International Journal of Applied Geospatial Research
Volume 14 • Issue 1

Perspectives on Applications of Geospatial Technology and Landscape Ecology for Conservation Planning in the Global South

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ABSTRACT

Rapidly changing landscapes and disturbance regimes in the Global South impact the viability of conservation planning. Although conservation planning processes benefit from reliable multi-scale and multi-temporal data on landscape changes, this is not widely understood. In this paper, the authors examine landscape change dynamics and disturbance regimes in the Global South and discuss the methodological needs of characterizing pattern-process relationships of landscape disturbance to facilitate effective conservation planning. For example, geospatial analysis of Nairobi-Namanga Road, in the Kaputei Plains of Kenya, was used to highlight impacts of road infrastructure on wooded grassland and open grasslands, on wildlife migration corridors and livelihoods. The authors discuss how integration of geospatial technologies and landscape ecology metrics could enhance conservation planning and decision-making in the Global South. The benefits of coupling the decision-making process with stakeholder engagements and nature-based solutions to ensure viable conservation of biodiversity were also discussed.

KEYWORDS

Conservation Planning, Disturbance Regimes, DPSIR Framework, Essential Biodiversity Variables (EBVs), Geospatial Science and Technology, Global South, Landscape Ecology, Stakeholder Participation

INTRODUCTION

Conservation planning is gaining global attention but especially in the global south where issues of natural resource degradation are more prevalent. Increases in land degradation coupled with recent global arrangements such as the Sustainable Development Goals (SDGs) and Aichi Biodiversity Targets have generated increased attention on formulating policies and resource planning strategies

DOI: 10.4018/IJAGR.313941

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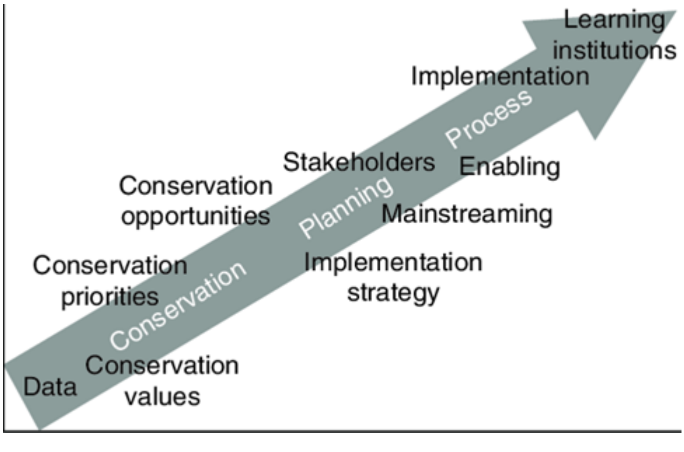
geared toward biodiversity and natural resource conservation, particularly in the Global South. Conservation planning as illustrated in Figure 1 involves the use of a systematic approach to delineate priority areas for biodiversity conservation within the landscape, from local to regional scales. This goes beyond protected area networks to encompass integrated management of critical biodiversity areas. It also involves data-driven and spatially explicit land-use planning and decision-making mechanism to prioritize critical areas in need of biodiversity conservation actions (Knight et al., 2009; Botts et al., 2019; Harris et al., 2019). A critical part in the process of conservation planning is access to reliable data on landscape changes and disturbance regimes occurring or projected to occur at various spatiotemporal scales (Hobbs et al., 2014; Costa et al., 2017; Ward et al., 2018; Mahmoud et al, 2019).

Landscape changes and disturbance regimes often have spatial and temporal characteristics, and these have been studied extensively in the developed countries of the Global North (e.g. Turner, 2010; Johnstone et al., 2016; Summerfield et al., 2018; Newman, 2019) while the Global South context has received less attention. There are differences in contexts and dimensions of landscape changes and disturbances between the Global South and Global North. These differences can be attributed to differences in prevailing climatic, ecological, social, economic and governance structures. In this paper, we discuss key drivers of landscape change and disturbance regimes that often result in habitat loss and threaten biodiversity integrity of landscapes in the Global South. The drivers are mostly anthropogenic and include grazing (transhumance), agricultural expansion, urbanization, mining and drilling, and deforestation.

Landscape disturbances are random or cumulative events that result in a departure from an optimal or desired state of a resource (Perera et al., 2007). Turner (2010) suggested the potential for profound consequences of rapidly changing disturbance regimes on ecosystems and linked social-ecological systems. Newman (2019) also noted that there are “large shifts in characteristics of individual disturbances and disturbance regimes”. These observations indicate that there are opportunities for landscape ecologists and conservation practitioners to learn more about the pattern–process interactions across different landscape scales (Turner, 2010; Newman, 2019).

The focus of this paper is to discuss the nature of rapidly changing landscape dynamics and disturbance regimes (including grazing, cropland expansion, urbanization, deforestation, as well as mining and drilling) in the Global South (specifically Sub-Saharan Africa and Latin America), and to examine how Landscape ecology and geospatial technology has facilitated or could further facilitate conservation planning in the Global South. The approach for this paper involved the

Figure 1. From theory to practice: Designing and situating spatial prioritization approaches to better implement conservation action (Source: Knight et al., 2009)

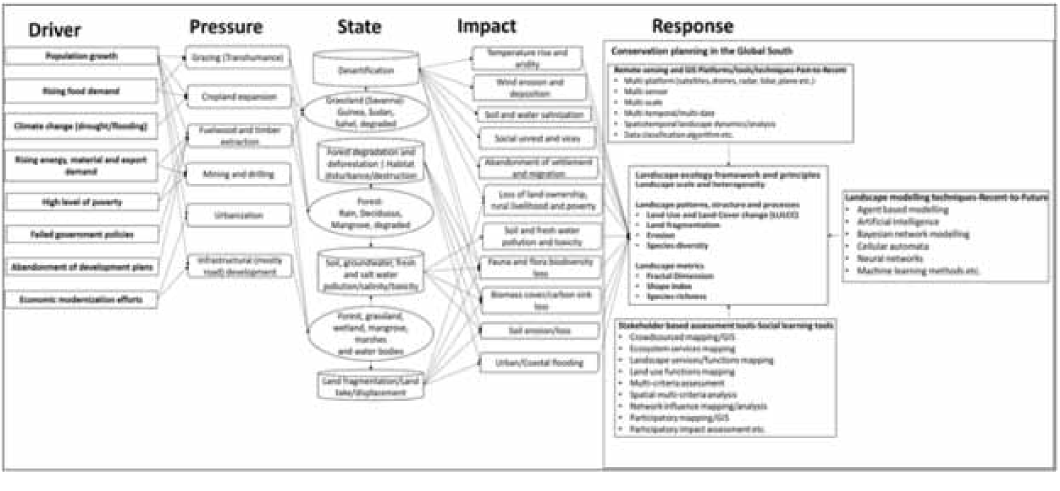


definition of the scope and nature of landscape disturbance regimes in the Global South, especially Sub-Saharan Africa and Latin America. We then applied an analytical framework (Driver, Pressure, State, Impact and Response-DPSIR) for understanding the pattern-process relationships related to landscape disturbance regimes in Sub-Saharan Africa (SSA) and Latin America, and then mapped the data needs for characterizing such pattern-process relationships. We posit that: (a) understanding the unique drivers and spatiotemporal variations of disturbance regimes in SSA and Latin America are key to effective conservation planning in these regions; (b) Landscape Ecology and Geospatial Science and Technologies (GIS&T) provide a holistic scientific framework and analytic tools/metrics for understanding the drivers and spatiotemporal variations of disturbance regimes in the Global South; and (c) integrating stakeholder and indigenous knowledge are essential to the viability of conservation planning initiatives through nature-based solutions (NbS) in SSA and Latin America. The next section describes the changing landscapes and disturbance regimes in the Global South using the DPSIR analytical framework; followed by a discussion of the role of landscape ecology, geospatial technologies and stakeholder participation for meeting conservation planning information needs and enhancing sustainability in the Global South; and finally underscore the need for the appropriation of these three methodological elements (landscape ecology, geospatial technologies and stakeholder participation) to provide critical data and information to facilitate conservation planning in SSA and Latin America.

CHANGING LANDSCAPES AND DISTURBANCE REGIMES IN THE GLOBAL SOUTH

Changing landscapes and disturbance regimes are a product of the interplay of anthropogenic and natural agents (Turner, 2010; Newman, 2019). Such interplay needs to be contextually understood for effective conservation planning and management in the Global South. In the light of this, we describe the anthropogenic drivers and the socioecological impacts of landscape change and disturbance regimes in the Global using the DPSIR (Driver, State, Pressure, Impact and Response) analytical framework (Figure 2). The DPSIR framework is a systems approach that has been widely used to facilitate in-depth integrated analysis of socio-economic systems and the natural systems interactions within them (Bidone & Lacerda, 2004; Potschin, 2009). Its premise is based on the notion that changes in demographic and socioeconomic development in society serve as “drivers” that generate

Figure 2. Schematic representation of DPSIR (Driver, State, Pressure, Impact and Response) framework of landscape disturbance regimes and the roles of GIS&T and landscape ecology in conservation planning in the Global South



"pressures" on the environment (Müller & Burkhard, 2012). The use of the DPSIR framework enables one to examine and represent the causal relationships drivers/pressures and their impact on decision-making processes by resource planners and stakeholders (Bidone & Lacerda, 2004). For example, Kyere-Boateng & Marek's (2021) used a DPSIR Framework to examine literature-based sources of social-ecological causes of deforestation and forest degradation in Ghana helped identify appropriate mitigation response measures.

Grazing as a Disturbance Regime

The Amazon Basin of Latin America has the largest global biomass stock and carbon sinks, and the largest biomass consumption rate (with a per capita of 5.8 tC/cap per year), even though it has moderate yields compared to the Global North (Krausmann et al, 2013). Increased grazing activities and soybean cultivation for beef production and export to the Global North has put significant pressure on forest resources which have led to conversion of Amazon rainforest areas to pastures. Intense desertification across parts of SSA, such as Sudan Savanna and Sahel regions in West Africa, and semi-arid regions in Eastern and Southern Africa, have also been attributed largely to increased nomadic grazing activities i.e., transhumance herding (Hein et al, 2011; Owusu et al, 2013). This is driven by a rise in food demand (specifically meat-based protein) as the population increases exponentially (Symeonakis & Drake, 2004; Mansur & Ismail, 2016). Transhumance herding in SSA has led to gradual desertification and other natural land encroachments (e.g. wetland conversion). Transhumance grazing together with the expansion of irrigation farming in the forest-savanna transition zones (i.e. guinea savanna regions) of West Africa, growing food demand and climate change impacts (i.e. longer dry seasons, fluctuating rainfall amounts, reduced crop yield, etc.) are the causes and aggravating factors responsible for desertification and expansion of the Sahel region in West Africa (Tiffen & Mortimore, 2002; Olagunju, 2015).

The negative impacts of grazing on the environment include loss of valuable biomass and carbon sinks; destruction of biodiversity; increased surface temperature, soil aridity and salinity; loss of water bodies; and increased sand dune formation. These lead to loss of livelihood and poverty; abandonment of rural settlements and migration; as well as social vices such as criminal violence, and inter-communal clashes (Holtz, 2007; Gadzama & Ayuba, 2016).

Deforestation as a Disturbance Regime

Large scale deforestation activities in the Global South is driven primarily by population increase, accompanying rise in food, energy, raw materials, and export demands, as well as government policies favoring modernization of local economies (Mahmoud et al, 2016; Ingram et al, 2017; Laurance et al, 2018; Junior et al 2021). The extent of deforestation and land degradation across the tropical rainforest in the Global South can be estimated using earth observation data and remote sensing techniques. For example, Junior et al (2021) recently suggested that the 2020 deforestation rate in Brazilian Amazon is the fastest rate to be recorded in a decade. However, the drivers of these degradations are usually assumed and rarely are they validated locally (Laurance et al, 2015; Haddad et al, 2015). Deforestation in the Global South is divided into large-scale and small-scale scenarios (Lambin, 1999; de Wasseige et al, 2012). Large scale deforestation across SSA is mainly the result of pressures such as urbanization and road infrastructure developments, industrial logging, cropland expansions to meet local livelihood and food needs, as well as cash crop/commodity export demands e.g., Jatropha cultivation for biofuel and feedstock export in parts of Western, Eastern and Southern Africa (Arndt et al 2011; Vijay et al., 2016).

In the Amazon Basin, large-scale deforestation is caused mainly by land clearing for animal feed production (mostly soybeans) and grazing (Barona et al, 2010; Macedo et al 2012), and to a lesser extent by global biofuel expansion (Lima et al, 2011; Aide et al, 2013). Another driver is the commercial interest of multinational corporations that pushes governments to maximize their export potential. This leads to larger forest fragmentation and degradation, loss of biomass and carbon sinks, increase in soil erosion, and loss in soil fertility, flora, and fauna biodiversity. Small scale deforestation on the other hand is driven primarily by subsistence lifestyle of rural communities in their search of food and income to meet their immediate needs (Alamgir et al, 2017; Mahmoud et al, 2019). These include activities such as wood extraction for energy, woodland and forest clearing for food cultivation, timber extraction (logging) for building raw materials and retail for cash (Tchuenté et al, 2011; Potapov et al, 2017). Forest cover losses or leakages from small-scale deforestation and forest degradation have become more rampant in the Equatorial SSA (Herold & Skutsch, 2011, Ogbodo et al, 2014). This slows down the expected global carbon sequestration and storage functions of the tropical forest.

Accelerated forest degradation, as well as encroachment of other natural landscapes (e.g. savanna, mangrove forest, and wetlands) across the Global South is also fueled by population increase and its attendant demand for food, energy and raw materials for local use and increase in the level of rural poverty (Hein et al, 2011; Laurance et al, 2018). Forests and other natural landscapes are often the only resources for the subsistence livelihood of rural communities; hence they engage in farming, hunting, wine tapping and illegal mining activities for survival, thereby putting further pressure on the environment and its ecosystem functions (Haddad et al, 2015; Nwokoro & Chima, 2017). Failed Government policies and abandonment of development plans also further exacerbates direct exploitation of natural landscapes by rural communities, resulting in an increase in landscape fragmentation, degradation of environmental quality and biodiversity loss (Hein et al, 2011; Gadzama & Ayuba, 2016; Laurance et al, 2018).

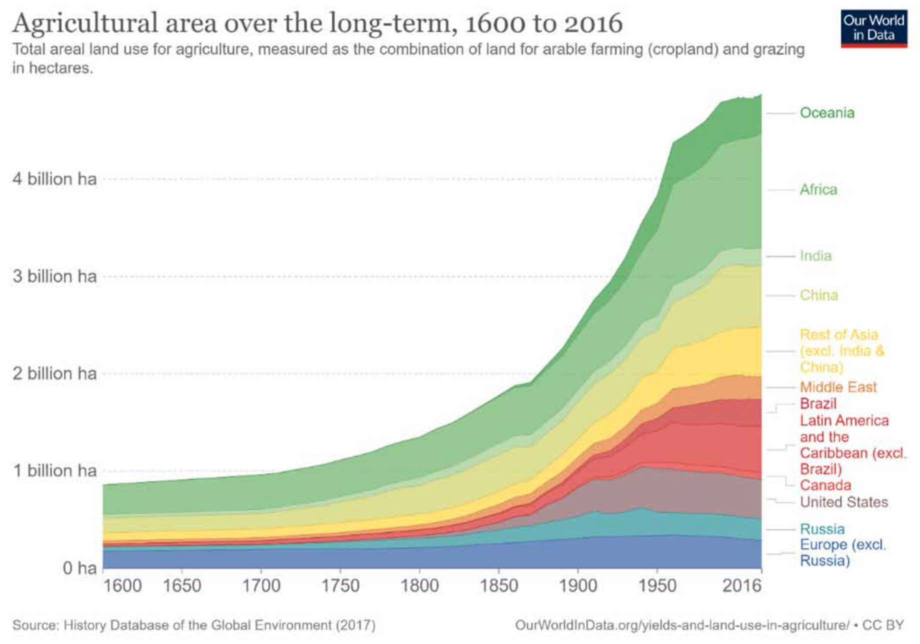
Agricultural Expansion as a Disturbance Regime

Land conversion for agriculture and expansion of croplands can be considered as one of the most important drivers of environmental change since the industrial revolution (Paine, 2019). Agricultural land use accounts for the largest portion of land cover globally (GEF-STAP, 2010; FAO, 2014). Agricultural land constitutes 40% of global land mass, as compared to forest's (30%), desert's (20%), urban areas (3%) and others (including bare rock, degraded land, wetlands, coastlands, and marshes, etc.) (7%) (Malagnoux, 2007; FAO and UNEP, 2020). Pastoral grazing accounts for the largest use (26%) of agricultural land globally, compared to cropland's (14%) (Ritchie & Roser, 2018; Stanimirova et al, 2019). Over the last century animal feed for livestock (e.g. soybeans) accounts for the largest share of biomass use, followed by energy carriers such as fuelwood, food and other dissipative uses (Krausmann et al, 2013; Krausmann et al, 2017). It is important to note that the pressures of agricultural land expansions are more pronounced in the Global South, especially Africa and Latin America (Figures 2 and 3).

The disturbance effects of agricultural activities in the Global South range from small-scale (e.g., selective subsistence farming and plantations of native tree species) to large-scale disturbance regimes (e.g., cattle ranching activities, conventional plantations of annual cash crops such as chili, corn, soybean, and perennials crops such as oil palm, eucalyptus, rubber trees (Macedo et al, 2012; Zermeño et al, 2015).

The major drivers of agricultural expansion as an ecological disturbance of natural landscapes and ecosystems in SSA include population growth and rising food demand. These drivers put high pressure on ecosystems and impact biodiversity. This trend is of particular concern because most of the population is rural and rely on natural resources as the primary source of income. Some farmers are adopting recessional agriculture practice as an adaptive strategy to cope with irregular precipitations due to climate change. Recessional agriculture is an off-season cultivation of short-term crops on riverbanks and wetlands. All these practices expand agricultural land into wildlife habitats and hence threaten their biodiversity. Agricultural expansion is a challenge for conservation planning because it triggers land use changes that are considered to be the most important drivers of land degradation and biodiversity loss (Purswani et al, 2020). For example, decreases in species richness (biodiversity loss) and changes in species composition of the natural habitat have been linked to agricultural expansion in SSA (Kehoe et al, 2017; Houessou et al, 2019; Stenchly et al, 2019). Moreover, others like Balima

Figure 3. Agricultural area over the long-term (Source: Our world in data, 2021)



et al. (2020) demonstrated strong correlation between agricultural land expansion and disruption of ecosystem services like carbon sequestration.

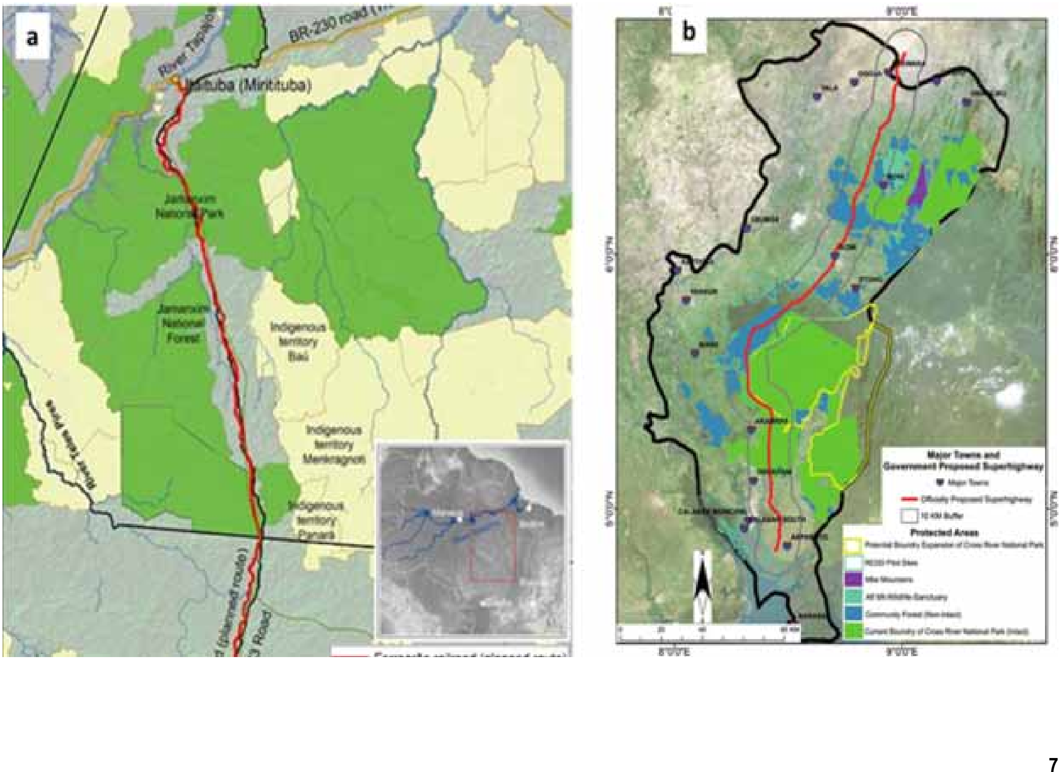
The impacts of agricultural expansion as an ecological disturbance regime is even more severe in the Amazon rainforest of Latin America. Large scale forest conversions have occurred in the Amazon rainforest since the 1970’s where commercial farming has been a major component of economic growth in South American countries like Brazil and Colombia. For example, about 40% of the cattle herd and 36.5% of soybean production in Brazil are in the Brazilian Amazon, with growth of 14.7% in the cattle herd and 94% in soy production from 2004–2014 respectively (Börner & Wunder, 2011; Koch et al, 2019). Forest clearings in the Amazon occur mostly around the “arc of deforestation” from Para in the north to Mato Grosso in the South and the Brazil-Peru-Bolivia area in the southwest (Börner et al, 2010; Simonet et al., 2019). With the growth in cultivated area in the Amazon region of Brazil far outpacing the growth in the rest of the country, the Brazilian Amazon might be the new frontier of Brazilian agriculture expansion (ITTO, 2011; Laurance, 2015). This trend is predicted to increase even more, and recent simulations of future land use change in Paragominas municipality in the Brazilian Amazon indicate a loss of almost half of the municipality’s forests by 2030 (Börner & Wunder, 2011; Osis et al, 2019). Permanent agriculture comprises a smaller percentage of the land clearings in the Amazon Basin with most of the cleared land dedicated to soybean production (Barona et al, 2010; Macedo et al, 2012). Most crops grown in the forest clearings had moderate rather than the expected high yields, and this triggered a shift to forest clearings for cattle pasture (an estimated 45 million hectares or about 62% of total cleared land) (Cronkleton et al, 2011; Krausmann et al, 2013).

Urbanization as Disturbance Regime

It is projected that 68 percent of the world population will be urban by 2050, with nine of the 10 megacities expected to be located in developing countries of the Global South between 2018 and 2030 (Ritchie & Roser, 2018; UN, 2018). Urbanization and road infrastructure development is one of the main accelerators of landscape changes in Sub-Saharan Africa and Latin America (Laurance et al, 2017; Andrade-Núñez & Aide, 2018). Road infrastructure accounts for up to 90 percent of the new infrastructure projects in developing countries and SSA has been hotspot of these developments in the last two decades (Dulac, 2013; Caro et al, 2014; Ingram et al, 2017). The growth in major national and transboundary highway construction in Africa and Latin American has resulted in concerns over environmental degradation and potential risks to biodiversity (Alamgir et al, 2017; Mahmoud et al, 2019; Datamarnews, 2019). These include the Abidjan-Lagos corridor in West Africa, Arusha-Namanga-Athi River Road Development Project in East Africa (African Development Bank, 2020), the proposed Superhighway' project linking Cross River State in Southern Nigeria to Northern Nigeria and parts of Cameroon (Mahmoud et al, 2019), and the proposed Ferrogrão grain railway in Brazil (Datamarnews, 2019).

Urbanization and infrastructural development trends in the Global South is driven primarily by population increase and economic development efforts often backed by government policies and China's Belt and Road Initiative (Tchuenté et al, 2011; Mahmoud et al, 2016; Peters et al, 2018). These urban and infrastructural development activities can be linked to environmental degradation manifested as increased soil erosion and soil loss activities upstream, urban and coastal flooding downstream (in coastal cities), biomass and carbon sink losses, loss of valuable flora and fauna biodiversity, as well as loss of land ownership rights and economic hardships for displaced rural communities (Brandford & Torres, 2017; Mahmoud et al, 2017; Mahmoud et al, 2019; Datamarnews, 2019). The potential impact of major infrastructural development on biodiversity and local communities requires careful consideration of the conservation needs in the areas that are likely to be affected by such projects. As an example, despite local resistance and concerns by conservationists that proposed highway corridors in Brazil and Nigeria are both expected to cause major landscape disturbance and environmental degradation of protected habitat, these projects are scheduled to be implemented without a comprehensive assessment of the potential disturbance to the landscape and ecosystem (Figure 4).

Figure 4. (a) Map of the proposed Ferrogrão railway across the Brazillian Amazon (Source: Datamarnews, 2019); (b) Map of proposed Cross River state Superhighway over protected ecosystems in Nigeria (Source: Mahmoud et al, 2019)

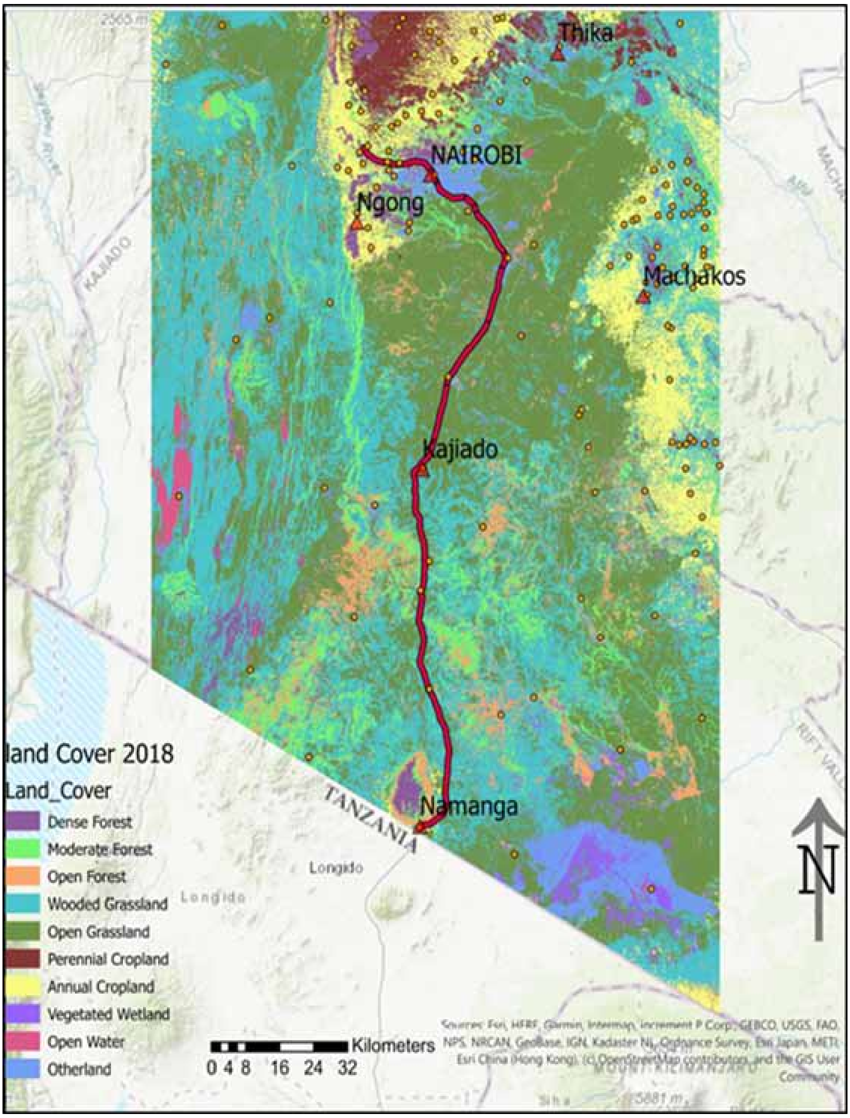


Case Study of Nairobi-Namnga Road Development in East Africa

The potential impacts of major roads infrastructure on biodiversity conservation and rural livelihood in an ecologically sensitive area is exemplified by the consequences of construction of the Nairobi–Namanga Road, part of the transborder Arusha-Namanga-Athi River Road Development Project between Kenya and Tanzania (Figure 5). Our assessment of the land cover change between 2000 and 2018 in the area around Nairobi-Namanga Road was based on GIS analysis of classified satellite data from 2000 and 2018.

The results show that wooded grassland and open grassland were the land cover classes most affected by infrastructure development in the region, with significant land cover transition to "other land" (i.e. 21.21% and 46.42% conversion respectively from wooded grassland and open grassland to other land; where "*other land"* here includes urban land use) (Table 1). The Nairobi-Namanga Road

Figure 5. Map of the Nairobi–Namanga Road, part of the transborder Athi River Road project between Kenya and Tanzania (map produced by Henry Bulley)



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Table 1. Percent Land Cover Change between 2000 and 2018 around the Nairobi – Namanga Road

LAND_COVER	Dense Forest	Moderate Forest	Open Forest	Wooded Grassland	Open Grassland	Perennial Cropland	Annual Cropland	Vegetated Wetland	Open Water	Other land***
Dense Forest		8.87	2.51	5.56	0.98	29.84	6.77	2.12	2.78	3.58
Moderate Forest	7.68		11.95	10.84	3.02	12.27	6.04	1.24	7.58	5.62
Open Forest	8.04	13.00		13.02	10.04	1.47	6.81	3.51	4.46	5.23
Wooded Grassland	21.34	33.06	32.61		33.48	24.61	27.78	16.09	18.03	21.21
Open Grassland	25.99	23.75	39.77	38.40		9.45	29.43	41.74	43.27	46.42
Perennial Cropland	15.79	5.86	0.58	3.49	2.13		7.21	0.49	6.19	3.54
Annual Cropland	11.70	6.79	2.01	6.76	3.63	14.10		1.48	3.70	5.14
Vegetated Wetland	2.30	1.08	2.18	1.87	2.51	0.88	2.23		3.12	3.50
Open Water	2.12	2.08	1.79	1.78	8.14	2.85	1.24	0.39		5.76
Other land**	5.04	5.50	6.59	18.28	36.08	4.52	12.48	32.94	10.86	

Note: *** - "Other land" includes bare lands and built-up areas (towns and cities)

cuts across the Kaputei Plains, one of the few remaining conservation areas for wildlife migration and pastoral dispersal. This wildlife-pastoral ecosystem occupies 2456 km^2. The Northern edge of the plains were transformed into a protected area with the establishment of the Nairobi National Park 117 km^2 in 1946 (Reid, 2012). The park is located 5 km from Nairobi's Central Business District, an active urban area that covers an ecological transition zone between a semi-ever green forest and a savanna ecosystem.

Nomadic Massai, their livestock and wildlife historically migrated to the Kaputei Plains, during the dry season because of water and abundant grass. During the wet seasons, they dispersed out into what was once open grasslands south of Nairobi (Reid, 2012). The establishment of the Parklands however curtailed the movement of the Nomadic Massai and wildlife within the Kaputei Plains. The situation got worse as agricultural societies emerged and some non-pastoral European and African communities secured titles to land around the base of the Ngong Hills in the 1950s and 1960s and this further limited connectivity for the Nomadic Massai's livestock and wildlife. Additionally, conservational fencing of the western and northern edges of Nairobi National Park along with its extension into the eastern base of Ngong Hills reduced movement to this part of the dry-season grazing reserve by at least 50% (Norton-Griffiths and Southey, 1995; Homewood et al, 2004; Said et al 2016; Davidson & Ihwagi, 2017). Following independence, the Kenyan government tried to address the loss of connectivity within the Kaputei Plains by establishing "group ranches" which gave the Maasai control over 2240 km^2 of land. Solidifying pastoral control of these large areas slowed down the spread of cultivation and fencing for several years (Homewood et al, 2004; Said et al 2016; Davidson & Ihwagi, 2017).

This notwithstanding, recent landscape transformation linked to increased capital investments in road construction threaten the future of wildlife migration corridors and dispersal areas within the Kaputei Plains through increased density of fencing and the intensity of land fragmentation near Nairobi-Namanga Road. Closely packed industrial enterprises, small commercial centers, and residential buildings straddle either side of the Nairobi-Namanga Road between Nairobi and Kitengela. The spillover effects of the congestion within the City of Nairobi have culminated in rapid expansion of Kitengela township, which lies immediately south-east of Nairobi. From South of Kitengela town, the landscape transitions gradually into more open grasslands with fewer fences, farms and buildings. Reid (2012) observed higher movements of wildlife and pastoral livestock in tracks of land that are further from the road. Hence, the socio-ecological impact of such a major road construction like the Nairobi-Namanga Road, on an ecologically sensitive area serves as cautionary example for the potential impacts of the proposed highway corridors in Brazil and Nigeria (Figure 4). This highlights the need for an environmental impact assessment to protect biodiversity integrity through effective conservation planning.

Mining and Drilling as a Disturbance Regime

Drilling for crude oil and other hydrocarbons as well as inorganic resource extraction across the Global South, mostly SSA and Latin America, have often resulted in contamination and pollution of significant portions of soils, wetlands, and freshwater systems (both groundwater and surface water) (Banza et al, 2012; Mogollon, 2013; Ogbonna et al, 2015; Benshaul-Tolonen et al, 2019). These activities include coal mining on Udi Hill (Nigeria), tin and columbite mining on Jos Plateau (Nigeria), underground and surface gold mining (Ghana and South Africa), Copperbelt Province (Zambia), cobalt mines (Congo), oils field in Niger Delta (Nigeria), Voltaian basin oil exploration (Ghana), oil sands (Venezuela), open-pit diamond mining, e.g. Venetia mines (South Africa) and Orapa mines (Botswana), and iron ore extraction in Guinea, phosphate mines (Togo), Uranium mines (Niger), etc.

In many cases, these activities have resulted in negative environmental impacts including polluted freshwater resources that have become toxic and unsafe for drinking and fishing, as well as pollution of wetlands and soils rendering them unsafe for agriculture (Sracek et al, 2012; Aliyu et al, 2015). This is particularly evident in the severe impact of oil spills from drilling activities in the Niger Delta (Nigeria) on the livelihoods of local communities. Oil spill contamination of the estuarine resources made most of the fish catches in this area unsuitable for human and livestock consumption (Ordinioha & Brisibe, 2013; Ayanlade & Proske, 2016). Additionally, the ecologically sensitive - mangrove forest of the Niger Delta region have experienced continued decline in biomass and carbon sinks, loss of wildlife habitats, as well as biodiversity due to crude oil drilling activities (Kadafa, 2012; UNEP, 2017).

The proliferation of mining ponds, channels, heaps, and pits across the Global South have also contributed to higher incidences and magnitude of soil erosion and soil loss, as well as coastal flooding in some mining areas close to the coasts (Wantzen & Mol, 2013; Moomen & Dewan, 2017). For example, recent increase in Chinese nationals' involvement in illegal mining in Ghana, commonly referred to as "galamsey", has resulted in large scale indiscriminate forest clearing, loss of wildlife habitats, and water pollution (Boateng et al, 2014; Hess & Aidoo, 2016; Mantey et al, 2017; Yiridomoh, 2021). Recent focus on Lithium powered electronics have resulted in increased interest in the developing the Lithium expansive deposits in lithium in Chile, Argentina, and Bolivia (Barandiarán, 2019). However, Lithium and Copper mining in Chile have been linked to pollution of groundwater, as well as the scarcity of water safe for irrigation and human consumption (Bauer, 2015, Aitken et al., 2016). Additionally, mining activities have also been linked to high Arsenic concentrations in the Altiplano-Puna plateau of Argentina, Bolivia, Chile, and Perú (Tapia et al, 2019) while Gold mining in the Peruvian Amazon have also been associated with Deforestation and Forest Degradation (Caballero et al, 2018).

Overall, landscape disturbance from mining and drilling activities and the resulting contamination of soil and water, as well as degradation of ecosystem functions and biodiversity loss has often led to disruptions in rural livelihood, impoverishment of rural communities, as well as social unrest and vices e.g., insurgency and criminal violence (Huisamen & Rooy, 2012; Isumonah, 2013; Iyida, 2015). The primary drivers of these mining and drilling activities are rising energy needs, raw materials, and export demands, previously by Western countries and more recently by China (Ettler, 2012; Sommer et al, 2020).

All of the aforementioned landscape disturbance regimes in the Global South pose a significant threat to conservation planning, as well as the achievement of the Aichi Biodiversity Targets, and Sustainable Development Goals (SDGs) in the Global South. We therefore propose that enhanced understanding of the unique drivers and spatiotemporal variations of landscape disturbance regimes in SSA and Latin America is key to effective conservation planning in the in the Global South.

FACILITATING CONSERVATION PLANNING IN THE GLOBAL SOUTH

Conservation planning and management of natural resources for sustainability cannot be achieved without the application of appropriate tools, methodologies and frameworks that address issues related to where (*space*), when (*time*), what (*impact*) and who (*stakeholder*) related research and policy questions (Arodudu et al., 2017, Rodriguez et al. 2020). Using the Space, Time, Impact and Stakeholder (STIS) concept allows us to examine the strengths and weaknesses of tools, methodologies, and frameworks for holistically assessing the various elements of sustainability associated with conservation planning in the Global South. Consequently, the next sections discuss how the integration of landscape ecology and geospatial technology could facilitate efforts to address the where, when, and what related research and management questions associated with conservation planning in the Global South, and the role of stakeholder participation in ensuring the viability of conservation planning in the Global South.

Landscape Ecology and Geospatial Technology in Conservation Planning in Global South

Landscape Ecology and Conservation Planning in the Global South

Landscape ecology provides conceptual and theoretical framework for understanding landscape function, structure, and change over time and space (Golley, 1987; Risser, 1987; Forman, 1995; O'Neill et al. 1999; Turner et al., 2001; Hobbs et al., 2014; Riitters 2019), and this is vital for conservation planning in the Global South. For example, achieving better outcomes for post 2020 Aichi Biodiversity Targets and 2030 Sustainable Development Goals (SDGs) require careful consideration of biodiversity conservation at multiple landscape scales, and by maintaining connectivity to ensure movement of species between habitat patches (Topp & Loos, 2019; Kuempel et al, 2020). Conservation at multiple landscape scales can also facilitate adaptation to the adverse impacts of climate change, which are more prevalent in the Global South. Kremen & Merenlender (2018) suggested that it is important to manage the matrix of protected areas using biodiversity-based production systems including agroecological farming or ecosystem-based forest management practices. The design of conservation areas as standalone blocks of protected areas should in some cases be replaced with the maintenance of well-connected patches of conserved areas within an ever-growing human modified landscape. This is exemplified by wildlife and pastoral migration in Kenya, East Africa. Patches are a complex mosaic of ecosystems in varying state of change, and they often have differing sets of ecosystem services and management challenges (Hobbs et al, 2014). Accounting for the complex dynamics and attributes associated with patches (using landscape ecology principles) are essential for effective conservation planning in SSA and Latin America.

As human activities have led to more rapid increases in landscapes disturbance regimes across the Global South, managing the impacts of climate change calls for both a paradigm shift in our approach to developing conservation plans and strategies that provide locally relevant applications. Landscape ecology can provide a management framework including methodologies and metrics to monitor the impacts of landscape disturbances and develop sustainable solutions for conservation planning to mitigate loss of critical habitats and biodiversity. As an interdisciplinary field that seeks to understand the biophysical and societal causes and consequences of landscape heterogeneity at multiple spatial and temporal scales, landscape ecology is well positioned to provide much-needed scientific framework.

Integrating Geospatial Technologies and Landscape Ecology for the Conservation Planning in the Global South

Landscape variables and indicators are important for measuring landscape's pattern-process relationships, and they are often derived using Geospatial Science and Technologies (GIS&T) and methods, including remote sensing and Geographic Information Systems (GIS). In accordance STIS approach to rigorous and holistic resource assessments, remote sensing and GIS-based land cover change analyses and modelling can be used to derive spatiotemporal indicators (such as NDVI, EVI) and variability of the trajectories of landscape disturbance regimes across the Global South. Assessments of landscape disturbance regimes, such as deforestation are made possible mostly due to geospatial techniques.

Participatory GIS-based mapping is also an effective means to incorporate stakeholder inputs in conservation planning initiatives (Fagerholm et al 2019; Vukomanovic et al 2019; Eilola et al 2021; Fagandini et al 2021; Ioki et al 2021). Participatory mapping facilitates the integration local knowledge in spatially explicit form and enhances stakeholder engagement in a collaborative planning process (Vukomanovic et al 2019; Eilola et al 2021). The application of geospatial technologies is therefore a vital first step in conservation planning in the Global South, especially at multiple spatial and temporal scales as shown in Table 1.

GIS&T and landscape ecology metrics can support conservation planning initiatives to mitigate the diverse disturbance pressures in the Global South (Figure 2). Satellite remote sensing and more recently unmanned aerial vehicles (Drone) technology are becoming more important in making high resolution data readily available in the Global South at very reduced costs. These are essential in the SSA and Latin America where critical landscapes are often not accessible due to poor road network. Hence the use of non-evasive GIS&T to meet the data needs for conservation planning and ecological restoration of degraded habitats in the Global South has been widely adopted for frequent monitoring of land use changes in sensitive landscapes, such as the Amazon Forest and Virunga Mountains in Central/East Africa (Lambin, 1999; Steklis et al 2008; Mugagga et al. 2012; Ogbodo et al, 2014; Snapir et al, 2017). This includes the creation of land use and land cover (LULC) maps to delineate the distribution of different land cover types and structure, as well as to identify areas undergoing land degradation and fragmentation. The outcome of the LULC change analysis of the Nairobi-Namangan Road project (Figure 5; Table 1) highlights the utility of remote sensing and GIS in the conservation planning process. It demonstrated the impact of "Road Construction", as a disturbance regime on wildlife migration patterns and livelihood of the local Masai people in Kenya.

Another use of remotely sensed earth observation data to monitor landscape changes at multiple spatial and temporal scales, is the derivation of datasets that are vital to effective conservation planning, such as Essential Biodiversity Variables (EBVs) (Potapov et al, 2017; Herold & Skutsch, 2011; Topp & Loos, 2019; Arenas-Castro et al, 2019; Jetz et al, 2019). Remote sensing-based analytics can reveal where humans have encroached on ecologically sensitive landscapes and provide evidence for interventions to protect critical habitats (Mugagga et al. 2012; Petersen et al., 2021; Ibrahim et al., 2022). For example, Mugagga et al. (2012) used multi-spatial and multi-temporal Landsat satellite data analysis and revealed that human encroachment into the Mt. Elgon Conservation Park in Uganda underpinned the disastrous landslide that killed about 300 people. Mt. Elgon Park is home to more than 300 species of animals some of which were killed by the landslide.

Additionally, satellite-based assessments have played an effective role in the REDD+ (Reduce Emissions from Deforestation and forest Degradation) initiative to conserve biodiversity in the Bolivian, Brazilian and Peruvian Amazon (e.g., Cronkleton et al, 2011; Potapov et al, 2017; Simonet et al, 2019). Simonet et al (2019) used satellite-based estimates of forests biomass to estimate the carbon in forest area under the REDD+ PAS project (Projeto Sustainable Settlements in the Amazon) in the Brazilian Amazon. They then calculated the impact of the forest conserved in tons of CO2 (tCO2) and concluded that the REDD+ PAS project led to reduction of 639,080 tCO2 emissions over two years.

These examples illustrate how the growing application of geospatial technology in the Global South is vital to realizing international conservation planning objectives such as Aichi Biodiversity targets and the 2030 Sustainable Development Goals. Recommendations of the Species Populations working group of the Group on Earth Observations Biodiversity Observation Network (GEO BON) include workflows for earth observation data products and/or derived indicators for use in biodiversity conservation (Jetz et al, 2019). Implementing this in the Global South will require GIS&T capacity building at national and local levels. As the adoption of landscape ecology grows in Sub-Saharan Africa and Latin America, improved capacities in GIS&T in these regions will provide an opportunity to effectively monitor landscape disturbance regimes and provide EBVs to support conservation planning efforts.

Stakeholder Participation to Ensure Viability of Conservation Planning in Global South

In line with Knight et al. (2009), patterns and processes observed from spatiotemporal remote sensing and GIS analysis over space and time can help identify and prioritize portions of, or whole, landscapes with high conservation values or needs. Enlisting stakeholders in enabling, mainstreaming, and implementing pre-determined and/or agreed conservation strategies (via participatory GIS or crowdsourcing) will not only guarantee its success and viability, but also provide lessons for the enhancement of future conservation actions.

An important aspect of conservation planning at multiple landscape scales is an explicit consideration of cultural landscapes by integrating socio-ecological systems into the planning process. Cultural landscapes play an essential role not only in biodiversity conservation but also as ecosystem "provisioning" services (Maldonado et al, 2019). Some of the conservation responses to landscape disturbance regimes in the Global South include community-based activities that integrate new land use techniques with traditional knowledge of local stakeholders, and indigenous practices such as agroforestry, controlled grazing, *Zai* farming practices, and establishment of forest and grassland reserves (Figure 2) (Amede et al, 2011; Reid, 2012; Ehiakpor et al, 2019). These activities could help mitigate biodiversity loss due to desertification induced by anthropogenic drivers like transhumance grazing and crop expansion, habitat fragmentation from forest degradation and deforestation, as well as soil erosion and soil loss (Kremen & Merenlender, 2018; Maldonado et al, 2019).

The institution of participatory governance for mediation and compensation of the displaced communities as a result of urbanization and infrastructural development in SSA or reduction of carbon in the Amazon Basin in Latin America are essential to ensuring the long-tern viability of conservation of natural habitats and biodiversity in the Global South (Botha, 2019; Correa et al, 2019; Mahmoud et al, 2019; Maldonado et al, 2019; Simonet et al, 2019). For example, Botha (2019) showed how stakeholder engagement in the Grootvadersbosch Conservancy project, a voluntary landscape scale conservation initiative in South Africa, reconciled competing interests of agricultural productivity and landscape conservation. The environmental, social, and economic benefits of the project had a positive impact on the landscape. Such approaches to engaging relevant stakeholders and community participation in resource management ventures are not only helpful, but critical to the success of any biodiversity conservation planning in the Global South (Figures 1 and 2). They are also referred to as nature-based solutions (NbS) and represent an overarching concept about ecosystem-related approaches to protect, manage and restore disturbed landscapes and ecosystems (Cohen-Shacham et al. 2016 and 2019; Potschin et al. 2016). Potschin et al. 2016, examined the development of NbS from early 2000's and identified four societal challenges to their implementation, including human well-being, sustainable ecosystem management and competitiveness.

DISCUSSIONS AND CONCLUSION

Landscape disturbance regimes in the Global South poses high risk for humans and nature, and it is important for the attainment of several global sustainability aspirations (e.g. Post 2020 Aichi conservation targets, Paris Climate Agreement etc.). There is therefore a vital need for (i) understanding the drivers and spatiotemporal variations of landscape disturbance regimes; and (ii) offering appropriate local and regional nature-based solutions (NbS) for sustainable management of disturbed landscapes. Geospatial technology and landscape ecology perspectives can play a major role in achieving the above-mentioned goals. The potential of NbS particularly to mitigate risk in rural and urban landscapes under changing climate conditions need to be considered and accounted for in spatial conservation planning and management strategies (Kalantari et al, 2018). Some nature-based land and water remediation solutions have been applied in the cases of fresh and saltwater pollution, soil and groundwater pollution, as well as soil erosion and soil losses (Davies, 2012; Sracek et al, 2012; Wantzen & Mol, 2013; Moomen & Dewan, 2017; Wang and Banzhaf, 2018). For example, urban expansion and associated destruction of natural landscapes and carbon sinks could be mitigated through NbS such as urban forestry, urban gardening, and horticulture (Specht et al, 2015; Opitz et al, 2016). More recently, there have been discussions of frameworks, typologies, performance assessments, limits, and implementation of NbS (Seddon et al. 2020; Kumar et al. 2021; Midgley et al. 2021; de Oliveira et al. 2021; Woroniecki et al. 2021).

The rapidly changing landscapes and disturbance regimes in the Global South are driven internally by population growth and associated food insecurity, energy and raw material demands, and urbanization. Since the economies of most countries in this region are dependent on agriculture and extractive industries, there are immense external pressures for cash crops and other resources for export to the Global North (mostly Europe and North America). This is compounded by failure of government policies and abandonment of development plans. Investment in physical infrastructure development by China to facilitate the export of agricultural and natural resources from SSA and Latin America has also exacerbated the situation by increasing the rate of conversion of natural landscapes and their impacts on ecosystem functions and biodiversity. As the rapidly changing landscape disturbance regimes in SSA and Latin America continue to pose a threat to conservation planning to meet Aichi Biodiversity Targets and Sustainable Development Goals (SDGs), we submit that an understanding of the unique drivers and spatiotemporal variations of disturbance regimes remain key to effective conservation planning in these regions.

Similarly, landscape ecology provides a scientific framework for provision of analytical tools and metrics for conservation planning in the Global South. Together with geospatial technologies and various analytical and modelling tools, landscape ecology can facilitate the synthesis of information from different sources and scales, most notably Essential Biodiversity Variables (EBVs). Finally, we reiterate the role of stakeholder participation as vital to the viability of conservation planning initiatives in SSA and Latin America. This is particularly important in areas where indigenous knowledge and community involvements are needed for finalizing the protocols that govern conservation plans, in order to ensure harmony in project implementation. Aside from countries like South Africa that have made some progress in conservation planning, lack of harmony for project implementation remains a major impediment to conservation planning efforts in most of SSA and Latin America. We therefore suggest that researchers in Geospatial Science and Landscape ecology prioritize supporting conservation planning in the Global South, not only through their research activities but also through stakeholder outreach and engagements.

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