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Equitable nature-based solutions begin with addressing the root causes of inequity

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Equitable nature-based solutions begin with addressing the root causes of inequity

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Abstract

As global funds are increasingly directed towards nature-based solutions (NbS), these interventions are expected to support climate-resilient development, particularly in Africa. Yet there are concerns that NbS can create new social inequities or exacerbate existing ones. We systematically reviewed 93 English-language studies of NbS implemented in southern Africa, published between 1960 and 2021, to identify the underlying drivers of negative social impacts and unequal benefit sharing. Our findings show that inequitable outcomes often persist despite equitable intentions, with the greatest burdens falling on poorer and marginalised groups. We inductively mapped the reasons for these inequitable outcomes into 32 Social Equity Constraints (SEC), which are factors that hinder the achievement of procedural, distributional, and recognitional equity. By identifying the contextual factors through which social equity in NbS is constrained or enabled, this study provides a framework to help funders, implementers, and communities design more equitable and sustainable NbS.

1. Introduction

Nature-based solutions (NbS) are a well-established approach to climate action and environmental governance, aiming to protect, restore, sustainably manage, or design ecosystems and land- and waterscapes in ways that address societal challenges while also supporting human wellbeing and biodiversity [1,2]. There is considerable evidence that NbS can reduce climate risk while generating biodiversity and livelihood co-benefits [3].

Despite this evidence, NbS have attracted sustained criticism, particularly from actors in the Global South, including Indigenous Peoples (IPs), local communities (LCs), practitioners, policy makers, and researchers [4–7]. A central concern is that mainstream NbS can produce social inequities, including negative impacts for those most vulnerable, and unequal benefit sharing where poorer or more marginalised groups receive few or no benefits, while less vulnerable groups capture a larger benefit share.

These concerns have persisted despite efforts by multilateral bodies, including IUCN and UNEA, to clarify NbS definitions and safeguards [8–11]. Critics have cautioned that NbS can be co-opted to legitimise narrow and easily quantified interventions, obscure trade-offs, enable green grabbing or green gentrification, or be framed as substitutes for rapid emissions reductions or rights-based and locally-led climate action, without the safeguards required to secure equitable outcomes [2,12–14].

Responding to these concerns requires engaging explicitly with social equity. Social equity is commonly understood through three dimensions: distributional equity, concerning how benefits, burdens, risks, and harms are allocated; procedural equity, concerning who participates in decision making and whether processes are transparent, inclusive, and accountable; and recognitional equity, concerning whether diverse identities, knowledge systems, and statutory and customary rights are acknowledged, respected, and represented[15]. A fourth, less frequently foregrounded dimension is contextual equity, also described as structural equity or equity in access. Contextual equity situates the other three dimensions within pre-existing conditions, including entrenched power asymmetries, historical exclusions and injustices, and socio-economic inequalities, that shape who can influence decisions, participate, access resources, and benefit or bear costs from interventions [16,17].

Contextual equity is thus particularly important for NbS because it mediates whether equitable intentions across the other three equity dimensions translate into equitable processes and outcomes. For example, limited consideration of contextual equity helps explain why some participatory or collaborative approaches do not necessarily lead to equitable outcomes and may instead reproduce power imbalances, exclusion, and tokenistic engagement [18,19]. Participation is not simply a matter of people being present, but whether those that are present are able to shape processes on fair terms. Here, epistemic injustice is especially relevant. It arises where some people or groups are wrongfully discounted as credible knowers because of their identity (testimonial injustice), or where differences in language, education, culture, or class prevent their experiences and knowledge from being understood and taken seriously (hermeneutical injustice) [20]. Without attention to contextual equity, participatory NbS processes risk becoming extractive or tokenistic, overlooking the factors that constrain epistemic justice and the differential capabilities required to participate meaningfully [21,22].

Despite the importance of contextual equity in mediating the other dimensions of social equity, there remains limited systematic understanding of the contextual factors through which NbS produce inequitable social outcomes. Existing work on barriers or constraints in climate change adaptation and NbS has often adopted effectiveness- or feasibility-centred

framings [23–27], which can obscure the mechanisms through which inequities are reproduced. Contextual factors such as poverty, weak institutions, or lack of finance are frequently treated as barriers to intervention performance rather than as factors that shape who participates, whose values count, who bears costs, and who benefits. A more explicit social equity-centred analysis is therefore needed.

Here, we apply a systematic approach to review the peer-reviewed literature on inequitable outcomes of NbS implemented in southern Africa. We focus only on papers reporting inequitable NbS outcomes, defined here as negative social impacts and/or unequal benefit sharing between social groups. Using these cases, we characterise inequitable outcomes by social group and outcome type. We then inductively and systematically develop 32 Social Equity Constraints (SEC) in NbS from the reasons described in the papers for why inequitable outcomes occurred.

Building on these systematically-derived constraints, we also qualitatively synthesise recurring themes in recommendations for enabling more equitable NbS. Together, the SEC and these recommendations inform a broader eight-factor synthesis of Social Equity Enablers and Constraints (SEEC) in NbS. These categories capture contextual domains that, depending on how they are recognised and addressed, can either constrain or enable social equity as a process or outcome of NbS.

Although the SEC and SEEC categories were developed from 93 papers on NbS implemented in rural southern Africa, they are more broadly relevant, particularly in settings shaped by historical inequality and power asymmetries in decision making, and for external agencies and institutions working in these contexts to promote more socially just NbS. Their wider applicability should, however, be tested in other rural and urban contexts.

2. Results

2.1 Inequitable outcomes and affected social groups

We found a steady increase in papers on inequitable NbS outcomes in southern Africa from 1990 onwards, with the greatest increase occurring from 2012 (Fig. 1a). Most reviewed papers investigated outcomes of sustainable management NbS followed by a combination of NbS types, protection NbS and restoration NbS (Fig. 1b; Methods Fig. 4d; Supplementary 1 Fig. 1).

The reviewed papers described a total of 148 examples of inequitable NbS outcomes: 75 examples of negative impacts on people (81%) and 73 examples of unequal benefit sharing (78%). This is because most papers (59%) reported evidence of the NbS having both negative impacts and unequal benefit sharing. The remaining papers described NbS as having only negative impacts (22%) or unequal benefit sharing (19%).

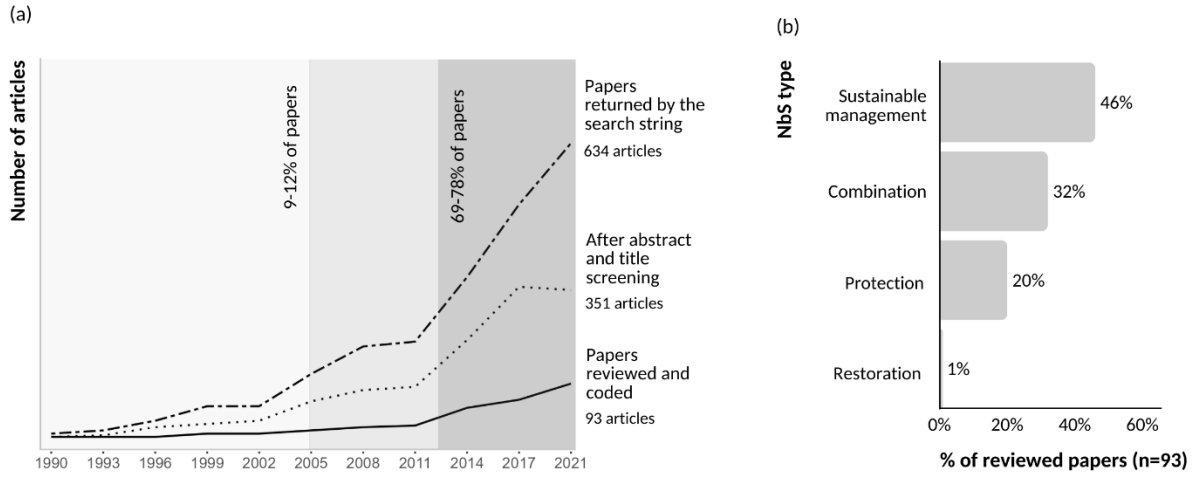


Fig. 1: Papers providing evidence of NbS resulting in inequitable social outcomes in southern Africa have increased steadily over time and are characterised mostly by sustainable management NbS or a combination of NbS types. (a) Distribution of articles over the search (n=634), screen (n=351) and review and coding periods (n=93) from 1990 to 2021. (b) Distribution of papers reviewed and coded (n=93) by NbS type for the period 1990-2021. The time-period was from 1960, but the single article found prior to 1990 was excluded on screening. The research cut-off was April 2021.

Concerningly, 82% of the papers that described negative impacts and/or unequal benefits of NbS (inequitable NbS outcomes) also reported that the NbS in question had some form of equitable intentions. In other words, the NbS in question had considered social equity in one way or another during its design, planning or implementation. This included 71% of papers that described the NbS as using a "participatory" or "community-based" approach, including co-creation or collaborative agreements, and 38% of papers that described the NbS as focusing on those most vulnerable. Further, 72% of papers described the NbS as incorporating elements of equity dimensions: distributional equity (63%), procedural equity (49%), or recognitional equity (29%).

Inequitable outcomes of NbS were more frequently reported for those most vulnerable (Fig. 2a-b). Papers most frequently reported NbS having negative impacts or little to no benefits for minority and marginalised groups, poor individuals and households, women, and LCs without explicit disaggregation. These outcomes most often negatively affected income, employment or assets; access to resources or rights; livelihoods; social-ecological relations (e.g., social cohesion and connection to nature); and social development (Fig. 2c).

Where NbS benefits were reported to be unequally shared, we found that the larger share of benefits was more frequently reported to be experienced by individuals in positions of authority or with greater power, elite or wealthier individuals and families, NbS board or committee members, men, and those at higher national or global societal levels (Fig. 2a). As with negatively impacted aspects, unequal sharing of benefits was most often reported for income, employment or assets; access to resources or rights; livelihoods; social–ecological relations (e.g., social cohesion and connection to nature); social development; and knowledge, learning and inspiration (Fig. 2c).

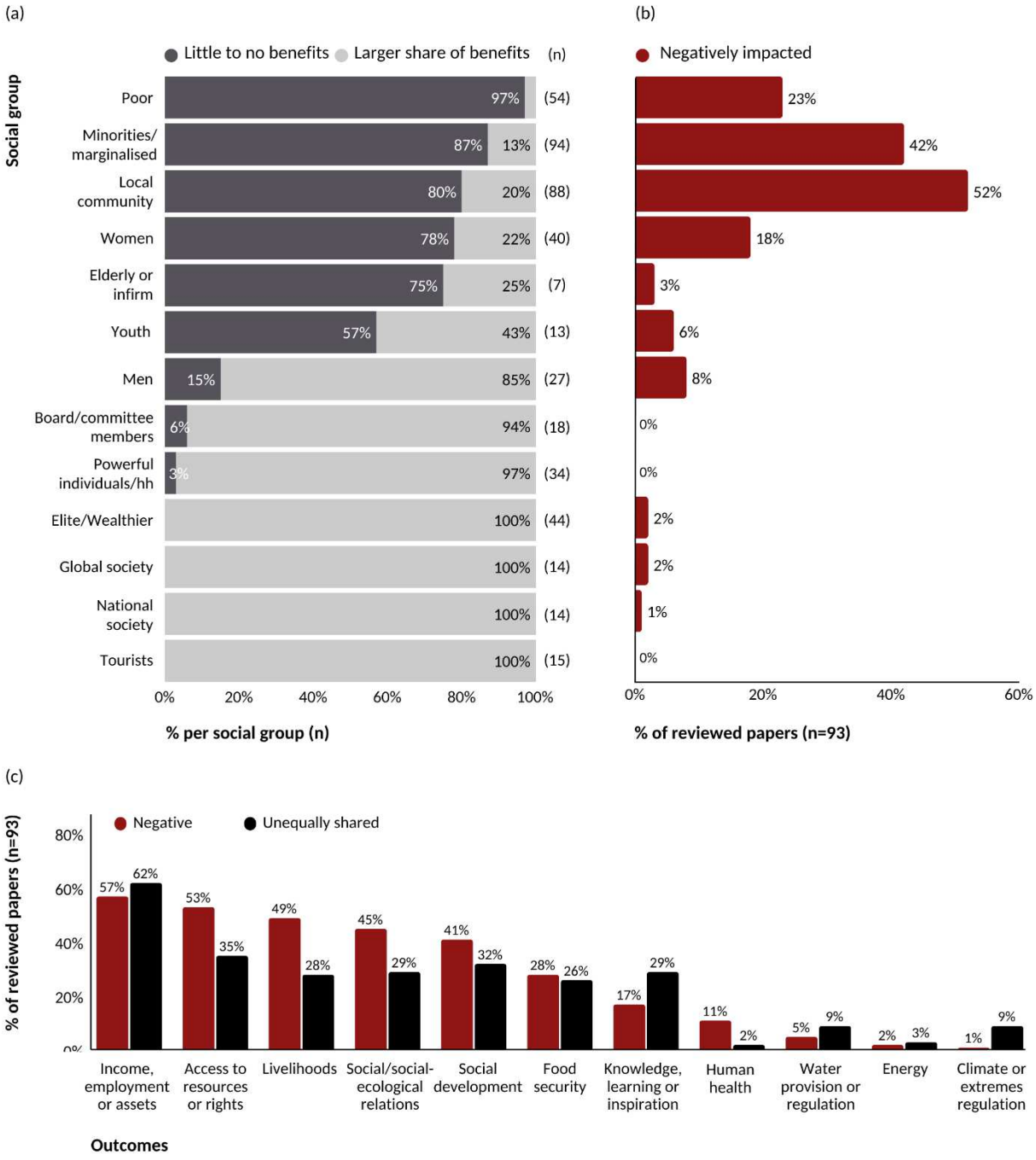


Fig. 2: Inequitable outcomes of NbS were more frequently reported for those most vulnerable. Distribution of reviewed papers reporting (a) little to no benefits versus a larger share of the benefits of NbS across social groups; (b) negative impacts across social groups; and (c) aspects either negatively impacted or unequally shared across social groups.

2.2 Social Equity Constraints in NbS

Despite equitable intentions of NbS in reviewed papers, inequitable outcomes still occurred and for those most vulnerable. Nearly all reviewed papers (97%) described underlying reasons for inequitable outcomes. We systematically and inductively synthesised these into

32 Social Equity Constraints (SEC) in NbS, that capture the contextual factors that constrain the achievement of social equity as a process or outcome in NbS. We also grouped these 32 SEC into eight higher-order categories (Fig. 3a-b; Supplementary 3 Table 2). The full SEC definitions, summaries, and illustrative examples are provided in Supplementary 3 Table 2.

Most SEC were described as created or reinforced by implementers (88%) and funders (69%), with LCs only rarely identified as the source of the constraint (6%). In contrast, SEC were most often described as experienced by implementers (84%) and LCs (66%), rather than by funders (22%). Below we summarise the main categories and the mechanisms through which they contributed to inequitable outcomes.

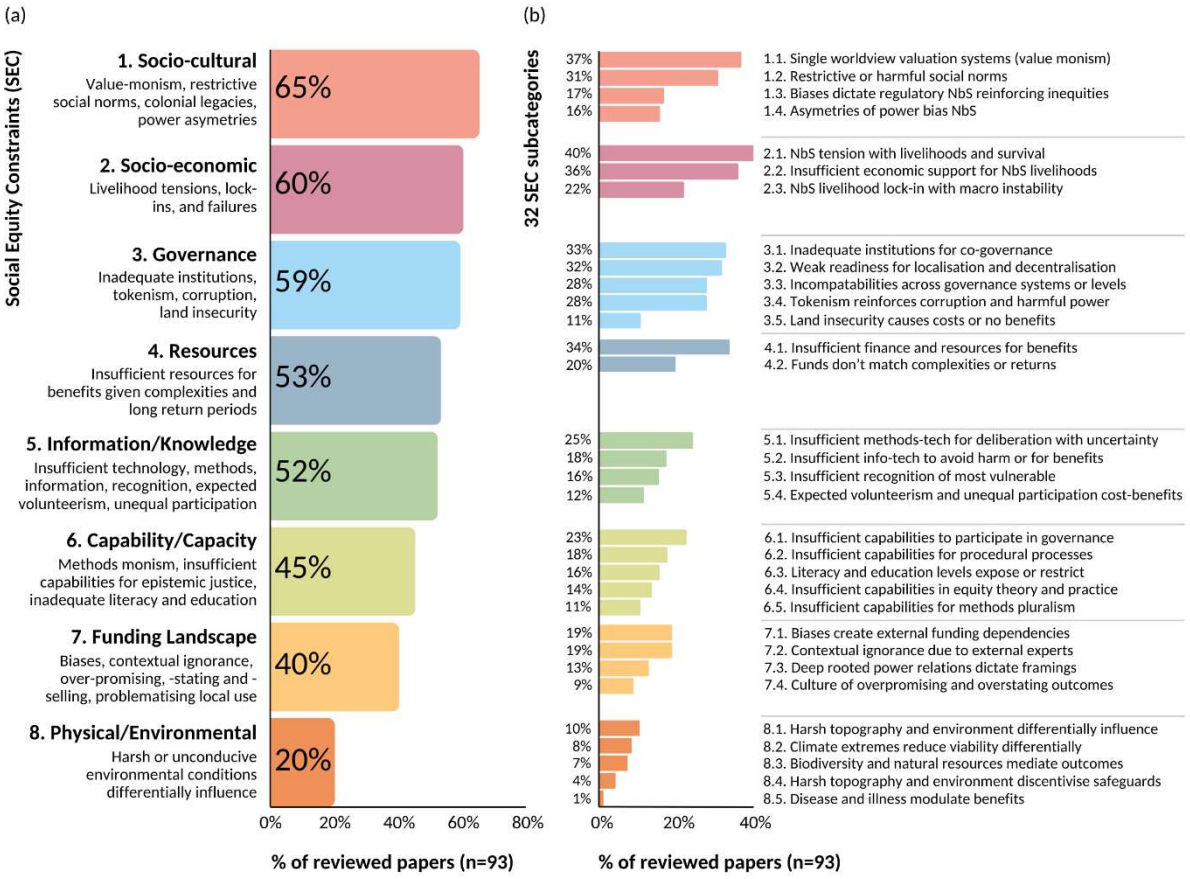


Fig. 3: Social Equity Constraints (SEC) that actors might face in NbS. Distribution of reviewed papers across (a) the eight main SEC categories; and (b) 32 SEC sub-categories.

2.2.1 Socio-cultural SEC

Socio-cultural SEC included value monism, restrictive social norms, regulatory and policy biases, and pre-existing power asymmetries (Fig. 3b, 1.1-1.4; Supplementary 3 Table 2). Inequitable outcomes occurred where NbS framings privileged economic and instrumental values over relational values, including place attachment, identity, social cohesion, and kinship. They also occurred when broader, often globally oriented, indirect and non-use instrumental values, such as carbon sequestration and existence, bequest, and option values,

were prioritised over local relational and instrumental values essential to wellbeing, livelihoods and food security [28–30]. Restrictive social, especially gender, norms further shaped who could participate, influence decisions, access land and resources, and benefit from interventions, often increasing labour burdens and risks for women [31–35]. Regulatory and extension systems reproduced colonial and other entrenched biases by restricting local resource use or directing opportunities towards already advantaged groups, especially men [32,36–40]. Further, unaddressed power asymmetries often re-entrenched pre-existing inequalities in NbS [41–45].

2.2.2 Socio-economic SEC

Socio-economic SEC were characterised by tensions between NbS objectives and livelihood and survival strategies, insufficient economic support for required livelihood changes, and the vulnerability of narrow NbS-related income sources and livelihoods to wider instability (Fig. 3b, 2.1-2.3; Supplementary 3 Table 2). These tensions emerged where NbS restricted farming, hunting, grazing, or other land- or resource-based practices without adequately compensating losses or providing viable alternatives, thereby increasing risks to food security and income for vulnerable households [37,46–49]. Even where alternative livelihoods were introduced or promoted, uptake and persistence often depended on unevenly distributed access to land, credit, insurance, markets, storage, labour, and tenure security, such that wealthier households were better placed to manage short-term costs and risks while poorer households faced lower adoption and higher chances of failure [32,50,51]. NbS also sometimes narrowed livelihood options by tying benefits to volatile tourism, carbon, or commodity markets, shifting wider political-economic instability onto already vulnerable households [52,53].

2.2.3 Governance SEC

Governance SEC reflected incompatibilities across formal, customary, and informal institutions; weak readiness for co-governance, decentralisation or localisation; corruption reinforced by tokenistic participation approaches, and insecure land tenure (Fig. 3b, 3.1-3.5; Supplementary 3 Table 2). Such constraints undermined equity when governance arrangements failed to sustain meaningful participation and deliberation, recognise plural values and rights, or distribute authority and accountability fairly across actors and institutions [35,44,54–56]. Decentralisation often transferred responsibilities without the fiscal, administrative, or political conditions needed for equitable local governance, enabling local elites, traditional leaders, or committee members to consolidate control over decisions and benefits [19,39,45,48,50,55,57–60]. Incompatibilities between governance systems also created uncertainty over rules, rights, and enforcement, favouring already powerful actors [35,39,44,56,58,61,62]. Unequal and insecure land tenure, often shaped by gendered power relations, further reduced willingness or ability to engage in NbS for some, and increased risks of exclusion or dispossession once benefits became visible [33–35,60,62].

2.2.4 Resources SEC

Resource-related SEC reflected uneven access to the financial and material resources needed to adopt, participate in, and sustain NbS, as well as mismatches between external funding

conditions and the scale, flexibility, duration and allowable costs required to address risks, compensate for costs, and sustain NbS under complex baseline conditions of poverty and degradation (Fig. 3b, 4.1-4.2; Supplementary 3 Table 2). Here equity was constrained where NbS participation, adoption, or benefits required access to income, savings, credit, or other productive inputs, such as seed, mulch, tools, cover crops, and nutrient inputs, that poorer households could not reliably mobilise, particularly before benefits accrued [32,63–65]. Resource constraints were also influenced by the design of external support, with funding and compensation often too limited, inflexible, or short-term to match baseline environmental degradation, entrenched poverty, delayed benefit accrual, and uneven potential of different social groups to take on investment risk [42,50,65–67]. These constraints were most pronounced where NbS assumed that all households had equal opportunity or financial reserves needed to invest and sustain practices long enough to accrue benefits or payouts.

2.2.5 Information/Knowledge SEC

Information- and knowledge-related SEC covered methodological and technological blind spots, uneven awareness or access to information and technology, and insufficient attention to participation ethics and transaction costs (Fig. 3b, 5.1-5.4; Supplementary 3 Table 2). These constraints influenced inequitable outcomes by limiting the integration of diverse values, knowledge systems, lived realities, and uncertainties in NbS, which influenced who and what was identified as important for benefit sharing, and related unintended consequences [59,68–70]. Uneven information access and awareness further influenced who could participate effectively, harness opportunities, and avoid unintended harms, with NbS extension and communication systems often privileging men, older adults, or better-connected groups over women, youth, and others with less access to information or technology [34,60,62,65,67]. Limited awareness of value pluralism, contextualised safeguarding, and distributional justice also reduced the ability of implementers to anticipate differentiated impacts and weakened NbS social safeguarding [31,44,48,55,61,71]. Reduced understanding of participation ethics led to high levels of expected volunteerism that overlooked unequal participation costs for different groups involved. Through these so-called participatory or collaborative approaches, substantial time and labour burdens were often placed on community members without compensation. Expected volunteerism also intersected with gendered divisions of labour and often was as an early barrier to entry or uptake of NbS when women, or other vulnerable groups, were unwilling or unable to contribute time, money, or labour to an initiative that had unclear benefits and returns, and that provided no compensation for their time [31,40,59,72,73].

2.2.6 Capability/Capacity SEC

Capability and capacity related SEC reflected unequal abilities across communities and implementers to participate in, design, and sustain equitable NbS processes. It included factors such as methods monism, insufficient capabilities to achieve epistemic justice, and limitations in distribution of literacy and education across groups (Fig. 3b, 6.1-6.5; Supplementary 3 Table 2). Here, some groups lacked the literacy, education, legal knowledge, organisational experience, language proficiency, mobility, or confidence needed to engage meaningfully in decision making, negotiation, consent, accountability, and other

participatory or co-creation processes, limiting their ability to determine outcomes on fair terms [34,40,43,66,74–77]. At the same time, implementers often lacked the capabilities required to facilitate inclusive and reflexive processes, including to identify intersecting vulnerabilities, navigate institutional tensions, or define communities in ways that reflected local realities. This undermined partnerships, participation and consent processes [59,61,66,71,78,79]. Limited expertise in social equity, safeguarding, and methodological pluralism also weakened the capacity of implementers to recognise and work with relational, including biocultural, and place-based values alongside instrumental ones, contributing to narrow intervention design and limited responses to unintended consequences [28,29,40,43,44,62,66,78,80].

2.2.7 Funding landscape

Funding landscape SEC captured how funder priorities, criteria, metrics, and delivery approaches influenced access to NbS finance and the terms attached to this access and promoted a culture of overselling NbS outcomes without prioritising the actions needed to ensure that those outcomes would be equitable (Fig. 3b, 7.1-7.4; Supplementary 3 Table 2). These constraints were most evident where funding systems favoured short-term, externally driven, and administratively straightforward projects over the long-term, flexible, and context-responsive processes needed to build trust, strengthen institutions, recognise rights, and address distributional concerns. This process incentivised project-based interventions reinforcing dependence on external funds and weakening local ownership [49,50,57,71,73,81–83]. Simplified reporting requirements and performance metrics often privileged easily measured outputs over slower social processes such as participation, relationship building, accountability, and safeguarding, encouraging overpromising of social benefits without adequately resourcing the work needed to realise them [49,53]. Reliance on consultants, intermediaries, and external technical expertise also narrowed understanding of local histories, power relations, and locally appropriate approaches to integrating social equity, and reinforced dependence on external actors while disempowering local ownership [69,73]. Funding agendas also influenced how NbS problems were framed. This included delegitimising local resource use while ignoring broader drivers of degradation and global change [36,37,69,73,80,84]. Competition for funds encouraged overpromising of social benefits, including those linked to participatory approaches, without adequately resourcing meaningful engagements or the safeguards, partnerships, and learning needed to realise social benefits, and ultimately contributed to unmet expectations [49,53,73,79,85].

2.2.8 Physical and Environmental SEC

Physical and environmental SEC included how unevenly distributed harsh or unconducive environmental and climate conditions, or poor health from disease or illness, influenced NbS feasibility, participation, monitoring, and the distribution of costs and benefits for some groups (Fig. 3b, 8.1-8.5; Supplementary 3 Table 2). These factors constrained equity if overlooked because they altered NbS feasibility, changed the risks and returns associated with participation, and reduced or disincentivised inclusion, monitoring, safeguarding, and sustained engagement of certain areas or groups within NbS [46,60,66,75,86]. This included where the same intervention produced different outcomes depending on soils, climate, water access, biodiversity, wildlife movements, location, plot size, or remoteness, with benefits

more likely to accrue to some given certain environmental or spatial characteristics [46,72,81,83,87,88]. Further, where climate shocks and variability had not been adequately anticipated or buffered, they undermined expected returns, or caused debt, livelihood stress, or loss for some groups [48,50,72,87,89]. Remoteness and rugged terrain also reduced monitoring frequency and discouraged engagement with hard-to-reach and often most vulnerable groups [49,66,80], while illness and caregiving burdens reduced labour availability and the ability to adopt or sustain NbS practices [33].

2.3 Emerging themes of recommendation for enabling social equity in NbS

Alongside the constraints described above, most reviewed papers (98%) provided recommendations for moving towards more equitable NbS. Although a full systematic analysis of these recommendations was beyond the scope of this study, we qualitatively synthesised six recurring themes that point to pathways for enabling social equity in NbS. These included: i) represent multidimensional and pluralistic values and value systems; ii) integrate diverse forms of knowledge and information as evidence; iii) focus on locally relevant financial mechanisms, incentives, safety nets, and land security; iv) create safe multi-actor networks and spaces to deliberate trade-offs and synergies; v) use facilitation to foster capability, collaboration, trust, and transparency; and vi) focus on those most vulnerable, including vulnerable social groups in poverty. Across papers, these recommendations consistently called for NbS to recognise relational, cultural, livelihood, and place-based values, to work with diverse evidence and knowledge systems, strengthen local institutions and capabilities, and avoid shifting risks, costs, and participation burdens onto poorer and more marginalised groups. A summary for each theme with illustrative citations are provided in Supplementary 1 Section 7 and Supplementary 3 Table 3.

2.4 Broader Social Equity Enablers and Constraints in NbS

Together, the systematically coded SEC and the qualitatively synthesised recommendation themes for enabling social equity informed eight broader categories of Social Equity Enablers and Constraints (SEEC) in NbS (Table 1; Supplementary 3 Table 1). These categories indicate that the same contextual domains, including socio-cultural, socio-economic, governance, resources, information and knowledge, capability and capacity, funding landscape, and physical and environmental conditions, can either constrain or enable social equity depending on context, and how they are recognised and addressed across NbS phases (design, planning, implementation, monitoring, and evaluation). The SEEC framework therefore provides a higher-level synthesis of the contextual factors that shape whether NbS reproduce existing inequities or help redress them.

Table 1 Social Equity Enabling or Constraining (SEEC) contextual factors. These SEEC contextual factors either enable or constrain the achievement of social equity (including procedural, recognitional, and distributional) in NbS as a process or outcome, across all phases: design, planning, implementation, monitoring and evaluation (Supplementary 3 Table 1).

SEEC	Description
1. Socio-cultural	Social (including gender) norms, customs, traditions, worldviews, and value systems (e.g., intrinsic, instrumental, and relational values, and value monism or pluralism); along with historical legacies, and the presence or absence of social justice institutions and support mechanisms (formal or informal). These factors legitimise or contest NbS approaches and reproduce or perpetuate inequities or help redress them.
2. Socio-economic	Livelihoods, survival strategies, access to economic opportunities (including economic mobility and viable alternative livelihoods); and how these interact with macroeconomic and political conditions (e.g., employment trends, inflation, market access, policy or other shocks) to shape who participates, benefits, or experiences costs including unintended consequences of NbS.
3. Governance	(In)compatibilities between informal, customary, and formalised governance systems (including laws, regulations, procedural requirements, institutional arrangements, tenure systems), the level of integrity and trust, approach to gatekeeping, and incentives and readiness for balanced decentralisation and multi-level/actor co-governance that integrate those most vulnerable.
4. Resources	Alignment of external funds with levels of community or implementor access to and control over financial resources (e.g., income, savings, credit, insurance, compensation) and non-financial resources (e.g., assets, land/tools, inputs such as seeds). This factor includes alignment with what is required to innovate and sustain NbS given levels of baseline environmental degradation, poverty, inequality, and the timing and distribution of NbS benefit accrual (including lagged or delayed NbS returns and risk exposure before benefits accrue).
5. Information/ Knowledge	Biases and bias blind spots relative to critical self-awareness, reflexivity and general awareness regarding value pluralism, distributional justice, contextualised safeguarding, and appropriate participation ethics, and the availability and accessibility of methodologies and technologies to support these approaches and processes. In addition, uneven accessibility, availability, and awareness limit the ability of some groups to avoid unintended harms and to adopt, participate in, or sustain NbS.
6. Capability/ Capacity	Distribution and adequacy of capacity and capability for meaningful and equitable NbS governance and procedural processes (participation, consent, legal and administrative requirements), including community and implementer capabilities, literacy and education, and social equity and safeguarding expertise to recognise and address epistemic injustices (testimonial and hermeneutical) and to apply methodological and value pluralism drawing on diverse evidence types.
7. Funding landscape	Systemic, meso- to macro-level features of NbS finance that shape funding access and terms including funder criteria, priorities, risk/return expectations, eligibility and compliance (dis)incentives or perverse incentives, time horizons, safeguarding requirements, and intermediaries, partners and service provider processes. These conditions can either reinforce existing inequalities or support equitable outcomes (e.g., privilege project-based or externally driven approaches with short timelines relative to long-term, flexible and patient approaches that tolerate delayed, uncertain and process-based returns with accessible criteria and compliance, and equity-centred funding allocations).
8. Physical/ Environmental	Biophysical and spatial conditions that mediate the feasibility of NbS and the distribution of costs/benefits across groups. These factors affect NbS viability and the feasibility of alternative livelihoods, enable or constrain participation/adoption, and shape safeguarding and monitoring feasibility and risk exposure (e.g., remoteness, terrain, land parcel size/fragmentation, access to water, climate extremes, climate variability, salinity, animal and plant species distribution and abundance).

3. Discussion

3.1 An equity-centred typology to achieve equitable NbS

Our review findings show that even where NbS are introduced with equitable intentions, contextual constraints can make equity difficult to achieve in practice. Drawing on our review of 93 papers on NbS implemented in southern African rural landscapes that reported

inequitable outcomes, we mapped 32 SEC that help explain why inequitable outcomes occur. These constraints do not imply that equitable NbS are unattainable, but that equity depends on whether the conditions shaping participation, recognition, and benefit distribution are identified and addressed across NbS phases.

Our approach differs from much of the existing literature on constraints to adaptation and NbS, which has tended to adopt effectiveness- or feasibility-centred framings [23–27]. In those framings, contextual factors such as poverty, weak institutions, or lack of finance are often treated primarily as barriers to effective intervention performance. By contrast, we use a social equity-centred lens to examine how such factors shape who participates, whose values count, who bears costs, and who benefits. By focusing only on cases where NbS were associated with negative impacts and/or unequal benefit sharing, we were able to build a typology using a bottom-up, data-driven approach.

Although contextual equity is recognised within multidimensional equity environmental frameworks, it remains comparatively underdeveloped in comparison to the other dimensions of equity. It is often framed conceptually or via broad categories and indicators rather than systematically assessed through empirical evidence of inequitable NbS outcomes and their underlying causes [16,17,90]. Our SEC and broader SEEC categories provide an empirical framework that can be used to test, inform and understand contextual equity in NbS, including its interactions with the other three forms of social equity. This contributes to efforts to move equity scholarship to more concrete and nuanced understandings of how distributional, procedural and recognitional equity dimensions are shaped by contextual equity in NbS contexts. This also aligns with arguments that recognise the importance of understanding the interactions between equity pathways to strengthen multidimensional equity frameworks and enhance their empirical usefulness [91].

3.2 Implications for funders and implementers

The imbalance between those creating or reinforcing constraints and those experiencing them suggests both opportunity and responsibility for funders and implementers to adequately consider and address SEC across NbS phases. This includes working with multiple local actors to reduce the conditions that produce inequitable outcomes, and consistent with literature showing that adaptation interventions – including those framed as locally led – can generally reinforce, redistribute or create new vulnerability [92,93].

For implementers, this means using the SEC typology as an anticipatory tool across NbS phases to identify likely equity risks. For funders, it means recognising that equitable NbS may require funding models that move beyond short project cycles, simple metrics, and externally driven models, since these can undermine local ownership and weaken the long-term, flexible, and process-oriented work that equity requires.

More equitable NbS will depend on funding environments that tolerate uncertainty, support contextualisation, enable long-term relationship building, and focus on the social processes needed for meaningful participation, capability strengthening, and safeguarding. A more open culture of learning from failure is also needed, as NbS challenges and unintended

harms are often downplayed in competitive funding landscapes. These findings reflect broader patterns in climate adaptation finance, where control over resources by non-local actors reinforce injustices by limiting meaningful local participation and decision making [92].

3.3 Limitations, future research, and conclusion

Several limitations should be considered when interpreting the findings of this review. First, the SEC were developed from reported cases of inequitable outcomes of NbS in southern African terrestrial and freshwater rural areas. While this enabled the development of an equity-centred constraints typology, it does not provide a comparative assessment for cases of NbS with equitable outcomes.

Thus, comparative work is needed to examine how the SEC differ across NbS effectiveness cases, including those with more and less equitable outcomes, and whether some constraints are particularly influential under certain contexts. More explicit study of enabling conditions is also needed, including how plural valuation, local institutional strengthening, safeguarding, and funding reform can help address contextual inequities in practice. Approaches such as the Capability Approach and the linked Capabilities Pathways Approach may be especially useful because they foreground how socio-institutional and structural conditions shape people's real freedoms to participate in, influence, and benefit from NbS [20,22]. Future work should examine how NbS can expand the capabilities of those most vulnerable in NbS decision making and governance.

Overall, our 32 SEC and eight-factor SEEC frameworks provide a basis for understanding the root causes of inequitable outcomes in NbS and for identifying where action is needed to support more equitable design and implementation. NbS that fail to recognise and address these contextual social equity factors risk reproducing the inequalities they often claim to redress. Conversely, actively engaging with these contextual social equity factors, offers a pathway to better align climate resilience, biodiversity goals, and social justice.

4. Methods

4.1 Review scope

Using established environmental review guidelines and standards [94,95] we developed a review protocol to respond to the question: "What are the reported reasons why inequitable outcomes occur due to NbS?" We framed this question by the following PICOs (Population, Intervention, Comparator and Outcome) to help determine the inclusion criteria:

- **Population:** Human individuals, social groups and communities in southern Africa found at various scales (national, subnational, regional and local) and in 11 countries (Angola, Botswana, Eswatini, Swaziland, Lesotho, Madagascar, Malawi, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe).

- **Intervention:** Any NbS applied to non-urban and non-coastal terrestrial natural/semi-natural ecosystems or cultural/farming landscapes, including protection, restoration, and sustainable management covering terrestrial and freshwater rural landscapes.
- **Comparator:** We did not require a comparator because the review aimed to characterise evidence on the drivers of inequitable outcomes across diverse methods and cases rather than to estimate a standardised intervention effect. Accordingly, all study designs were eligible, provided study outcomes were explicitly or implicitly linked to the NbS intervention.

4.2 Eligibility criteria

Aside from the PICOs, we included English papers that had been published between January 1960 to April 2021, although there were no articles relevant pre-1990 (Supplementary 1 Fig. 1). This is in response to calls to connect scientific evidence from past academic literature to the NbS terminology and associated concepts in a way that uses past research to support existing NbS practice [1]. We included all types of NbS and recognised NbS societal challenges (Fig. 1b and Fig. 4a-d) characterised according to existing international multilateral relevant NbS guidelines, principles and definitions (e.g., IUCN, UNEA, CBD) and past research on this topic (Supplementary 2 Table 5).

Because the aim of the review was to identify and characterise reported drivers of inequitable outcomes across diverse contexts and NbS study designs, rather than to estimate a uniform intervention effect, we included multiple forms of empirically grounded evidence. Inclusion was restricted to studies that assessed the impacts of NbS implemented in the field. All data types were eligible, including qualitative (51%), quantitative (20%) and mixed-methods studies (29%). Eligible studies included primary empirical studies (76%) and literature syntheses (23%), including systematic reviews, narrative reviews and document-based analyses, where findings were derived from empirical or otherwise documented evidence. We also included modelling studies in which models were used to estimate the impacts of implemented NbS based on observed or documented data (1%).

Where review articles were included, we cross-checked their underlying papers against all other included records to exclude overlap, ensuring that no primary study in the final sample was duplicated through inclusion both as an individual study and within an included review. Studies addressing the same NbS were nevertheless retained where they contributed distinct evidence, for example, by examining different time periods, outcomes or analytical perspectives.

Importantly, we did not impose the restriction that a paper had to have an NbS that focused on explicitly reducing climate risk. Hence, we did not have climate terms as part of our searching protocol. Given our terrestrial and freshwater rural focus, we used search terms typically associated with protection, restoration and sustainable management in rural terrestrial and freshwater landscapes and ecosystems such as protected areas, conservancies, agroforestry, conservation agriculture, invasive species clearing, restoration, revegetation, and rehabilitation. We also included broader policy-related terms used for NbS (e.g.,

Ecosystem-based Adaptation, REDD+, NbS, Ecological Infrastructure, Ecosystem Approach). Doing this enabled the review to not be biased by terminology changes and preferences in peer-reviewed literature. Due to our non-urban focus, we did not include urban-related design type NbS (e.g., green roofs, sustainable urban drainage, swales, bioretention ponds). A summary of the inclusion and exclusion criteria is provided in Supplementary 2 Table 3.

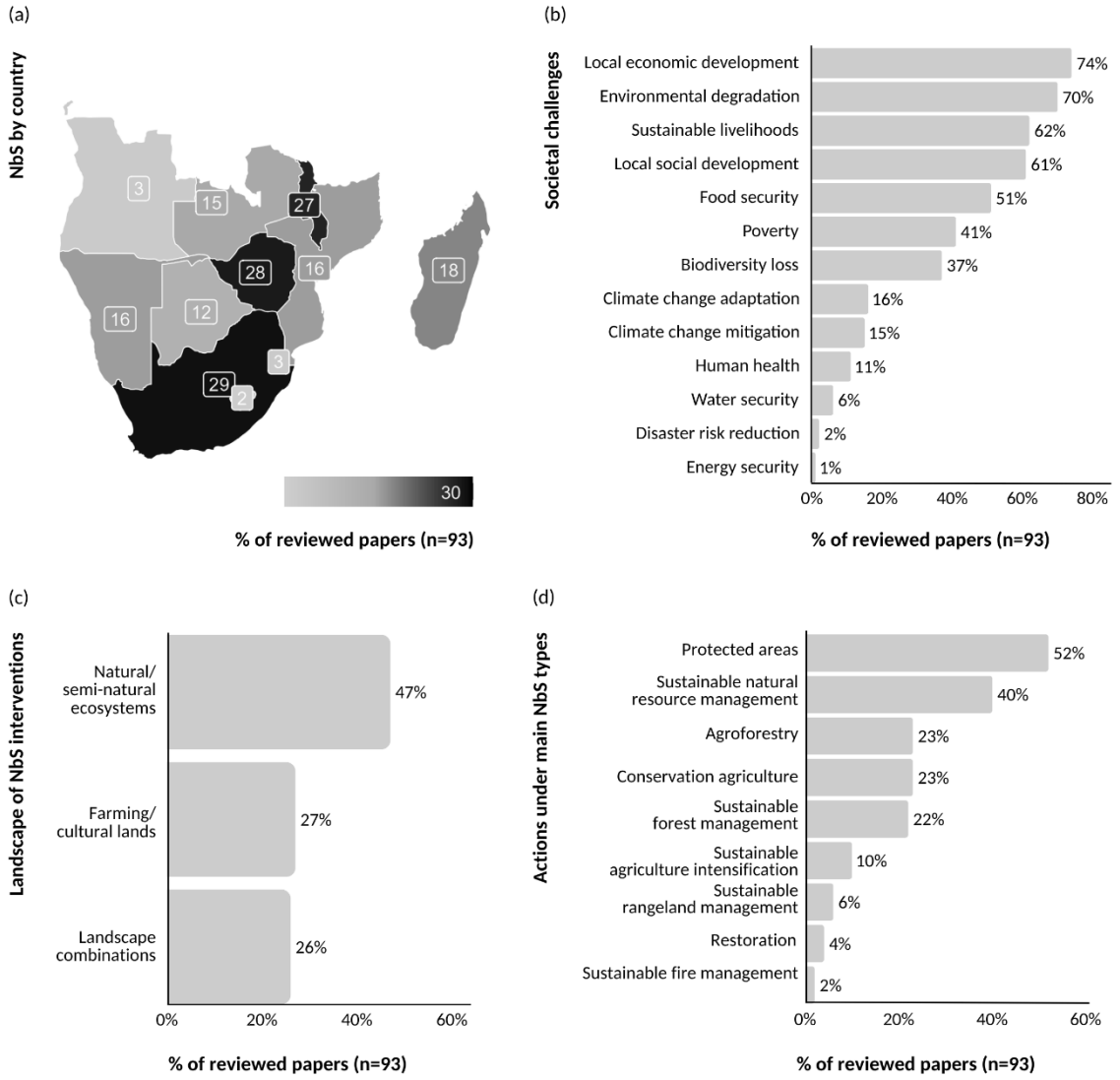


Fig. 4 Distribution of inequitable cases of NbS (a) NbS location across southern African countries; (b) NbS societal challenge targeted; (c) ecosystem/landscape type; and (d) NbS type (also see Fig 1b for broader NbS type groupings). The number of studies sums to more than the total number of studies reviewed because studies mostly reported NbS in relation to more than one of these categories (i.e., NbS targets both climate change adaptation and food security).

4.3 Search protocol

We used two databases, including Web of Science and Scopus. We developed our search string by reviewing review questions, objectives and related search strings of 35 existing

systematic reviews or maps on NbS or related topics (Supplementary 2 Table 2 and 6). We established four sets of terms corresponding to the research question and related PICOs and used these to search both databases (n=number of papers from Web of Science and Scopus):

1. Country focus "AND" (n=205088 and 268833) [Population (country focus)]
2. Inequitable outcomes "AND" (n=15555 and 22394) [Outcome]
3. NbS intervention "AND" (n=507 and 745) [Intervention]
4. Inequitable outcomes for whom (n=436 and 627) [Population (more detail)]

We found that, in both Scopus and Web of Science, the Topic field (Title, Abstract, and Keywords) captured both author keywords and AI-generated keywords. Because the AI-generated keywords led to the retrieval of many irrelevant papers, we instead searched the Title, Abstract, and Author Keywords fields separately in each database. See Supplementary 2 Tables 1 and 2 for the final search terms and search strings which followed this logic below.

[(southern African Country list OR southern Africa terms) AND (inequitable outcome terms) AND (NbS intervention with ecosystem terms) AND (inequitable outcomes for whom terms)]

This process left us with 634 papers once duplicates (n=429) were removed (Supplementary 1 Fig. 1 and Supplementary 2 Table 1-2).

4.4 Screening process

Two reviewers, one of whom was the lead author, independently screened all 634 papers at the title and abstract stage and identified 351 potentially relevant studies for full-text screening. Only three conflicts arose and were resolved through discussion. Using the studies included and excluded at the title and abstract stage, we piloted several machine learning models and active learning features to inform the full-text screening approach [96,97]. Across models, many relevant papers were assigned low inclusion probabilities. This appeared due to an uneven distribution of evidence across NbS types, such that papers on more frequently studied NbS types tended to receive higher inclusion probabilities than papers on less studied NbS types. Because these limitations were consistent across models, and given the large number of papers, the small review team and the depth of the coding process, we adopted a time-based stopping strategy for full-text screening and coding.

A team of four, comprising the lead author and three co-authors, screened and coded a random sample drawn from the full set of 351 papers. This resulted in 190 of the 351 papers (54%) being screened at full text, leaving 161 unscreened. Of the 190 papers screened, 97 were excluded, and 93 were included for data extraction and coding. If inclusion had continued at the same rate among the remaining unscreened papers, we may have missed approximately 76 additional papers reporting inequitable NbS outcomes that could have informed development of the SEC. However, by the time the stopping threshold was reached, we had also reached saturation in the range of SEC categories represented across the included studies.

4.5 Data extraction and coding

Data from all included studies were extracted and coded by four reviewers, including the lead author, with studies divided across the team. For each included paper, we completed a structured extraction template comprising 41 fields, including 10 metadata fields, 25 closed-ended fields, and 6 open-ended fields (Supplementary 2 Table 4). The closed-ended fields were based on a predefined coding framework provided in Supplementary 2 Table 5.

The extraction templated covered the following: study metadata, research methods, NbS type, societal challenge addressed, ecosystem and landscape type, inequitable outcomes, social groups affected, whether equity was an intention of the intervention, reasons inequitable outcomes occurred, and recommendations provided for achieving more equitable NbS. The completed extracted dataset underwent two rounds of quality control. The first was conducted by the lead author and the second by a co-author who had not participated in screening or data extraction. Any conflicts or issues identified were resolved through discussion.

Closed-ended binary and multi-category variables were analysed deductively using predefined categories. Full category definitions are provided in Supplementary 2 Table 5. Open-ended responses describing why inequitable outcomes occurred were analysed inductively to develop the SEC typology. Open-ended responses were reviewed across all included papers and iteratively grouped into conceptually distinct subcategories, which were then consolidated into 32 SEC subcategories and eight higher-order SEC categories. This coding was applied systematically across the full sample. We then synthesised the reported explanations across papers for each SEC category to identify the main mechanisms through which that constraint contributed to inequitable social outcomes in NbS. The full framework, including category descriptions, illustrative examples, and citations, is provided in Supplementary 3 Table 2.

Recommendations reported in the papers were analysed separately. We qualitatively synthesised recurring themes that pointed to pathways for enabling social equity in NbS. Because the recommendation data were not subjected to the same systematic coding procedure as the SEC, they are treated as emerging themes rather than as a second formal typology. These themes nonetheless informed the broader synthesis of Social Equity Enablers and Constraints in NbS presented in the study (Supplementary 3 Table 3).

4.6 Methodological limitations

Several limitations should be considered when interpreting the findings of this review. First, the evidence base was restricted to peer-reviewed literature, which means the study does not capture potentially relevant evidence from grey literature, programme documentation, or other unpublished sources. The review therefore provides a structured but partial account of how inequitable outcomes of NbS have been documented in the academic literature, rather than a complete account of inequity across all NbS in practice.

Second, the unit of analysis was the peer-reviewed paper rather than the NbS intervention itself. The dataset therefore reflects how authors chose to frame and report interventions,

equity intentions, affected groups, inequitable outcomes, and their explanations for why those outcomes occurred. As a result, the findings may be influenced by patterns in research attention, case selection, and reporting practices, including the kinds of NbS studied.

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