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An actor-centered, scalable land system typology for addressing biodiversity loss in the world's tropical dry woodlands

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ABSTRACT

Land use is a key driver of the ongoing biodiversity crisis and therefore also a major opportunity for its mitigation. However, appropriately considering the diversity of land-use actors and activities in conservation assessments and planning is challenging. As a result, top-down conservation policy and planning are often criticized for a lack of contextual nuance widely acknowledged to be required for effective and just conservation action. To address these challenges, we have developed a conceptually consistent, scalable land system typology and demonstrated its usefulness for the world's tropical dry woodlands. Our typology identifies key land-use actors and activities that represent typical threats to biodiversity and opportunities for conservation action. We identified land systems in a hierarchical way, with a global level allowing for broad-scale planning and comparative work. Nested within it, a regionalized level provides social-ecological specificity and context. We showcase this regionalization for five hotspots of land-use change and biodiversity loss in dry woodlands in Argentina, Bolivia, Mozambique, India, and Cambodia. Unlike other approaches to present land use, our typology accounts for the complexity of overlapping land uses. This allows, for example, assessment of how conservation measures conflict with other land uses, understanding of the social-ecological co-benefits and trade-offs of area-based conservation, mapping of threats, or targeting area-based and actor-based conservation measures. Moreover, our framework enables cross-regional learning by revealing both commonalities and social-ecological differences, as we demonstrate here for the world's tropical dry woodlands. By bridging the gap between global, top-down, and regional, bottom-up initiatives, our framework enables more contextually appropriate sustainability planning across scales and more targeted and social-ecologically nuanced interventions.

1. Introduction

Millennia of land use have shaped the global ecosystem, yet recent increases in the extent and intensity of land use have led to unprecedented biodiversity loss (Ellis et al., 2021; IPBES, 2018; Jaureguiberry et al., 2022; Newbold et al., 2015; Pimm et al., 2014), putting billions of livelihoods at risk (IPBES, 2019; Olesen et al., 2022). Unless major societal transformations take place, pressure from land use is expected to increase further as global demands for food, feed, and biomass continue to rise (Díaz et al., 2019; Kehoe et al., 2017). How to limit ecosystem degradation and species' decline, while safeguarding the livelihoods of local people, is a major challenge of the 21st century (Ellis, 2019; Gurney et al., 2021).

However, despite much investment in area-based conservation over many decades, current extent and effectiveness are insufficient, and it is failing to halt global biodiversity loss (Maxwell et al., 2020; Williams et al., 2022). The recently agreed global targets under the Global Biodiversity Framework thus aim to increase the global coverage of protected areas and other effective area-based conservation measures (OECMs) to at least 30 % by 2030, as well as to restore degraded lands on an unprecedented scale (Convention on Biological Diversity, 2022). These ambitious goals imply that the importance of conservation must increase in most landscapes across the globe, inevitably leading to overlaps and competition with other land uses, as well as potentially affecting hundreds of millions of rural people who live in landscapes of high conservation value (Sandbrook et al., 2023; Schleicher et al., 2019). Conservation agendas misaligning with local needs and disregarding the complex interactions between local people and their environment have often led to conflict, violence and conservation failure (Brockington, 2002; Iwamura et al., 2018; Sandbrook et al., 2023). Carefully considering how conservation interventions interact with local land uses is therefore critically important. At the heart of this challenge are land-use actors as the ones making decisions on how land is used, thus potentially posing threats to species and ecosystems, through activities like cropping, logging, or pesticide application (Balmford et al., 2009; Iwamura et al., 2018). Therefore, it is crucial that conservation and land-use planning considers how interventions both affect and engage local land-use actors to ensure both just and effective conservation outcomes (Lees et al., 2021; Raymond et al., 2022).

The core tenets of such a nuanced conservation planning approach hinge fundamentally on recognizing the complexity and diversity of different land-use actors and their activities (Alves-Pinto et al., 2021; Srivathsa et al., 2023). Yet, how to address this complexity remains a major challenge, as conservation science builds on a legacy of concepts and tools suited for simpler challenges and has often relied on coarse land-cover proxies to represent land use (Game et al., 2014). This is problematic as land cover cannot capture crucial land-use characteristics on the ground. For example, tree cover can signal primary forests, managed forests, or tree crop plantations, all of which have very different biodiversity impacts (Barlow et al., 2007). Land-cover proxies also rarely capture variation in land-use intensity (Kuemmerle et al., 2013), although intensity largely determines threat levels to biodiversity (Semenchuk et al., 2022). Likewise, the diversity of land uses is often oversimplified. For example, smallholder farmers may collect firewood, graze livestock, or hunt in nearby forests in addition to their agricultural activities (Olesen et al., 2022; Shackleton & Shackleton, 2004). Finally, limited information is typically available about diverse human interests on land, such as economic aspirations and cultural practices (Ban et al., 2013; Game et al., 2014), although ignoring these in conservation agendas can lead to conflict with local communities (Pressey et al., 2007; Sandbrook et al., 2023). The lack of effectiveness and fairness of many past conservation interventions can thus be, at least partly, attributed to the oversimplification of land-use actors and activities on the ground (Löfqvist et al., 2023; Oldekop et al., 2016). How to go beyond such oversimplification, while avoiding getting trapped in case specificity, is a challenge for conservation and in sustainability science more broadly.

A systems perspective provides great potential to recognize and structure land-use heterogeneity: similar land uses in comparable social-ecological systems often create similar landscapes, affect biodiversity in similar ways, and present similar conservation opportunities. The challenge of identifying such typical, recurring patterns of land use lies at the core of land system typologies (Kostrowicki, 1992; Malek et al., 2019; Václavík et al., 2013). However, available typologies are insufficient as tools for conservation planning: while global typologies can offer important insights at the macroscale (Asselen & Verburg, 2012; Ellis & Ramankutty, 2008), they are hampered by the limited availability of thematically and spatially- detailed datasets, have mainly taken a land-cover perspective, and are not suited for planning at scales relevant for conservation practitioners (e.g., landscapes to regions). Conversely, more localized typologies offer site-specific details (Duvernoy, 2000; Pacheco-Romero et al., 2021), but inhibit learning and knowledge transfer across regions, cannot inform decisions at broader scales, and lack a link to global-scale policymaking and target setting. What is missing is a scalable, 'middle-ground' typology that enables synthesis, comparisons, and planning, while retaining regionalized contextuality (Cohen-Shacham et al., 2019; Keith et al., 2022).

The need for, and potential of, such scalable typologies has recently been recognized for describing ecosystems, culminating in a major effort by the International Union for Conservation of Nature (IUCN) to produce a new ecosystem typology that organizes all of Earth's ecosystems based on a unifying theoretical context, emphasizing ecosystem functioning instead of available land-cover or species data (Keith et al., 2022). This expert-based typology links higher levels that represent generic functional groups with lower levels that consider differences in biotic composition. However, a comparable, conceptually consistent, and scalable approach that accounts for land use and actors is missing. In the context of conservation, such a land system typology should represent generalizations of social and ecological land-use components that transcend case specificity, but still entail an appropriate level of contextual complexity for targeted conservation action. In particular, it should (1) acknowledge the diversity of land-use actors and activities that represent threats to biodiversity, as well as opportunities for conservation, (2) capture site-based contextual knowledge for action on the ground, and (3) retain global consistency for large-scale planning and comparison.

Here, we propose an approach to operationalize these three design principles and build a conservation-relevant land-system typology. We use archetype analysis as a tool to generalize knowledge across cases and geographies in a context-sensitive way (Eisenack et al., 2021; Oberlack et al., 2023). Archetype analysis is especially valuable for bridging the science-policy gap in under-researched, and data-wise underrepresented sustainability aspects (Sietz et al., 2019), a situation common in many biodiverse regions in need of conservation planning. We demonstrate our approach for the world's tropical dry forests and savannas (hereafter: tropical dry woodlands), which harbor exceptional biodiversity and sustain the livelihoods of hundreds of millions of people. Although these ecosystems face high and rising land-use pressure (Buchadas et al., 2022a), they have often been overlooked by science and policy (Kuemmerle et al., 2017; Schröder et al., 2021). This is partly due to the difficulties of broad-scale, satellite-based assessments in accurately capturing the, often subtle, vegetation changes and degradation processes within tropical dry woodlands (Ryan et al., 2012). Moreover, there is a significant "attention bias" of conservation organizations, conservation funders, governance, and policymakers, as well as the general public towards the more charismatic tropical rainforests that leaves many tropical dry ecosystems weakly protected (Qin et al., 2023; Schröder et al., 2021; Stan et al., 2024). Our goal here is to structure land-use complexity in tropical dry woodlands in a way that can inform conservation science and action. To do so, we have developed a scalable typology of land systems, with two levels, a global level describing systems that could occur in all tropical dry woodlands, and, nested within, a place-based, regionalized level. We demonstrate this regionalization for five hotspots of land-use change and biodiversity loss in dry woodland regions: the Chaco dry forest in Argentina, the Chiquitano dry forest in Bolivia, the Deccan dry forests in India, the Miombo-Mopane woodlands in Mozambique, and the Indochina dry forests in Cambodia.

2. Methods

We used an expert-based archetyping approach to conceptualize and develop our land system typology, following four key steps (Fig. 1): (A) development of the conceptual framework; (B) collecting place-based knowledge on actors and activities; (C) archetyping land systems; and (D) expert triangulation and evaluation. We performed these steps through an iterative process. Hence, insights from each step informed the development of the next and permitted refining the typology through several versions.

2.1. Focus regions

We developed the typology for the world's tropical dry woodlands (Fig. 2). Tropical dry woodlands, including tropical and subtropical dry broad-leaved forests, wooded grasslands, savannas, and shrublands, cover about 20 % of the global terrestrial surface (Dinerstein et al., 2017). Tropical dry woodlands harbor many endemic plant and animal species (Banda-R et al., 2016) and hold about 25 % of the global terrestrial carbon (Bonan, 2008). They also support millions of people in some of the world's poorest areas for farming, grazing, hunting, and collecting forest-based products, including firewood and medicinal plants (Altrichter, 2006; Baldi et al., 2013; Olesen et al., 2022). Much of the existing knowledge on land use and its impacts on tropical biodiversity has focused on rainforests, even though deforestation has expanded more drastically in the dry woodlands over recent decades (Pacheco et al., 2021).

Land use in tropical dry woodlands is heterogenous and the landscapes have been inhabited and co-produced for millennia (Lehmann & Parr, 2016) with high cultural diversity. The colonial trade system, and the incorporation of geographically distant regions into international networks of food production, have spurred the rapid expansion of modern agriculture over the last decades (le Polain de Waroux et al., 2018; Ordway et al., 2017). In many dry woodland regions, this has led to profound transformations of ecosystems, biodiversity, and rural livelihoods (Chaudhary & Kastner, 2016; Levers et al., 2021), while in other regions, (semi-)subsistence agriculture is the main cause of transformations. Given these heterogeneous land-use contexts, simplistic "one-size-fits-all" conservation interventions are likely to fail, making tropical dry woodlands an interesting case to explore how the diversity surrounding land use can be structured and organized for conservation science, planning and action (Baldi & Jobbágy, 2012).

We selected five tropical dry woodland regions as case studies to demonstrate the regionalization of our typology (Fig. 2). All of them are major hotspots of land-use change and biodiversity loss (Buchadas et al., 2023), either due to substantial historical deforestation, as in the dry forests of India (Ravikanth et al., 2000), high recent deforestation, as in the Gran Chaco and Chiquitano dry forests in South America (Baumann et al., 2022; Romero-Muñoz et al., 2019) and the Indochina dry forests in Cambodia (Davis et al., 2015), or ongoing activation of large-scale deforestation frontiers, as in the Miombo-Mopane woodlands in Southern Africa (Ordway et al., 2017). The selection of the cases was furthermore influenced by the geographies with which the core team of authors were familiar and where they could assemble a network of regional experts. We analyzed our dry forest regions within single countries to ensure homogeneity of institutional conditions, as land-use and conservation planning typically takes place within countries. More detailed descriptions of the selected focus regions are provided in Supplementary Information 1.

2.2. Development of the conceptual framework

To develop a conceptual model for our land-system typology, we consider land systems as integrated social-ecological systems with land

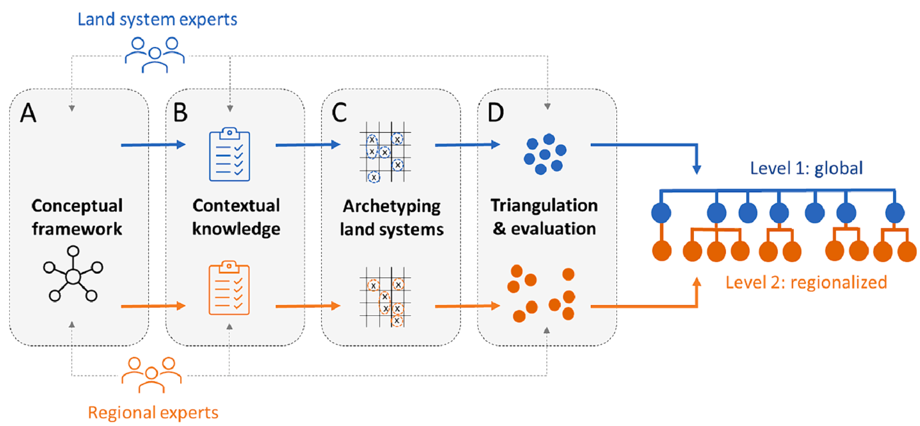

Fig. 1. Workflow for the development of our scalable land-system typology (global/regionalized level). We followed a stepwise process to develop our typology: A. Development of the conceptual framework, drawing on middle-range theories; B. Collecting place-based, contextual knowledge on actors and activities, using expert workshops; C. Archetyping land systems; and D. Iterative expert triangulation and evaluation.

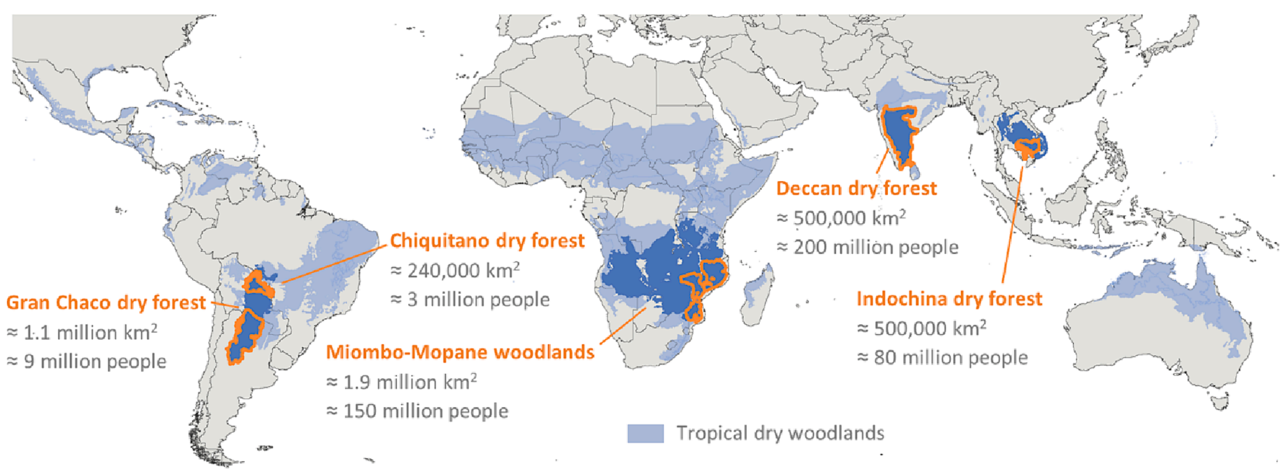

Fig. 2. Global tropical dry woodlands and our five study regions (with the selected regions in dark blue and the country-level focus outlined in orange). As tropical dry woodlands, we considered all forests, shrublands, and savannas as falling into two biomes according to the updated biome classification of Dinerstein et al., (2017; Olson et al., 2001): (1) tropical and subtropical dry broad-leaved forests and (2) tropical and subtropical grasslands, savannas and shrublands. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

use as the central link between the social and ecological subsystem (Verburg et al., 2015). To identify key factors that shape land use and thus, in turn, present challenges and opportunities to conservation, we reviewed synthesis studies on land system science, specifically on middle-range theories, generalizable knowledge claims, and land-use frameworks (Magliocca et al., 2018; Meyfroidt et al., 2018). Building primarily on the framework put forward by Turner et al. (2020), we identified main groups of factors that influence land-system patterns and dynamics (Fig. 3): economic context, institutions, actor characteristics, and management strategies. Following recent calls to consider the diverse perceptions and valuations of nature, and how they are influenced by cultural dynamics (le Polain de Waroux et al., 2021; Meyfroidt et al., 2022; Pascual et al., 2023), we specifically added a component on motives to highlight the core importance of various motivations for using land. This component is key in our framework, as conservation action must account for and potentially modify these motives in order to be successful.

Motive describes the diverse and multiple motivations of actors for using land, including for food production, income, capital, the exercise of power and control, cultural practices, or conservation (Meyfroidt et al., 2018; Turner et al., 2020). *Economic context* accounts for the broad-scale political-economic order affecting land use, as well as constraints or opportunities related to markets and rents (Angelsen, 1999; le Polain de Waroux et al., 2018) and distal economic links such as through supply chains (Lambin et al., 2018; Meyfroidt et al., 2013) or foreign funding of conservation initiatives (Qin et al., 2022). *Institutions* related to land describe the formal and informal rules and norms that govern land use, commonly addressing incentives and governance of land and resources access and use via tenure, policies, laws, and informal arrangements (Baragwanath & Bayi, 2020; Holland et al., 2022; Ostrom, 1990). *Actor characteristics* encompass cultural systems, agency, and social and material capacity (Bebbington, 1999; le Polain de Waroux et al., 2021), often linked to power dynamics and interaction with other actors, such as via networking, organizing, or conflict (Porter, Michael E., 2000; Richards, 2018). Finally, *management strategies* encompass the available technology and infrastructure for land use, such as the level of technological inputs or labor (Erb et al., 2013), or the use or suppression of fire for land management (He et al., 2019).

Measuring the variables entailed in our five groups of factors is not feasible with fine-grained detail over large regions. Therefore, we structure land-use complexity by defining land systems as distinct combinations of major types of land-use actors, as the agents utilizing a specific area of land for a specific purpose, and their activities, as the diverse agricultural, institutional, and cultural practices leading to an interaction with natural assets. These actors (e.g., capitalized farmers) and their activities (e.g., soybean cropping) then produce typical land-

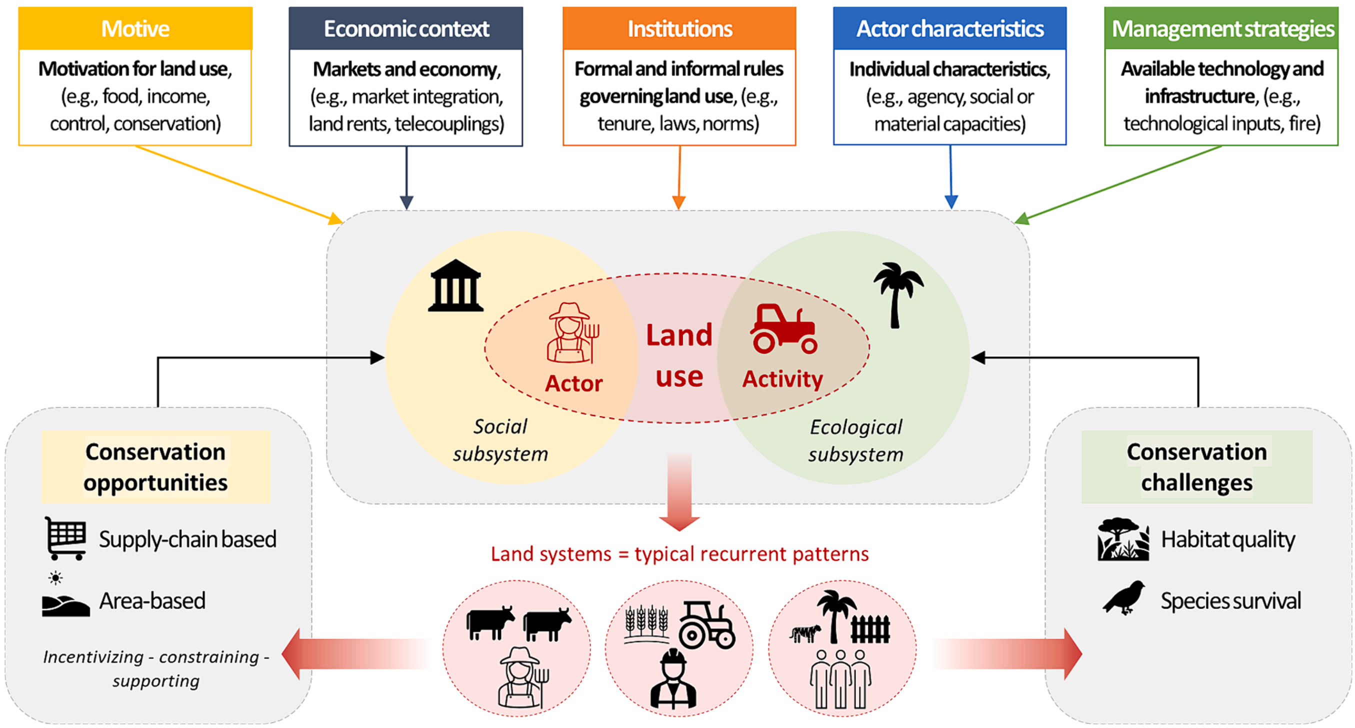

Fig. 3. Conceptual model underlying our land system typology. We regard land systems as integrated social-ecological systems with land use as the link between social processes (via land-use actors) and ecosystem changes (via land-use activities). We consider five groups of interacting factors that shape land use (boxes in the first row). To structure the resulting complexity and diversity of land-use actors, activities, and contexts (second row), we define specific land systems (red circles in the third row) as typical recurring patterns of land-use actors, activities, and social-ecological contexts, translating into specific conservation challenges (threats to species and ecosystems) and opportunities for conservation action. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

system patterns (e.g., an agricultural landscape dominated by homogenous, large soybean fields, producing commodities for international supply chains using capital-intensive inputs) (Marinaro et al., 2017). In our typology, actors (whether individuals, communities, private companies, government agencies, or NGOs) do not always hold formal property rights over land, but, in practice, determine how land is used. In short, we identify key types of actors and activities so that the types differ in one or more of our factors and, accordingly, group similar actors and activities into relatively homogeneous land systems.

Since our systems are defined by key land-use activities, they can be linked to land-use-related threats to biodiversity (e.g., habitat loss and pesticide pollution in the case of soybean cropping) relying on an existing threat categorization (Balmford et al., 2009), which broadly differentiates between threats from habitat transformation and threats that directly reduce survival. Likewise, as our systems are defined based on land-use actors, systems can be linked to specific sets of conservation action (e.g., supply-chain mechanisms in the case of capitalized farmers), broadly differentiating between area-based measures (e.g., protected areas) and supply-chain-based measures (e.g., certification systems). We further distinguish among instruments that incentivize (e.g., payment for ecosystem services), that constrain (e.g., protected areas), or that support or inform (e.g., formalization of land rights).

2.3. Collecting place-based knowledge

We operationalized our conceptual model through place-based expert knowledge, drawing on a narrative perspective on land use (Lambin et al., 2003). We chose an expert-knowledge-driven co-production approach for two reasons. First, verified and systemized empirical knowledge on the established working hypotheses in our conceptual model is not available for most tropical dry woodlands. Second, integrating contextual expert knowledge allows the incorporation of place-specific detail and interpretation that would be hard or impossible to capture otherwise, such as the social-ecological properties of land use structured by local institutions and culture that can only be apprehended from an historical, interpretative vantage point (Batterbury & Bebbington, 1999). To source place-based, contextual knowledge about land-use actors and activities, we organized 10 expert workshops including 46 experts on land use in tropical dry woodlands from diverse disciplinary backgrounds (e.g., land system science, geography, sociology, agrarian studies, agronomy, ecology, and conservation science and practice) (see Supplementary Information 2 for a list of experts' regional expertise and discipline). All experts had extensive working experience in tropical dry woodlands and many of them lived in these regions. The workshops took place in person or online (see Supplementary Information 3 for more information on the workshops). To foster group dialogue, we used participatory assessment tools (the World Café methodology, https://theworldcafe.com) in the in-presence setting (Löhr et al., 2020) and online collaboration platforms (i.e., miro). During workshops, participating experts worked on collecting lists of regionally operating land-use actors and regionally occurring land-use activities.

2.4. Archetyping land systems

We applied an archetypes approach to identify land systems at a meaningful level of complexity. Archetype analysis is used to recognize and structure complexity by depicting patterns of human-environment interactions across cases and in a context-sensitive way (Eisenack et al., 2021; Oberlack et al., 2023; Sietz et al., 2019). This is done by analytically decomposing complexity and then classifying recurrent configurations of attributes at an intermediate level of abstraction. Such typifying involves analytical decisions about the appropriate level of abstraction to obtain non-universal, but recurrent patterns (Eisenack et al., 2021).

We used expert assessment as our qualitative archetyping methodology. The process began with establishing a shared understanding of archetypes among experts and defining an appropriate level of abstraction based on meaningfully representing challenges (i.e., threats from land use to biodiversity) and opportunities (i.e. conservation interventions) for conservation planning. Hence, the goal was to develop the land system types as middle-ground between case-specificity and overgeneralization, thus retaining the necessary nuance to be matched with specific threats to biodiversity and targeted conservation action while still enabling comparison across cases. To depict land systems as generalizations of the social-ecological complexity surrounding land use, land use was analytically decomposed into two main components, land-use actor and land-use activity, and further described by a list of more specific attributes from our conceptual framework outlined above (Fig. 3). Interdisciplinary expert discussions provided the basis for grouping lists of land-use actors and land-use activities developed in our workshops into land systems that encompass key combinations of both. We commenced with an initial set of land systems, which we checked and discussed with participating experts and, if needed, subdivided further or merged them. This process was informed by our conceptual framework (Fig. 3) as a decision support tool and guided by the goals to establish a level of detail meaningful for characterizing threats and opportunities on the one hand, and cross-regional planning, on the other.

2.5. Iterative expert triangulation and evaluation

To validate the outcome of the archetyping process, we conducted further rounds of expert consultation and evaluation. We used an online collaboration platform to facilitate exchange across regions and time zones. Based on graphical representations and documentation of the preliminary typology drafts, and to obtain the experts' opinion on the internal homogeneity of the derived land systems, we specifically asked whether land systems could be merged or should be split to reach a level of generalization that is most meaningful for conservation planning in the given context. Finally, experts evaluated the alignment between the global systems and the respective regionalized ones. To evaluate the scope of the typology beyond the five focus regions, we consulted with experts on our focus regions and other tropical dry woodlands (i.e., Neotropical dry forests generally, Cerrado, Caatinga, Miombo and Mopane woodlands generally, Madagascar, Australia) and assessed the fit of the global system types for their region of expertise.

3. Results

3.1. Global land systems

The global level of our typology identifies 15 land systems based on typical combinations of land-use actors and activities. These could, in theory, occur in all tropical dry woodland regions and translate into typical conservation challenges and opportunities (Table 1). The first four land systems are capitalized farming systems, which are characterized by large-scale agricultural operations and involve significant capital investment and technologies: (1) *Industrial annual cropping* systems are mechanized, use advanced agronomic technology, and high-input practices, and produce commodities for national and international markets with high productive output. (2) *Capitalized ranching* systems describe large-scale ranching operations, typically with management techniques that increase livestock production, such as through improved pastures and concentrated fodder. (3) *Speculative land holding* describes the clearing of (previously forested) land essentially for speculative purposes (i.e., selling the land at higher prices, cultivating it later when market conditions are most favorable, or leaving it idle after taking the logs off the ground). In (4) *industrial tree cropping* systems, tree crops are cultivated at a large scale for commercial purposes.

Table 1
Land systems entailed in the general, global level of our typology and examples of potential threats to biodiversity. These generic land systems were designed so they could occur in any tropical dry woodland region.

Land systems		Exemplary potential threats to biodiversity
Capitalized farming systems		
1	Industrial annual cropping	Full removal of tree cover and non-forest natural vegetation or wetlands; agrochemical pollution; biological contamination; persecution and control of non-beneficial flora and fauna
2	Capitalized ranching	Full removal of tree cover and partial removal of non-forest natural vegetation or wetlands; potential persecution and control of non-beneficial flora and fauna
3	Speculative land holding	May include the removal of tree cover and non-forest natural vegetation or wetlands
4	Capitalized tree cropping	Full replacement of natural tree cover and non-forest natural vegetation or wetlands; agrochemical pollution; persecution and control of non-beneficial flora and fauna
Small-scale systems		
5	Smallholder farming	Partial removal of tree cover and non-forest natural vegetation; potential persecution and control of non-beneficial flora and fauna; potentially overharvesting of wild species; potentially uncontrolled use of fire
6	Shifting cultivation	Partial and temporary removal of tree cover; potentially overharvesting of wild species; potentially uncontrolled use of fire; potentially soil degradation
7	Pastoralism	Partial removal of non-forest natural vegetation; potentially overharvesting of wild species; potentially forest degradation
8	Forest-dwelling	Potentially overharvesting of wild species; potentially uncontrolled use of fire
Forestry		
9	Forest plantation	Replacement of natural tree cover or transformation of open grassy ecosystems; potential introduction of invasive species; agrochemical pollution
10	Forestry in native forests	Modification and potential degradation of natural tree cover
Conservation land uses		
11	State conservation	Potentially ineffective or inappropriate management; potentially misinformed afforestation
12	Private conservation	Potentially ineffective or inappropriate management; potentially misinformed afforestation
13	Community conservation	Potentially ineffective or inappropriate management
Highly modified land uses		
14	Energy land uses	Full removal of tree cover and (partially) non-forest natural vegetation
15	Mining and construction	Full removal of soil and biosphere; hydrological pollution

Next, we identified a group of four diverse small-scale systems, all characterized by small land areas, limited financial resources, and often managed by individual families or local communities: (5) *Smallholder farming* systems describe mixed, sedentary small-scale farms, where actors usually rely on a bundle of agricultural activities for their livelihoods, involving (tree) cropping, horticulture, and livestock rearing but also the use of adjacent woodlands for hunting and sourcing wood and non-timber forest products (NTFPs). Farm size, land-use intensity, use of capital-intensive inputs, and market integration vary within this land system, encompassing a spectrum from (semi)subsistence to more market-oriented smallholders. (6) *Shifting cultivation* systems are mixed land-use activities with traditional rotational farming practices that involve the temporary clearing of land for several years of cropping, before moving to a different plot, allowing the previous plot to regenerate. (7) *Pastoralist* systems are characterized by livestock as the main source of livelihoods and income. Actors can be sedentary or semi-nomadic (i.e., herders moving their animals seasonally in search of pastures). (8) *Forest-dwelling* systems are characterized by community forest use that is primarily based on collecting NTFPs and subsistence hunting, possibly with a more minor role of gardening. Next, we identified two forestry systems where forests are managed for timber extraction: In (9) *Forest plantations,* timber is harvested from commercial, large-scale tree plantations, whereas (10) *forestry in native forests* describes the selective logging of trees from native forests for timber and charcoal production.

We differentiate three area-based conservation systems, encompassing areas explicitly managed for conservation or restoration purposes, and usually implying restrictions on extractive activities and access: (11) *State conservation* systems encompass all area-based conservation efforts led and managed by government entities and typically formerly designated as protected areas. (12) *Private conservation* systems encompass all area-based conservation initiatives driven by individuals, non-governmental organizations, or corporations. (13) *Community conservation* describes institutionally and culturally diverse arrangements that lead to the protection of landscapes (co-)managed by local communities. Note that conservation land systems are defined as having conservation as an explicit purpose, in contrast with other systems which can have conservation values and activities, but typically as subsidiary objectives.

The last two systems in our typology include land uses that involve significant landscape alteration resulting in a very high degree of modification: (14) *Energy land use* systems describe the use of land for energy production installations, such as solar farms, wind parks, or hydropower installations. (15) *Mining and construction* systems include a diverse set of land uses that entail the total removal of natural land cover for both extracting mineral resources and constructing infrastructure and buildings. All systems are described qualitatively, which allows for overlap in space and highlights the plurality of land uses in many landscapes.

3.2. Regionalized land systems

The regionalized level describes land systems in more detail, contextualized for five tropical dry woodland regions in Argentina, Bolivia, Mozambique, India, and Cambodia. The regionalization process can involve leaving out certain land systems, refining global systems to fit the regional context, or splitting global systems into regional subsystems (Fig. 4, Table 2). While we find recurring patterns of conservation threats and opportunities related to land use across tropical dry woodlands worldwide, not all of them are equally important for all dry woodland regions and contexts. Our regionalized systems thus capture the place-based nature of conservation challenges shaped by a given social ecology. Below, we highlight the most pronounced differences and similarities among the five regions we analyzed, acknowledging that these remain generalizations (see Supplementary Information for a more detailed description of land-use actors and activities per regionalized system).

The forms and importance of capitalized agriculture vary across our five regions. In Argentina and Bolivia, agribusiness cropping (mostly soybeans and maize) and capitalized ranching are most dominant in terms of the areas occupied and threats to biodiversity, most importantly through habitat transformation. Interestingly, and unlike the other dry forest regions we analyzed, land-use actors often engage in both ranching and cropping, sometimes alternating these activities on the same land, depending on market and weather conditions. Speculative land holding is a land use that often precedes agribusiness systems. It involves the clearing and subsequent selling of land and is widespread in Bolivia, where commodity frontiers are accelerating. Capitalized tree cropping is a major land use in many dry woodland regions but is most widespread in India (mostly rubber and fruit trees). These are often monocultures but, in some instances, large-scale tree plantations include crops or vegetables in horticultural agroforestry, resulting in higher landscape diversity and thus providing environmental and biodiversity benefits. In Cambodia, capitalized (tree) cropping operations may occur inside protected areas through economic land concessions.

The group of small-scale systems entails the largest diversity across

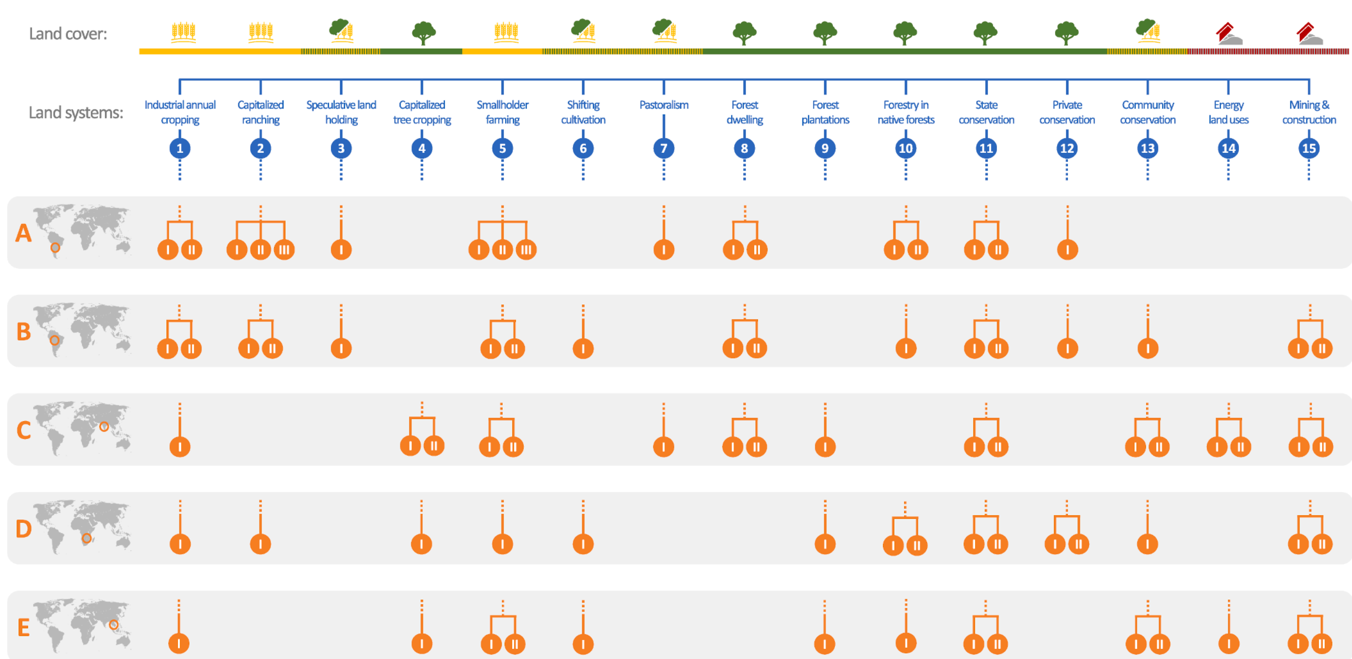

Fig. 4. Scalable land system typology, with 15 general land systems at the highest level, and regionalized systems for five regions: (A) the Gran Chaco dry forest in Argentina, (B) the Chiquitano dry forest in Bolivia, (C) the Deccan dry forests in India, (D) the Miombo-Mopane woodlands in Mozambique, and (E) the Indochina dry forests in Cambodia. The top row demonstrates the limited number of classes that a land-cover perspective would typically identify (cropland, tree cover, built-up, bare soil). See Table 2 for a short description of the associated regional land system. A detailed description of regionalized land systems (i.e., land-use actors and activities) as well as literature references validating the typology is provided in the Supplementary Information 4.

Table 2
Regionalized land systems. A detailed description (i.e., land-use actors and activities) is provided in the Supplementary Information.

Global	Argentina		Bolivia		India		Mozambique		Cambodia	
Industrial annual cropping	**A1.I**	Agribusiness cropping	**B1.I**	Agribusiness cropping	**C1.I**	Commodity cropping	**D1.I**	Commodity cultivations	**E1.I**	Agribusiness farming
	A1.II	Irrigated cropping	**B1.II**	Mennonite farming						
Capitalized ranching	**A2.I**	Cattle fattening and rearing	**B2.I**	Cattle fattening and rearing			**D2.I**	Commercial cattle ranching		
	A2.II	Cattle ranching and breeding	**B2.II**	Cattle ranching and breeding						
	A2.III	Dairy production								
Speculative land holding	**A3.I**	Speculative clearing	**B3.I**	Speculative clearing						
Capitalized tree cropping					**C4.I**	Tree crop plantations	**D4.I**	Commercial tree crop plantations	**E4.I**	Commercial tree crop plantations
					C4.II	Horticultural agroforestry				
Smallholder farming	**A5.I**	Organized smallholder farming	**B5.I**	Mechanized peasantry	**C5.I**	Agropastoral systems	**D5.I**	Medium-scale farming	**E5.I**	Commercial smallholding
	A5.II	Non-organized smallholder farming	**B5.II**	Traditional peasantry	**C5.II**	Marginalized farming			**E5.II**	Semi-subsistence smallholding
	A5.III	Mennonite farming								
Shifting cultivation			**B6.I**	Indigenous communal farming			**D6.I**	Semi-subsistence smallholding	**E6.I**	Communal Indigenous land use
Pastoralism	**A7.I**	Forest-dependent grazing			**C7.I**	Migratory pastoralism				
Forest-dwelling	**A8.I**	Formalized Indigenous forest use	**B8.I**	Indigenous community territories	**C8.I**	Forest-dwelling on recognized lands				
	A8.II	Non-formalized Indigenous forest use	**B8.II**	Indigenous isolated hunting-gathering	**C8.II**	Forest-dwelling without land rights				
Forest plantations					**C9.I**	Private forestry	**D9.I**	Commercial timber plantations	**E9.I**	Commercial timber plantations
Forestry in native forests	**A10.I**	Charcoal production	**B10.II**	Commercial logging			**D10.I**	Concessions-based logging	**E10.I**	Informal, commercial logging
	A10.II	Commercial logging					**D10.II**	License-based logging		
State conservation	**A11.I**	Strict state area protection	**B11.I**	Strict state area protection	**C11.I**	State protected areas	**D11.I**	Strict state area protection	**E11.I**	Conservation core zone
	A11.II	Less restrictive state area protection	**B11.II**	Less restrictive state area protection	**C11.II**	Reserve forests	**D11.II**	Less restrictive state area protection	**E11.II**	Sustainable use zone
Private conservation	**A12.I**	Private reserves	**B12.I**	Private reserves			**D12.I**	Safari reserves		
							D12.II	Game reserves		
Community conservation			**B13.I**	Indigenous reserves	**C13.I**	Communal forests	**D13.I**	Sacred forests	**E13.I**	Community forestry
					C13.II	Sacred groves			**E13.II**	Indigenous sacred forests
Energy land uses					**C14.I**	Water reservoirs and dams			**E14.I**	Water reservoirs
					C14.II	Electric power structures				
Mining & construction			**B15.I**	Large-scale resource extraction	**C15.I**	Mining	**D15.I**	Large-scale mining	**E15.I**	Large-scale mining
			B15.II	Small-scale mining	**C15.II**	Infrastructure development	**D15.II**	Artisanal mining	**E15.II**	Artisanal mining

and within the regions we assessed. Activities include subsistence and cash cropping with diverse management practices in terms of inputs, mechanization, the use of fire and fallows, gardening, animal rearing, both sedentary and migratory, aquaculture, small-scale timber plantations, charcoal production and harvesting timber from forests, the collection of NTFPs, and subsistence hunting and fishing. The main factors used to split the global small-scale farming system into multiple regionalized ones were market integration, land-use intensity, and mixed livelihood strategies, typically related to organization, access to technology and information, tenure, and landscape configuration. Small-scale systems are characterized by a gradient in terms of the share of labor or surplus production that is exchanged on local, regional, or global markets. This variety often results from different levels of integration into networks, commodity chains, or political organization, and consequently, access to technologies, information (e.g., on market prices), or infrastructure (e.g., processing, storing, transportation). For example, in Argentina and Bolivia, agricultural cooperatives and peasant movements play a critical role in shaping land systems, due to their role in negotiating better prices or access to public assistance policies. In Mozambique, urban investors and influential rural people have recently emerged as a new type of medium-scale agricultural actor and tend to dominate farm lobby groups to influence agricultural policies and public expenditures in their favor. Hence, their high access to capital and technologies not only translates to specific land-use activities and newly emerging associated threats but also shapes the market conditions in their surroundings by attracting large-scale grain traders and mechanization rental services.

Tenure is an important factor in determining access to land and resources. For example, the recognition or disrespect of Indigenous territorial rights strongly affects local land uses in Argentina, Bolivia, Cambodia, and India. Unlike in most dry woodland regions where shifting cultivation is uncommon, it is the most prevalent land use in Mozambique. Similarly, both pastoralist and forest-dwelling systems are regionally specific. For example, pastoralism in India takes the shape of extensive, transhumant herding along traditional routes with cattle and goats, whereas in Argentina, it describes sedentary grazing systems with cattle roaming freely inside the forest. Although all forest-dwelling systems are based on nomadic-seasonal subsistence traditions, most of these nomadic practices are restricted today, so actors are typically engaged in small-scale gardening and productive activities oriented at local markets, such as in Argentina and India. An exception are Indigenous tribes in some areas of Bolivia, living in voluntary isolation primarily from hunting and gathering.

Forestry occurs in all analyzed dry woodland regions but with some heterogeneity due to institutional settings and the different extent of remaining natural forest. Commercial timber plantations are among the most widespread capitalized land uses in India, Mozambique, and Cambodia. Additionally, large quantities of timber are sourced from native forests by a variety of regional actors. While forestry is mainly carried out based on large-scale concessions by capitalized actors in Argentina and Bolivia, there are two forestry systems in native forests in Mozambique, distinguished by regulations, management requirements and spatial scale. In Cambodia and India, large-scale forestry in native forests is banned but illegal logging is common, including companies bypassing the logging ban inside economic land concessions in Cambodia or small-scale logging for fuelwood in Indian dry forests.

Our regionalization also uncovered considerable variation in conservation-focused land systems, mainly due to restriction levels, privatization, agents, and primary purposes. The state is generally the most important and powerful actor for formal protection of lands in all our dry forest regions. However, as the levels of governance, funding, and restriction vary, conservation land uses translate into diverse and often incompatible land-use realities on the ground, ranging from strictly enforced use restrictions (e.g., national park core zones) to integrated management of land use (e.g., in transition and buffer zones of biosphere reserves). Cambodia, for example, has strict conservation core zones next to "sustainable use zones" of community forestry by local communities or Indigenous communal lands, yet the latter can also include hydropower reservoirs, industrial agriculture, or mining. Private reserves play a minor role in terms of area and often combine conservation and ecotourism goals, for example in Argentina and Bolivia. In Mozambique, private and state conservation are often entangled, as lands are owned by the state, but protected areas are usually co-funded and managed by private conservancies or international NGOs, and commercial companies are allocated land to develop safari tourism and game hunting. Community-based conservation approaches are also comparably small in extent. Examples are Indigenous community reserves in Bolivia, community forestry systems in Cambodia, communal forests in India, or sacred sites in the dry forests of India, Cambodia, and Mozambique.

Finally, in terms of highly modified land uses, the Deccan dry forests stand out as a region where the spatial footprints of industry, infrastructure, and energy land uses are substantial. Mining systems occur in most dry woodland regions, usually involving both commercial, large-scale operations and small-scale artisanal mining.

4. Discussion

With land use being the main driver of the biodiversity crisis, and with the formulation of ambitious global conservation targets (Alves-Pinto et al., 2021; Convention on Biological Diversity, 2022), there is an urgent need to improve approaches to representing the complexity of land-use actors and activities in conservation and sustainability planning. To address this challenge, we developed a scalable land system typology that combines the strengths of top-down and bottom-up approaches. Land systems in our typology represent typical, recurring combinations of land-use activities and actors, translating into key challenges and opportunities for conservation. Applying this framework to tropical dry woodlands, we demonstrate that considering and capturing land-use complexity is critical to inform regionalized conservation action that is frequently highlighted as key for effective and just conservation.

4.1. Insights from our land-system typology for conservation

Our typology addresses land-use complexity for conservation planning in five ways. First, a more detailed representation of land system diversity can improve the assessment of threats to biodiversity as these are tightly linked to specific actors and activities. While it is well known that capitalized land systems usually entail higher threat levels to biodiversity than less intensive land uses (Raven & Wagner, 2021), our typology goes substantially beyond such a generalization. Specifically, our typology is a basis for identifying, for each land system, the properties that influence related threats. For example, capitalized ranching in the Argentine Chaco can occur on fully cleared lands, in less land-demanding feedlots, or on partially cleared lands as silvopastures, where remaining tree cover offers some biodiversity benefits (Fernández et al., 2020). Similarly, capitalized tree-cropping systems constitute monocultures in most contexts but can also entail elements that provide considerable biodiversity benefits (Dhyani et al., 2021; Zemp et al., 2023). Some threats are actor-specific, and thus specific to certain land systems. For example, hunting is mainly motivated by tradition or subsistence in smallholder communities in many dry woodlands globally, but can also be a manifestation of human-wildlife conflict in (agro) pastoral systems, such as in Argentina or India (Camino et al., 2018; Sethi, 2021). Finally, some threats are linked to complex socioeconomic or political phenomena that require contextual knowledge to be understood. Examples of this include forest clearing to secure tenure or speculate on land prices in Bolivia (Vos et al., 2020), or forestry companies bypassing logging bans by obtaining economic land concessions in Cambodia (Milne, 2015). Our typology provides a tool to consider such nuances in conservation planning.

Second, accounting for actors and their economic, institutional, and cultural context can help to identify leverage points for tailored conservation action (Ban et al., 2013; de Snoo et al., 2013). For example, area-based initiatives might be effective in targeting land systems where actors are operating in one location but might lead to leakage when addressing flexible and mobile capitalized actors, such as agribusinesses in Argentina and Bolivia (de la Vega-Leinert & Huber, 2019; Le Polain De Waroux et al., 2016). Since these actors have the capacity to make decisions over land in multiple production sectors and locations, combining area-based measures and supply-chain-based measures such as certificates or trade regulations could prevent such leakage (Gasparri & le Polain de Waroux, 2014). Moreover, different motives and capacities of land-use actors influence whether incentivizing, constraining, or supporting measures are most appropriate. For example, incentivizing biodiversity-friendliness via certificates might be effective for profit-oriented actors with long-term interests, whereas constraining mechanisms such as enforced regulations might be a more appropriate tool in the case of actors interested in extracting short-term rent from the land (Vos et al., 2020). Weak consideration of actors' motivation and agency has been at the heart of many unwanted conservation outcomes (Colloff et al., 2017; Iwamura et al., 2018), which could be avoided by our actor-based typology.

Third, our typology can help highlight land-use contexts where conservation action can more easily provide co-benefits for people and nature (Alves-Pinto et al., 2021). For example, we identified several land systems where conservation is already a main goal, and strengthening institutional support could improve ecological and social outcomes, such as for sacred forests or spiritual sites in the Indian, Mozambican, or Cambodian dry forests (Dar et al., 2022; Khan et al., 2008; Virtanen, 2002). Similarly, Indigenous and traditional land uses, such as in the Argentine, Bolivian and Indian dry forests can have positive effects on nature conservation and ecosystem service provisioning (Pratzer et al., 2023; Sze et al., 2022; Umeek, 2011) but currently receive a small share of conservation funding and attention compared to state-protected areas (Qin et al., 2022; Tauli-Corpuz et al., 2020). Supporting actors in Indigenous and traditional land systems in maintaining stewardship of their lands and recognizing their historical rights to do so thus represents a significant opportunity for enabling equitable conservation.

Fourth, highlighting the plurality of land uses in many landscapes captures the real-world complexity of spatially overlapping land uses. Unlike previous approaches which assumed land uses to be categorical in space (Asselen & Verburg, 2012; Levers et al., 2018), our narrative typology can contribute to designing conservation strategies that appropriately address such plurality. For example, industrialized cropping and capitalized ranching activities in Argentina and Bolivia often co-occur on the same land, involving the same actors, but translate into distinct threats (Baldi et al., 2015; de la Vega-Leinert & Huber, 2019; Gasparri & le Polain de Waroux, 2014). Similarly, our typology highlights conflicting actor constellations that should be taken into account, such as energy land uses and pastoralist systems in the Deccan dry forests or industrial and communal land uses and conservation in the Cambodian dry forests (Baka, 2013; Diepart & Oeur, 2023; Diepart & Sem, 2018). Importantly, our typology can uncover conservation land uses overlapping with other land uses that are commonly 'hidden' (e.g., pastoralist or forest-dwelling people) or overlooked in large-scale assessments (de la Vega-Leinert, 2020; Levers et al., 2021; Singh et al., 2022).

Fifth, our hierarchical approach can help create a bridge between global-scale top-down policymaking and priority setting, and local-to-regional initiatives for action on the ground – as both scales are relevant for conservation planning and action (Tulbure et al., 2022; Wyborn & Evans, 2021). So far, cross-regional learning is often hindered by conservation planning focused on single regions as well as by global scale conservation planning that often must rely on highly generalized data. Our global level, on the one hand, provides coarse but comprehensive insights, matching the setting of targets of international policymaking (Convention on Biological Diversity, 2022), the geographic scales of the increasingly tele-coupled pressures on biodiversity (Allan et al., 2022), and the increasingly cross-border dynamics of conservation initiatives (Qin et al., 2022). On the other hand, our regionalized land systems provide contextual nuance. For example, in smallholder farming systems in Argentina, a crucial factor is the level of political organization since it determines the actors' access to markets and support by the government (Wald, 2014) thus shaping their responsiveness to supply-chain-based instruments or their capacities to adapt more biodiversity-friendly technologies. In turn, in Mozambique, the heterogeneous group of smallholder farmers comprises semi-subsistence farmers besides urban-based investors whose land use might threaten biodiversity mainly due to the application of pesticides or simplification of landscapes (Jayne et al., 2016). Consequently, global-scale conservation efforts, such as the design of supply chain mechanisms (e.g. sustainable coffee certification schemes) or trade regulations (e.g. EU-MERCOSUR agreement), can be informed by shared characteristics of smallholders across regions, while regional initiatives, like farm support schemes or regional land-use zoning plans, must consider contextual specificities. By linking global and regional system characterizations in one consistent framework, our scalable typology can detect inter-regional similarities that enable large-scale planning, comparison, and cross-regional learning, while retaining the contextual nuance needed to identify conservation action tailored to the threats or opportunities associated with specific actors and activities.

4.2. Making the typology actionable

Our typology can be used in conservation planning in four major ways. First, the regionalized land systems can be the basis for mapping key characteristics that are typically hard to represent spatially. Specifically, mapping regionalized land systems would allow mapping threats, a notoriously challenging task (Benítez-López et al., 2017; Blowes et al., 2019; Symes et al., 2018). For example, while deforestation may pose the greatest threat to woodland birds (Macchi et al., 2019), the presence of semi-subsistence ranchers could be the largest threat to carnivores, as they are likely to kill large carnivores to protect their livestock (Jędrzejewski et al., 2017). Hence, the diversity of actors and activities results in very different spatial patterns of threats and opportunities for co-existence for these taxa with people (Marinaro et al., 2017). By relying on expert-based archetyping instead of data-driven classification of systems, we overcome constraints imposed by the current availability of spatial data (on threats). Decoupling the mapping process from the typology development, furthermore, allows for progressive improvement as better data, for instance on land-use actors, becomes available.

Second, our typology framework can be used to identify the key variables within each land system that shape threats to biodiversity and opportunities for future conservation. For example, the gradient from feedlots to silvopastures in the capitalized ranching systems of the Argentine Chaco (Mastrangelo & Gavin, 2012), or the gradient from monocultures to agroforestry in capitalized tree cropping systems in Indian Deccan dry forests characterize heterogeneity that is most critical for biodiversity (Dhyani et al., 2021). Such insights can steer the design of biodiversity assessments, including what data should be collected over distinct land systems to measure the effectiveness of policies.

Third, the typology includes area-based conservation as a land use by itself and thus provides a framework for assessing social implications of governance and territorialization processes linked to conservation (Buchadas, et al., 2022b; Thaler et al., 2019). Since conservation always competes with other land uses and has often unevenly distributed costs and benefits (Brockington et al., 2008; Büscher et al., 2017), the social impacts of conservation can be substantial (Sandbrook et al., 2023) with sometimes devastating consequences for local communities (Barnes et al., 2023). By offering a lens to engage with the diverse nature and implications of area-based conservation, our typology can contribute to avoiding fortress conservation as an unwanted outcome of conservation (Brockington, 2002; Sandbrook et al., 2023).

Fourth, the typology framework we propose here can be transferred and expanded to other regions to reveal opportunities but also limitations of cross-regional learning. Although our study only included five regionalized cases, trends observed coincide with studies from other tropical dry woodland regions. Examples include the key importance of tenure regimes in dry forests in Mexico (Schroeder & Castillo, 2013), the conservation and livelihood challenges of forest-dependent pastoralism in Brazil (Schulz et al., 2018), wildlife-related threats to smallholder livelihoods in Botswana (Gupta, 2013), or the expansion of renewable energy areas in Australia (Guerin, 2019). Allocating case studies to a certain land system in the typology, through mapping or not, can provide the basis for comparative analyses and thus enable transferring knowledge and sharing experiences of successful strategies from one place to another (Diogo et al., 2023).

4.3. Limitations

Methods based on expert elicitation are prone to contextual biases since experts can make mistakes, be overconfident, or unevenly represent concerns (Hemming et al., 2018). We consider these biases minor in our case because we sought to collect a plurality of expert knowledge and worked with a large number of experts to capture a diversity of land systems, rather than deriving precise estimates or formulating specific recommendations based on expert judgement. By involving several experts in every workshop and including a wide range of disciplines and thematic foci related to land use and conservation, we believe that we could sufficiently capture the variety of scientific and conservation perspectives. However, our typology did not incorporate the views and concerns of local land users directly. This could be a useful future extension of our co-design approach.

Another shortcoming of our typology relates to neglected dimensions. As every generalization reduces complexity, several factors are absent or only indirectly present in our typology, mainly individual actor aspects (e.g., gender, race, or personal attitude), temporal dimensions (e.g., land-use change trajectories), or factors external to the systems (e.g., international political, legal, or economic contexts, political history). Although these might be critical for the precise design of conservation interventions, the value of middle-ground approaches for conservation planning is to establish context-sensitive abstractions that can most meaningfully inform policies and foster action (Oberlack et al., 2023).

5. Conclusion

Changes in land use are the main threat to global biodiversity, directly through the transformation of habitat, and indirectly, through the many other pressures that increase where land use expands and intensifies. Finding ways to improve consideration of the social-ecological complexity surrounding land use is crucial to addressing and mitigating these threats, yet incorporating the diversity of land-use actors and activities in broad-scale conservation and sustainability planning has been difficult due to the complexity of land use and a general lack of knowledge and data describing this complexity well. The typology framework and methodology we develop and demonstrate here effectively address this challenge, combining the strengths of top-down and bottom-up approaches. There is an increasing recognition that conservation challenges are complex and wicked problems that cannot be solved on a single scale or with a single strategy. When there are no silver-bullet solutions available, the challenge is to design contextually appropriate interventions carefully at multiple scales and from multiple perspectives, grounded in knowledge on socio-ecological systems. To meet this challenge, we propose a tool to foster careful conservation that links global imperatives with on-ground, place-based solutions considering the wide range of land-use actors and activities, connected to diverse portfolios of threats to biodiversity, opportunities for interventions, or trade-offs with conservation action. We suggest this can be a key step towards more effective and just conservation.

CRediT authorship contribution statement

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Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

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Appendix A. Supplementary data

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References

Allan, J.R., Possingham, H.P., Atkinson, S.C., Waldron, A., Di Marco, M., Butchart, S.H.M., Adams, V.M., Kissling, W.D., Worsdell, T., Sandbrook, C., Gibbon, G., Kumar, K., Mehta, P., Maron, M., Williams, B.A., Jones, K.R., Wintle, B.A., Reside, A.E., Watson, J.E.M., 2022. The minimum land area requiring conservation attention to

safeguard biodiversity. Science 376 (6597), 1094–1101. https://doi.org/10.1126/science.abl9127.
Altrichter, M., 2006. Wildlife in the life of local people of the semi-arid Argentine Chaco. Biodivers. Conserv. 15 (8), 2719–2736. https://doi.org/10.1007/s10531-005-0307-5.
Alves-Pinto, H., Geldmann, J., Jonas, H., Maioli, V., Balmford, A., Ewa Latawiec, A., Crouzeilles, R., Strassburg, B., 2021. Opportunities and challenges of other effective area-based conservation measures (OECMs) for biodiversity conservation. Perspect. Ecol. Conserv. 19 (2), 115–120. https://doi.org/10.1016/j.pecon.2021.01.004.
Angelsen, A., 1999. Agricultural expansion and deforestation: Modelling the impact of population, market forces and property rights. J. Dev. Econ. 58 (1), 185–218. https://doi.org/10.1016/S0304-3878(98)00108-4.
Asselen, S., Verburg, P.H., 2012. A Land System representation for global assessments and land-use modeling. Glob. Chang. Biol. 18 (10), 3125–3148. https://doi.org/10.1111/j.1365-2486.2012.02759.x.
Baka, J. (2013). The Political Construction of Wasteland: Governmentality, Land Acquisition and Social Inequality in South India. In *Governing Global Land Deals* (S. 211–229). Wiley. doi: 10.1002/9781118688229.ch10.
Baldi, G., Houspanossian, J., Murray, F., Rosales, A.A., Rueda, C.V., Jobbágy, E.G., 2015. Cultivating the dry forests of South America: Diversity of land users and imprints on ecosystem functioning. J. Arid Environ. 123, 47–59. https://doi.org/10.1016/j.jaridenv.2014.05.027.
Baldi, G., Jobbágy, E.G., 2012. Land use in the dry subtropics: Vegetation composition and production across contrasting human contexts. J. Arid Environ. 76, 115–127. https://doi.org/10.1016/j.jaridenv.2011.08.016.
Baldi, G., Verón, S.R., Jobbágy, E.G., 2013. The imprint of humans on landscape patterns and vegetation functioning in the dry subtropics. Glob. Chang. Biol. 19 (2), 441–458. https://doi.org/10.1111/gcb.12060.
Balmford, A., Carey, P., Kapos, V., Manica, A., Rodrigues, A.S.L., Scharlemann, J.P.W., Green, R.E., 2009. Capturing the many dimensions of threat: Comment on Salafsky et al. Conserv. Biol. 23 (2), 482–487. https://doi.org/10.1111/j.1523-1739.2009.01196.x.
Ban, N.C., Mills, M., Tam, J., Hicks, C.C., Klain, S., Stoeckl, N., Bottrill, M.C., Levine, J., Pressey, R.L., Satterfield, T., Chan, K.M.A., 2013. A social-ecological approach to conservation planning: Embedding social considerations. Front. Ecol. Environ. 11 (4), 194–202. https://doi.org/10.1890/110205.
Banda-R, K., Delgado-Salinas, A., Dexter, K.G., Linares-Palomino, R., Oliveira-Filho, A., Prado, D., Pullan, M., Quintana, C., Riina, R., Rodríguez, G.M., Weintritt, J., Acevedo-Rodríguez, P., Adarve, J., Álvarez, E., Aranguren, A.B., Arteaga, J.C., Aymard, G., Castaño, A., Ceballos-Mago, N., Pennington, R.T., 2016. Plant diversity patterns in neotropical dry forests and their conservation implications. Science 353, 1383–1387. https://doi.org/10.1126/science.aaf5080.
Baragwanath, K., Bayi, E., 2020. Collective property rights reduce deforestation in the Brazilian Amazon. PNAS 117 (34), 20495–20502. https://doi.org/10.1073/pnas.1917874117.
Barlow, J., Gardner, T.A., Araujo, I.S., Ávila-Pires, T.C., Bonaldo, A.B., Costa, J.E., Esposito, M.C., Ferreira, L.V., Hawes, J., Hernandez, M.I.M., Hoogmoed, M.S., Leite, R.N., Lo-Man-Hung, N.F., Malcolm, J.R., Martins, M.B., Mestre, L.A.M., Miranda-Santos, R., Nunes-Gutjahr, A.L., Overal, W.L., Peres, C.A., 2007. Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. Proc. Natl. Acad. Sci. 104 (47), 18555–18560. https://doi.org/10.1073/pnas.0703333104.
Barnes, P.A., Aninta, S.G., Ariyanto, T., Holle, M.J.M., Ikhawan, M.K., Jayanto, H., 2023. The gap between policy and practice for human rights in conservation: A case study in Papua Province. Indonesia*Oryx* 57 (3), 360–369. https://doi.org/10.1017/S0030605323000066.
Batterbury, S.P.J., Bebbington, A.J., 1999. Environmental histories, access to resources and landscape change: An introduction. Land Degrad. Dev. 10 (4), 279–288.
Baumann, M., Gasparri, I., Buchadas, A., Oeser, J., Meyfroidt, P., Levers, C., Romero-Muñoz, A., Waroux, Y. le P. de, Müller, D., & Kuemmerle, T. (2022). Frontier metrics for a process-based understanding of deforestation dynamics. *Environmental Research Letters*, *17*(9), 095010. doi: 10.1088/1748-9326/ac8b9a.
Bebbington, A. (1999). Capitals and Capabilities: A Framework for Analyzing Peasant Viability, Rural Livelihoods and Poverty. *World Development*, *27*(12), 2021–2044. doi: 10.1016/S0305-750X(99)00104-7.
Benítez-López, A., Alkemade, R., Schipper, A.M., Ingram, D.J., Verweij, P.A., Eikelboom, J.A.J., Huijbregts, M.A.J., 2017. The impact of hunting on tropical mammal and bird populations. Science 356 (6334), 180–183. https://doi.org/10.1126/science.aaj1891.
Blowes, S.A., Supp, S.R., Antão, L.H., Bates, A., Bruelheide, H., Chase, J.M., Moyes, F., Magurran, A., McGill, B., Myers-Smith, I.H., Winter, M., Bjorkman, A.D., Bowler, D. E., Byrnes, J.E.K., Gonzalez, A., Hines, J., Isbell, F., Jones, H.P., Navarro, L.M., Dornelas, M., 2019. The geography of biodiversity change in marine and terrestrial assemblages. Science 366 (6463), 339–345. https://doi.org/10.1126/science.aaw1620.
Bonan, G.B., 2008. Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests. Science 320 (5882), 1444–1449. https://doi.org/10.1126/science.1155121.
Brockington, D., 2002. Fortress Conservation: The Preservation of the Mkomazi Game Reserve. James Currey Publishers, Tanzania.
Brockington, D., Duffy, R., Igoe, J., 2008. Nature unbound: Conservation, capitalism and the future of protected areas. Earthscan.
Buchadas, A., Baumann, M., Meyfroidt, P., Kuemmerle, T., 2022a. Uncovering major types of deforestation frontiers across the world's tropical dry woodlands. Nat. Sustainability. https://doi.org/10.1038/s41893-022-00886-9.
Buchadas, A., Qin, S., Meyfroidt, P., Kuemmerle, T., 2022b. Conservation frontiers: Understanding the geographic expansion of conservation. J. Land Use Sci. 17 (1), 12–25. https://doi.org/10.1080/1747423X.2021.2018516.
Buchadas, A., Jung, M., Bustamante, M., Fernández-Llamazares, Á., Garnett, S.T., Nanni, A.S., Ribeiro, N., Meyfroidt, P., Kuemmerle, T., 2023. Tropical dry woodland loss occurs disproportionately in areas of highest conservation value. Glob. Chang. Biol. 00, 1–18. https://doi.org/10.1111/gcb.16832.
Büscher, B., Fletcher, R., Brockington, D., Sandbrook, C., Adams, W.M., Campbell, L., Corson, C., Dressler, W., Duffy, R., Gray, N., Holmes, G., Kelly, A., Lunstrum, E., Ramutsindela, M., Shanker, K., 2017. Half-Earth or Whole Earth? Radical ideas for conservation, and their implications. Oryx 51 (3), 407–410. https://doi.org/10.1017/S0030605316001228.
Camino, M., Cortez, S., Altrichter, M., Matteucci, S.D., 2018. Relations with wildlife of Wichi and Criollo people of the Dry Chaco, a conservation perspective. Ethnobiology and Conservation 7. https://www.ethnobioconservation.com/index.php/ebc/article/view/233.
Chaudhary, A., Kastner, T., 2016. Land use biodiversity impacts embodied in international food trade. Glob. Environ. Chang. 38, 195–204. https://doi.org/10.1016/j.gloenvcha.2016.03.013.
Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., Maginnis, S., Maynard, S., Nelson, C.R., Renaud, F.G., Welling, R., Walters, G., 2019. Core principles for successfully implementing and upscaling Nature-based Solutions. Environ Sci Policy 98, 20–29. https://doi.org/10.1016/j.envsci.2019.04.014.
Colloff, M.J., Lavorel, S., van Kerkhoff, L.E., Wyborn, C.A., Fazey, I., Gorddard, R., Mace, G.M., Foden, W.B., Dunlop, M., Prentice, I.C., Crowley, J., Leadley, P., Degeorges, P., 2017. Transforming conservation science and practice for a postnormal world. Conserv. Biol. 31 (5), 1008–1017. https://doi.org/10.1111/cobi.12912.
Convention on Biological Diversity. (2022). *COP15: Final text of Kunming-Montreal Global Biodiversity Framework*. https://www.cbd.int/article/cop15-final-text-kunming-montreal-gbf-221222.
Dar, J.A., Kothandaraman, S., Khare, P.K., Khan, M.L., 2022. Sacred groves of Central India: Diversity status, carbon storage, and conservation strategies. Biotropica 54 (6), 1400–1411. https://doi.org/10.1111/btp.13157.
Davis, K.F., Yu, K., Rulli, M.C., Pichdara, L., D'Odorico, P., 2015. Accelerated deforestation driven by large-scale land acquisitions in Cambodia. Nat. Geosci. 8 (10), Article 10. https://doi.org/10.1038/ngeo2540.
de la Vega-Leinert, A.C., 2020. Too small to count? Making Land Use Transformations in Chiquitano communities of San Ignacio de Velasco, East Bolivia, visible. J. Land Use Sci. 15 (2–3), 172–202. https://doi.org/10.1080/1747423X.2020.1753834.
de la Vega-Leinert, A.C., Huber, C., 2019. The Down Side of Cross-Border Integration: The Case of Deforestation in the Brazilian Mato Grosso and Bolivian Santa Cruz Lowlands. Environ. Sci. Policy Sustain. Dev. 61 (2), 31–44. https://doi.org/10.1080/00139157.2019.1564214.
de Snoo, G.R., Herzon, I., Staats, H., Burton, R.J.F., Schindler, S., van Dijk, J., Lokhorst, A.M., Bullock, J.M., Lobley, M., Wrbka, T., Schwarz, G., Musters, C.J.M., 2013. Toward effective nature conservation on farmland: Making farmers matter. Conserv. Lett. 6 (1), 66–72. https://doi.org/10.1111/j.1755-263X.2012.00296.x.
Dhyani, S., Murthy, I.K., Kadaverugu, R., Dasgupta, R., Kumar, M., Adesh Gadpayle, K., 2021. Agroforestry to Achieve Global Climate Adaptation and Mitigation Targets: Are South Asian Countries Sufficiently Prepared? Forests, 12(3). Article 3. https://doi.org/10.3390/f12030303.
Díaz, S., Settele, J., Brondízio, E.S., Ngo, H.T., Agard, J., Arneth, A., Balvanera, P., Brauman, K.A., Butchart, S.H.M., Chan, K.M.A., Lucas, A.G., Ichii, K., Liu, J., Subramanian, S.M., Midgley, G.F., Miloslavich, P., Molnár, Z., Obura, D., Pfaff, A., Zayas, C.N., 2019. Pervasive human-driven decline of life on Earth points to the need for transformative change. Science 366 (6471). https://doi.org/10.1126/science.aax3100.
Diepart, J.-C., Oeur, I., 2023. Communities at the Core of Protected Area Management: Learning from customary tenure documentation experiences in Cambodia: (8; MRLG Case Study Series). MRLG, WCS, HA.
Diepart, J.-C., Sem, T., 2018. Cambodian peasantry and formalisation of land right: Historical perspectives and current issues (Research Series). French Technical Committee on Land Tenure and Development (AFD-MEAE).
Dinerstein, E., Olson, D., Joshi, A., Vynne, C., Burgess, N.D., Wikramanayake, E., Hahn, N., Palminteri, S., Hedao, P., Noss, R., Hansen, M., Locke, H., Ellis, E.C., Jones, B., Barber, C.V., Hayes, R., Kormos, C., Martin, V., Crist, E., Saleem, M., 2017. An Ecoregion-Based Approach to Protecting Half the Terrestrial Realm. Bioscience 67 (6), 534–545. https://doi.org/10.1093/biosci/bix014.
Diogo, V., Bürgi, M., Debonne, N., Helfenstein, J., Levers, C., Swart, R., Williams, T.G., Verburg, P.H., 2023. Geographic similarity analysis for Land System Science: Opportunities and tools to facilitate knowledge integration and transfer. J. Land Use Sci. 18 (1), 227–248. https://doi.org/10.1080/1747423X.2023.2218372.
Duvernoy, I., 2000. Use of a land cover model to identify farm types in the Misiones agrarian frontier (Argentina). Agr. Syst. 64 (3), 137–149. https://doi.org/10.1016/S0308-521X(00)00019-6.
Eisenack, K., Oberlack, C., Sietz, D., 2021. Avenues of archetype analysis: Roots, achievements, and next steps in sustainability research. Ecol. Soc. 26 (2) https://doi.org/10.5751/ES-12484-260231.
Ellis, E.C., 2019. To Conserve Nature in the Anthropocene, Half Earth Is Not Nearly Enough. One Earth 1 (2), 163–167. https://doi.org/10.1016/j.oneear.2019.10.009.
Ellis, E.C., Gauthier, N., Goldewijk, K.K., Bird, R.B., Boivin, N., Díaz, S., Fuller, D.Q., Gill, J.L., Kaplan, J.O., Kingston, N., Locke, H., McMichael, C.N.H., Ranco, D., Rick, T.C., Rebecca Shaw, M., Stephens, L., Svenning, J.C., Watson, J.E.M., 2021. People have shaped most of terrestrial nature for at least 12,000 years. PNAS 118 (17), 1–8. https://doi.org/10.1073/pnas.2023483118.

Ellis, E.C., Ramankutty, N., 2008. Putting people in the map: Anthropogenic biomes of the world. Front. Ecol. Environ. 6 (8), 439–447. https://doi.org/10.1890/070062.

Erb, K.-H., Haberl, H., Jepsen, M.R., Kuemmerle, T., Lindner, M., Müller, D., Verburg, P. H., Reenberg, A., 2013. A conceptual framework for analysing and measuring land-use intensity. Current Opinion in Environmental Sustainability 5 (5), 464–470. https://doi.org/10.1016/j.cosust.2013.07.010.

Fernández, P.D., Kuemmerle, T., Baumann, M., Grau, H.R., Nasca, J.A., Radrizzani, A., Gasparri, N.I., 2020. Understanding the distribution of cattle production systems in the South American Chaco. J. Land Use Sci. 15 (1), 52–68. https://doi.org/10.1080/1747423X.2020.1720843.

Game, E.T., Meijaard, E., Sheil, D., Mcdonald-Madden, E., 2014. Conservation in a wicked complex world; challenges and solutions. Conserv. Lett. 7 (3), 271–277. https://doi.org/10.1111/conl.12050.

Gasparri, N. I., & le Polain de Waroux, Y. (2014). The Coupling of South American Soybean and Cattle Production Frontiers: New Challenges for Conservation Policy and Land Change Science. *Conservation Letters*, *8*(4), 290–298. doi: 10.1111/conl.12121.

Guerin, T.F., 2019. Impacts and opportunities from large-scale solar photovoltaic (PV) electricity generation on agricultural production. Environ. Qual. Manag. 28 (4), 7–14. https://doi.org/10.1002/tqem.21629.

Gupta, A.C., 2013. Elephants, safety nets and agrarian culture: Understanding human-wildlife conflict and rural livelihoods around Chobe National Park, Botswana. *Journal of Political*. Ecology 20 (1), Article 1. https://doi.org/10.2458/v20i1.21766.

Gurney, G. G., Darling, E. S., Ahmadia, G. N., Agostini, V. N., Ban, N. C., Blythe, J., Claudet, J., Epstein, G., Estradivari, Himes-Cornell, A., Jonas, H. D., Armitage, D., Campbell, S. J., Cox, C., Friedman, Whitney. R., Gill, D., Lestari, P., Mangubhai, S., McLeod, E., … Jupiter, S. D. (2021). Biodiversity needs every tool in the box: Use OECMs. *Nature*, *595*(7869), 646–649. doi: 10.1038/d41586-021-02041-4.

He, T., Lamont, B.B., Pausas, J.G., 2019. Fire as a key driver of Earth's biodiversity. Biol. Rev. 94 (6), 1983–2010. https://doi.org/10.1111/brv.12544.

Hemming, V., Burgman, M.A., Hanea, A.M., McBride, M.F., Wintle, B.C., 2018. A practical guide to structured expert elicitation using the IDEA protocol. Methods Ecol. Evol. 9 (1), 169–180. https://doi.org/10.1111/2041-210X.12857.

Holland, M. B., Masuda, Y. J., & Robinson, B. E. (Hrsg.). (2022). *Land Tenure Security and Sustainable Development*. Springer International Publishing. doi: 10.1007/978-3-030-81881-4.

IPBES. (2018). *The IPBES Assessment Report on Land Degradation and Restoration*. IPBES.

IPBES. (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. In *IPBES Secretariat*.

Iwamura, T., le Polain de Waroux, Y., & Mascia, M. B. (2018). Considering people in systematic conservation planning: Insights from land system science. *Frontiers in Ecology and the Environment*, *16*(7), 388–396. doi: 10.1002/fee.1824.

Jaureguiberry, P., Titeux, N., Wiemers, M., Bowler, D.E., Coscieme, L., Golden, A.S., Guerra, C.A., Jacob, U., Takahashi, Y., Settele, J., Díaz, S., Molnár, Z., Purvis, A., 2022. The direct drivers of recent global anthropogenic biodiversity loss. *Science*. Advances 8 (45), eabm9982. https://doi.org/10.1126/sciadv.abm9982.

Jayne, T. s., Chamberlin, J., Traub, L., Sitko, N., Muyanga, M., Yeboah, F. K., Anseeuw, W., Chapoto, A., Wineman, A., Nkonde, C., & Kachule, R. (2016). Africa's changing farm size distribution patterns: The rise of medium-scale farms. *Agricultural Economics*, *47*(S1), 197–214. doi: 10.1111/agec.12308.

Jędrzejewski, W., Carreño, R., Sánchez-Mercado, A., Schmidt, K., Abarca, M., Robinson, H.S., Boede, E.O., Hoogesteijn, R., Viloria, Á.L., Cerda, H., Velásquez, G., Zambrano-Martínez, S., 2017. Human-jaguar conflicts and the relative importance of retaliatory killing and hunting for jaguar (Panthera onca) populations in Venezuela. Biol. Conserv. 209, 524–532. https://doi.org/10.1016/j.biocon.2017.03.025.

Kehoe, L., Romero-Muñoz, A., Polaina, E., Estes, L., Kreft, H., Kuemmerle, T., 2017. Biodiversity at risk under future cropland expansion and intensification. Nat. Ecol. Evol. 1 (8), 1129–1135. https://doi.org/10.1038/s41559-017-0234-3.

Keith, D. A., Ferrer-Paris, J. R., Nicholson, E., Bishop, M. J., Polidoro, B. A., Ramirez-Llodra, E., Tozer, M. G., Nel, J. L., Mac Nally, R., Gregr, E. J., Watermeyer, K. E., Essl, F., Faber-Langendoen, D., Franklin, J., Lehmann, C. E. R., Etter, A., Roux, D. J., Stark, J. S., Rowland, J. A., … Kingsford, R. T. (2022). A function-based typology for Earth's ecosystems. *Nature*, *610*(7932), Article 7932. doi: 10.1038/s41586-022-05318-4.

Khan, M., Shalata, A., Khumbongmayum, D., Tripathi, R., 2008. The sacred groves and their significance in conserving biodiversity: An overview. Int. J. Ecol. Environ. Sci. © NATIONAL INSTITUTE OF ECOLOGY 34, 277–291.

Kostrowicki, J., 1992. A hierarchy of world types of agriculture. In: Mohammad, N. (Ed.), New Dimensions in Agricultural Geography: Historical dimensions of agriculture. Concept Publishing Company, pp. 163–203.

Kuemmerle, T., Erb, K., Meyfroidt, P., Müller, D., Verburg, P.H., Estel, S., Haberl, H., Hostert, P., Jepsen, M.R., Kastner, T., Levers, C., Lindner, M., Plutzar, C., Verkerk, P. J., van der Zanden, E.H., Reenberg, A., 2013. Challenges and opportunities in mapping land use intensity globally. Curr. Opin. Environ. Sustain. 5 (5), 484–493. https://doi.org/10.1016/j.cosust.2013.06.002.

Kuemmerle, T., Baldi, G., Camino, M., Cuellar, E., Cuellar, R.L., Decarre, J., Díaz, S., Gasparri, I., Giordano, A.J., Leynaud, G., Macchi, L., Piquer-rodríguez, M., Romero-, A., Semper-pascual, A., 2017. Forest conservation: Remember Gran Chaco. Science 355 (6324), 465–467. https://doi.org/10.1126/science.aal3020.

Lambin, E. F., Gibbs, H. K., Heilmayr, R., Carlson, K. M., Fleck, L. C., Garrett, R. D., Le Polain De Waroux, Y., McDermott, C. L., McLaughlin, D., Newton, P., Nolte, C., Pacheco, P., Rausch, L. L., Streck, C., Thorlakson, T., & Walker, N. F. (2018). The role of supply-chain initiatives in reducing deforestation. *Nature Climate Change*, *8* (2), 109–116. doi: 10.1038/s41558-017-0061-1.

Lambin, E.F., Geist, H.J., Lepers, E., 2003. Dynamics of Land-Use and Land-Cover Change in Tropical Regions. Annu. Rev. Env. Resour. 28 (1), 205–241. https://doi.org/10.1146/annurev.energy.28.050302.105459.

le Polain de Waroux, Y., Baumann, M., Gasparri, N. I., Gavier-Pizarro, G., Godar, J., Kuemmerle, T., Müller, R., Vázquez, F., Volante, J. N., & Meyfroidt, P. (2018). Rents, Actors, and the Expansion of Commodity Frontiers in the Gran Chaco. *Annals of the American Association of Geographers*, *108*(1), 204–225. doi: 10.1080/24694452.2017.1360761.

le Polain de Waroux, Y., Garrett, R. D., Chapman, M., Friis, C., Hoelle, J., Hodel, L., Hopping, K., & Zaehringer, J. G. (2021). The role of culture in land system science. *Journal of Land Use Science*, *16*(4), 450–466. doi: 10.1080/1747423X.2021.1950229.

Lees, C.M., Rutschmann, A., Santure, A.W., Beggs, J.R., 2021. Science-based, stakeholder-inclusive and participatory conservation planning helps reverse the decline of threatened species. Biol. Conserv. 260, 109194 https://doi.org/10.1016/j.biocon.2021.109194.

Lehmann, C.E.R., Parr, C.L., 2016. Tropical grassy biomes: Linking ecology, human use and conservation. Philos. Trans. R. Soc., B 371. https://doi.org/10.1098/rstb.2016.0329.

Levers, C., Müller, D., Erb, K., Haberl, H., Jepsen, M.R., Metzger, M.J., Meyfroidt, P., Plieninger, T., Plutzar, C., Stürck, J., Verburg, P.H., Verkerk, P.J., Kuemmerle, T., 2018. Archetypical patterns and trajectories of land systems in Europe. Reg. Environ. Chang. 18 (3), 715–732. https://doi.org/10.1007/s10113-015-0907-x.

Levers, C., Romero-Muñoz, A., Baumann, M., De Marzo, T., Fernández, P.D., Gasparri, N. I., Gavier-Pizarro, G.I., Polain, L.e., de Waroux, Y., Piquer-Rodríguez, M., Semper-Pascual, A., Kuemmerle, T., 2021. Agricultural expansion and the ecological marginalization of forest-dependent people. PNAS 118 (44), 1–9. https://doi.org/10.1073/pnas.2100436118.

Löfqvist, S., Kleinschroth, F., Bey, A., de Bremond, A., DeFries, R., Dong, J., Fleischman, F., Lele, S., Martin, D.A., Messerli, P., Meyfroidt, P., Pfeifer, M., Rakotonarivo, S.O., Ramankutty, N., Ramprasad, V., Rana, P., Rhemtulla, J.M., Ryan, C.M., Vieira, I.C.G., Garrett, R.D., 2023. How Social Considerations Improve the Equity and Effectiveness of Ecosystem Restoration. Bioscience 73 (2), 134–148. https://doi.org/10.1093/biosci/biac099.

Löhr, K., Weinhardt, M., & Sieber, S. (2020). The "World Café" as a Participatory Method for Collecting Qualitative Data. *International Journal of Qualitative Methods*, *19*, 1609406920916976. doi: 10.1177/1609406920916976.

Macchi, L., Baumann, M., Bluhm, H., Baker, M., Levers, C., Grau, H.R., Kuemmerle, T., 2019. Thresholds in forest bird communities along woody vegetation gradients in the South American Dry Chaco. J. Appl. Ecol. 56 (3), 629–639. https://doi.org/10.1111/1365-2664.13342.

Magliocca, N.R., Ellis, E.C., Allington, G.R.H., de Bremond, A., Dell'Angelo, J., Mertz, O., Messerli, P., Meyfroidt, P., Seppelt, R., Verburg, P.H., 2018. Closing global knowledge gaps: Producing generalized knowledge from case studies of social-ecological systems. Glob. Environ. Chang. 50, 1–14. https://doi.org/10.1016/J.GLOENVCHA.2018.03.003.

Malek, Ž., Douw, B., Van Vliet, J., Van Der Zanden, E.H., Verburg, P.H., 2019. Local land-use decision-making in a global context. Environ. Res. Lett. 14 (8), 083006 https://doi.org/10.1088/1748-9326/ab309e.

Marinaro, S., Grau, H.R., Gasparri, N.I., Kuemmerle, T., Baumann, M., 2017. Differences in production, carbon stocks and biodiversity outcomes of land tenure regimes in the Argentine Dry Chaco. Environ. Res. Lett. 12 (4), 045003 https://doi.org/10.1088/1748-9326/aa625c.

Mastrangelo, M.E., Gavin, M.C., 2012. Trade-Offs between Cattle Production and Bird Conservation in an Agricultural Frontier of the Gran Chaco of Argentina. Conserv. Biol. 26 (6), 1040–1051. https://doi.org/10.1111/j.1523-1739.2012.01904.x.

Maxwell, S.L., Cazalis, V., Dudley, N., Hoffmann, M., Rodrigues, A.S.L., Stolton, S., Visconti, P., Woodley, S., Kingston, N., Lewis, E., Maron, M., Strassburg, B.B.N., Wenger, A., Jonas, H.D., Venter, O., Watson, J.E.M., 2020. Area-based conservation in the twenty-first century. Nature 586 (7828), 217–227. https://doi.org/10.1038/s41586-020-2773-z.

Meyfroidt, P., Roy Chowdhury, R., de Bremond, A., Ellis, E. C., Erb, K. H., Filatova, T., Garrett, R. D., Grove, J. M., Heinimann, A., Kuemmerle, T., Kull, C. A., Lambin, E. F., Landon, Y., le Polain de Waroux, Y., Messerli, P., Müller, D., Nielsen, J., Peterson, G. D., Rodriguez García, V., … Verburg, P. H. (2018). Middle-range theories of land system change. *Global Environmental Change*, *53*(August), 52–67. doi: 10.1016/j.gloenvcha.2018.08.006.

Meyfroidt, P., Lambin, E.F., Hertel, T.W., 2013. Globalization of land use: Distant drivers of land change and geographic displacement of land use. Curr. Opin. Environ. Sustain. 5 (5), 438–444. https://doi.org/10.1016/J.COSUST.2013.04.003.

Meyfroidt, P., de Bremond, A., Ryan, C.M., Archer, E., Aspinall, R., Chhabra, A., Camara, G., Corbera, E., DeFries, R., Díaz, S., Dong, J., Ellis, E.C., Erb, K., Fisher, J. A., Garrett, R.D., Golubiewski, N.E., Grau, H.R., Grove, J.M., Haberl, H., zu Ermgassen, E.K.H.J., 2022. Ten facts about land systems for sustainability. Proc. Natl. Acad. Sci. 119 (7), e2109217118 https://doi.org/10.1073/pnas.2109217118.

Milne, S., 2015. Cambodia's Unofficial Regime of Extraction: Illicit Logging in the Shadow of Transnational Governance and Investment. Crit. Asian Stud. 47 (2), 200–228. https://doi.org/10.1080/14672715.2015.1041275.

Newbold, T., Hudson, L.N., Hill, S.L.L., Contu, S., Lysenko, I., Senior, R.A., Börger, L., Bennett, D.J., Choimes, A., Collen, B., Day, J., De Palma, A., Díaz, S., Echeverria-Londoño, S., Edgar, M.J., Feldman, A., Garon, M., Harrison, M.L.K., Alhusseini, T., Purvis, A., 2015. Global effects of land use on local terrestrial biodiversity. Nature 520 (7545), 45–50. https://doi.org/10.1038/nature14324.

Oberlack, C., Pedde, S., Piemontese, L., Václavík, T., Sietz, D., 2023. Archetypes in support of tailoring land-use policies. Environ. Res. Lett. 18 (6), 060202 https://doi.org/10.1088/1748-9326/acd802.

Oldekop, J.A., Holmes, G., Harris, W.E., Evans, K.L., 2016. A global assessment of the social and conservation outcomes of protected areas. Conserv. Biol. 30 (1), 133–141. https://doi.org/10.1111/cobi.12568.

Olesen, R.S., Hall, C.M., Rasmussen, L.V., 2022. Forests support people's food and nutrition security through multiple pathways in low- and middle-income countries. One Earth 5 (12), 1342–1353. https://doi.org/10.1016/j.oneear.2022.11.005.

Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V.N., Underwood, E.C., D'Amico, J.A., Itoua, I., Strand, H.E., Morrison, J.C., Loucks, C.J., Allnutt, T.F., Ricketts, T.H., Kura, Y., Lamoreux, J.F., Wettengel, W.W., Hedao, P., Kassem, K.R., 2001. Terrestrial ecoregions of the world: A new map of life on Earth. Bioscience 51 (11), 933–938. https://doi.org/10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2.

Ordway, E.M., Asner, G.P., Lambin, E.F., 2017. Deforestation risk due to commodity crop expansion in sub-Saharan Africa. Environ. Res. Lett. 12 (4) https://doi.org/10.1088/1748-9326/aa6509.

Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press. doi: 10.1017/CBO9780511807763.

Pacheco, P., Dudley, M., K. ,., Shapiro, N., Aguilar-Amuchastegui, A., Ling, P. Y. N., Anderson, C., & Marx, A. (2021). *Deforestation fronts: Drivers and responses in a changing world*. WWF, Gland, Switzerland.

Pacheco-Romero, M., Kuemmerle, T., Levers, C., Alcaraz-Segura, D., Cabello, J., 2021. Integrating inductive and deductive analysis to identify and characterize archetypical social-ecological systems and their changes. Landsc. Urban Plan. 215, 104199 https://doi.org/10.1016/j.landurbplan.2021.104199.

Pascual, U., Balvanera, P., Anderson, C.B., Chaplin-Kramer, R., Christie, M., González-Jiménez, D., Martin, A., Raymond, C.M., Termansen, M., Vatn, A., Athayde, S., Baptiste, B., Barton, D.N., Jacobs, S., Kelemen, E., Kumar, R., Lazos, E., Mwampamba, T.H., Nakangu, B., Zent, E., 2023. Diverse values of nature for sustainability. Nature 1–11. https://doi.org/10.1038/s41586-023-06406-9.

Pimm, S.L., Jenkins, C.N., Abell, R., Brooks, T.M., Gittleman, J.L., Joppa, L.N., Raven, P. H., Roberts, C.M., Sexton, J.O., 2014. The biodiversity of species and their rates of extinction, distribution, and protection. Science 344 (6187). https://doi.org/10.1126/science.1246752.

Porter, M.E., 2000. Location, Competition, and Economic Development: Local Clusters in a Global Economy. Econ. Dev. Q. 14 (1), 15–34.

Pratzer, M., Fernández-Llamazares, Á., Meyfroidt, P., Krueger, T., Baumann, M., Garnett, S.T., Kuemmerle, T., 2023. Agricultural intensification, Indigenous stewardship and land sparing in tropical dry forests. Nat. Sustainability 1–12. https://doi.org/10.1038/s41893-023-01073-0.

Pressey, R.L., Cabeza, M., Watts, M.E., Cowling, R.M., Wilson, K.A., 2007. Conservation planning in a changing world. Trends Ecol. Evol. 22 (11), 583–592. https://doi.org/10.1016/j.tree.2007.10.001.

Qin, S., Kuemmerle, T., Meyfroidt, P., Napolitano Ferreira, M., Gavier Pizarro, G.I., Periago, M.E., dos Reis, T.N.P., Romero-Muñoz, A., Yanosky, A., 2022. The geography of international conservation interest in South American deforestation frontiers. Conserv. Lett. 15 (1), e12859.

Qin, S., Pratzer, M., Meyfroidt, P., Kuemmerle, T., 2023. Changing determinants of international conservation funding committed to major deforestation regions in South America. Biol. Conserv. 288, 110362 https://doi.org/10.1016/j.biocon.2023.110362.

Raven, P.H., Wagner, D.L., 2021. Agricultural intensification and climate change are rapidly decreasing insect biodiversity. Proc. Natl. Acad. Sci. 118 (2), e2002548117 https://doi.org/10.1073/pnas.2002548117.

Ravikanth, G., Uma Shaanker, R., Ganeshaiah, K.N., 2000. Conservation status of forests in India: A cause for worry? By Gudasalamani Ravikanth, R. Uma Shaanker, K. N. Ganeshaiah · 1538683821 · OA.mg. J. Indian Inst. Sci. 80, 591–600.

Raymond, C.M., Cebrián-Piqueras, M.A., Andersson, E., Andrade, R., Schnell, A.A., Battioni Romanelli, B., Filyushkina, A., Goodson, D.J., Horcea-Milcu, A., Johnson, D. N., Keller, R., Kuiper, J.J., Lo, V., López-Rodríguez, M.D., March, H., Metzger, M., Oteros-Rozas, E., Salcido, E., Sellberg, M., Wiedermann, M.M., 2022. Inclusive conservation and the Post-2020 Global Biodiversity Framework: Tensions and prospects. One Earth 5 (3), 252–264. https://doi.org/10.1016/j.oneear.2022.02.008.

Richards, P., 2018. It's not just where you farm; It's whether your neighbor does too. How agglomeration economies are shaping new agricultural landscapes. J. Econ. Geogr. 18 (1), 87–110. https://doi.org/10.1093/jeg/lbx009.

Romero-Muñoz, A., Jansen, M., Nuñez, A.M., Toledo, M., Almonacid, R.V., Kuemmerle, T., 2019. Fires scorching Bolivia's Chiquitano forest. Science 366 (6469), 1082. https://doi.org/10.1126/science.aaz7264.

Ryan, C.M., Hill, T., Woollen, E., Ghee, C., Mitchard, E., Cassells, G., Grace, J., Woodhouse, I.H., Williams, M., 2012. Quantifying small-scale deforestation and forest degradation in African woodlands using radar imagery. Glob. Chang. Biol. 18 (1), 243–257. https://doi.org/10.1111/j.1365-2486.2011.02551.x.

Sandbrook, C., Albury-Smith, S., Allan, J.R., Bhola, N., Bingham, H.C., Brockington, D., Byaruhanga, A.B., Fajardo, J., Fitzsimons, J., Franks, P., Fleischman, F., Frechette, A., Kakuyo, K., Kaptoyo, E., Kuemmerle, T., Kalunda, P.N., Nuvunga, M., O'Donnell, B., Onyai, F., Zaehringer, J.G., 2023. Social considerations are crucial to success in implementing the 30×30 global conservation target. Nat. Ecol. Evol. https://doi.org/10.1038/s41559-023-02048-2.

Schleicher, J., Zaehringer, J.G., Fastré, C., Vira, B., Visconti, P., Sandbrook, C., 2019. Protecting half of the planet could directly affect over one billion people. Nat. Sustainability 2 (12), 1094–1096. https://doi.org/10.1038/s41893-019-0423-y.

Schröder, J.M., Rodríguez, L.P.A., Günter, S., 2021. Forest Policy and Economics Research trends: Tropical dry forests: The neglected research agenda? Forest Policy Econ. 122 (102333) https://doi.org/10.1016/j.forpol.2020.102333.

Schroeder, N.M., Castillo, A., 2013. Collective Action in the Management of a Tropical Dry Forest Ecosystem: Effects of Mexico's Property Rights Regime. Environ. Manag. 51 (4), 850–861. https://doi.org/10.1007/s00267-012-9980-9.

Schulz, K., Guschal, M., Kowarik, I., Almeida-Cortez, J.S., Sampaio, E.V.S.B., Cierjacks, A., 2018. Grazing, forest density, and carbon storage: Towards a more sustainable land use in Caatinga dry forests of Brazil. Reg. Environ. Chang. 18 (7), 1969–1981. https://doi.org/10.1007/s10113-018-1303-0.

Semenchuk, P., Plutzar, C., Kastner, T., Matej, S., Bidoglio, G., Erb, K., Essl, F., Haberl, H., Wessely, J., Krausmann, F., Dullinger, S., 2022. Relative effects of land conversion and land-use intensity on terrestrial vertebrate diversity. Nat. Commun. 13 (1), 615. https://doi.org/10.1038/s41467-022-28245-4.

Sethi, S., 2021. Insights into illegal wildlife hunting by forest guards of selected tiger reserves in Central India. Eur. J. Wildl. Res. 68 (1), 4. https://doi.org/10.1007/s10344-021-01553-8.

Shackleton, C., Shackleton, S., 2004. The importance of non-timber forest products in rural livelihood security and as safety nets: A review of evidence from South Africa. S. Afr. J. Sci. 100, 658–664.

Sietz, D., Frey, U., Roggero, M., Gong, Y., Magliocca, N., Tan, R., Janssen, P., Václavík, T., 2019. Archetype analysis in sustainability research: Methodological portfolio and analytical frontiers. Ecol. Soc. 24 (3) https://doi.org/10.5751/ES-11103-240334.

Singh, R., Bhutia, K.S., Bhutia, T.U., Babu, S., 2022. Rangeland Conservation, Pastoralist Displacement, and Long-term Implications of a Grazing Ban in the Indian Himalaya. Ecology, Economy and Society–the INSEE Journal 5 (1). https://doi.org/10.37773/ees.v5i1.335.

Srivathsa, A., Vasudev, D., Nair, T., Chakrabarti, S., Chanchani, P., DeFries, R., Deomurari, A., Dutta, S., Ghose, D., Goswami, V.R., Nayak, R., Neelakantan, A., Thatte, P., Vaidyanathan, S., Verma, M., Krishnaswamy, J., Sankaran, M., Ramakrishnan, U., 2023. Prioritizing India's landscapes for biodiversity, ecosystem services and human well-being. Nat. Sustainability 1–10. https://doi.org/10.1038/s41893-023-01063-2.

Stan, K.D., Sanchez-Azofeifa, A., Hamann, H.F., 2024. Widespread degradation and limited protection of forests in global tropical dry ecosystems. Biol. Conserv. 289, 110425 https://doi.org/10.1016/j.biocon.2023.110425.

Symes, W.S., Edwards, D.P., Miettinen, J., Rheindt, F.E., Carrasco, L.R., 2018. Combined impacts of deforestation and wildlife trade on tropical biodiversity are severely underestimated. *Nature*. Communications 9(1), Article 1. https://doi.org/10.1038/s41467-018-06579-2.

Sze, J.S., Carrasco, L.R., Childs, D., Edwards, D.P., 2022. Reduced deforestation and degradation in Indigenous Lands pan-tropically. Nat. Sustainability 5 (2), 123–130. https://doi.org/10.1038/s41893-021-00815-2.

Tauli-Corpuz, V., Alcorn, J., Molnar, A., Healy, C., Barrow, E., 2020. Cornered by PAs: Adopting rights-based approaches to enable cost-effective conservation and climate action. World Dev. 130, 104923 https://doi.org/10.1016/j.worlddev.2020.104923.

Thaler, G.M., Viana, C., Toni, F., 2019. From frontier governance to governance frontier: The political geography of Brazil's Amazon transition. World Dev. 114, 59–72. https://doi.org/10.1016/j.worlddev.2018.09.022.

Tulbure, M.G., Hostert, P., Kuemmerle, T., Broich, M., 2022. Regional matters: On the usefulness of regional land-cover datasets in times of global change. Remote Sens. Ecol. Conserv. 8 (3), 272–283. https://doi.org/10.1002/rse2.248.

Turner, B.L., Meyfroidt, P., Kuemmerle, T., Müller, D., Roy Chowdhury, R., 2020. Framing the search for a theory of land use. J. Land Use Sci. 15 (4), 489–508. https://doi.org/10.1080/1747423X.2020.1811792.

Umeek, 2011. Principles of Tsawalk. An Indigenous Approach to a Global Crisis. UBC Press.

Václavík, T., Lautenbach, S., Kuemmerle, T., Seppelt, R., 2013. Mapping global land system archetypes. Glob. Environ. Chang. 23 (6), 1637–1647. https://doi.org/10.1016/j.gloenvcha.2013.09.004.

Verburg, P.H., Crossman, N., Ellis, E.C., Heinimann, A., Hostert, P., Mertz, O., Nagendra, H., Sikor, T., Erb, K.H., Golubiewski, N., Grau, R., Grove, M., Konaté, S., Meyfroidt, P., Parker, D.C., Chowdhury, R.R., Shibata, H., Thomson, A., Zhen, L., 2015. Land system science and sustainable development of the earth system: A global land project perspective. Anthropocene 12, 29–41. https://doi.org/10.1016/j.ancene.2015.09.004.

Virtanen, P., 2002. The Role of Customary Institutions in the Conservation of Biodiversity: Sacred Forests in Mozambique. Environ. Values 11 (2), 227–241.

Vos, V.A., Gallegos, S.C., Czaplicki-Cabezas, S., Peralta-Rivero, C., 2020. Biodiversidad en Bolivia: Impactos e implicaciones de la apuesta por el agronegocio. Mundos Rurales 15 (1), 25–48.

Wald, N., 2014. In Search of Alternatives. Lat. Am. Perspect. https://doi.org/10.1177/0094582X14534608.

Le Polain De Waroux, Y., Garrett, R. D., Heilmayr, R., & Lambin, E. F. (2016). Land-use policies and corporate investments in agriculture in the Gran Chaco and Chiquitano. *Proceedings of the National Academy of Sciences of the United States of America*, *113* (15), 4021–4026. doi: 10.1073/pnas.1602646113.

Williams, D.R., Rondinini, C., Tilman, D., 2022. Global protected areas seem insufficient to safeguard half of the world's mammals from human-induced extinction. Proc. Natl. Acad. Sci. 119 (24), e2200118119 https://doi.org/10.1073/pnas.2200118119.

Wyborn, C., & Evans, M. C. (2021). Conservation needs to break free from global priority mapping. Nat. Ecol. Evol., 5(10), Article 10. doi: 10.1038/s41559-021-01540-x.

Zemp, D. C., Guerrero-Ramirez, N., Brambach, F., Darras, K., Grass, I., Potapov, A., Röll, A., Arimond, I., Ballauff, J., Behling, H., Berkelmann, D., Biagioni, S., Buchori, D., Craven, D., Daniel, R., Gailing, O., Ellsäßer, F., Fardiansah, R., Hennings, N., … Kreft, H. (2023). Tree islands enhance biodiversity and functioning in oil palm landscapes. *Nature*, *618*(7964), Article 7964. doi: 10.1038/s41586-023-06086-5.