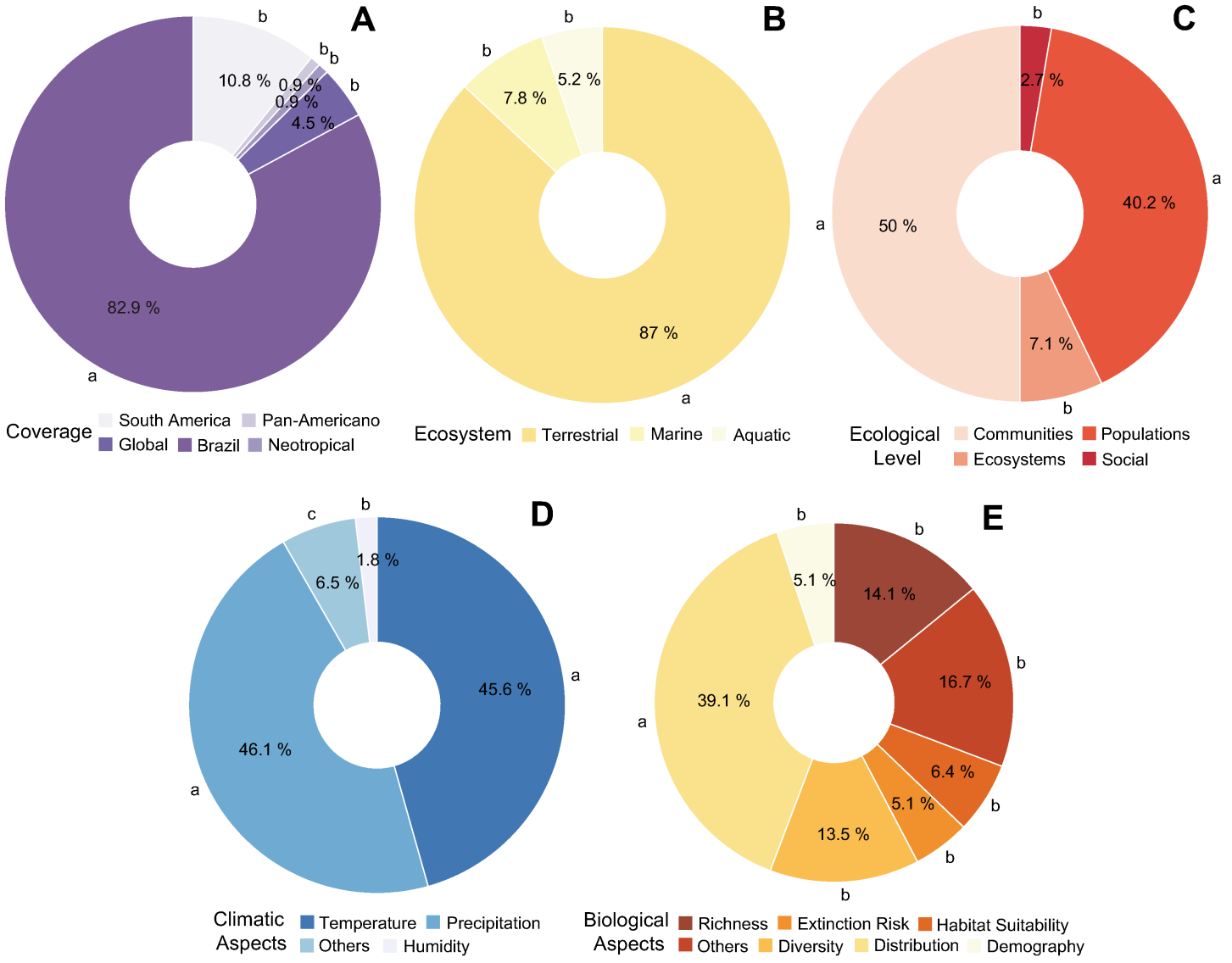


Figure 5

Distribution of coded study attributes across the 111 analyzed publications. Panels show the percentage of studies by geographic coverage (A), ecosystem type (B), ecological level (C), climatic driver (D), and biological response (E). Letters indicate groups that differ according to post hoc Tukey pairwise comparisons from the corresponding glmmTMB models; groups sharing the same letter do not differ significantly. Letters are ordered from higher to lower percentages (a > b > c > d).

Supplementary Files

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