**Impediments and solutions to biodiversity inspired decision-making**

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**Introduction** Humanity currently faces two major existentialist environmental threats: climate change and loss ofbiodiversity. Both will enormously impact economies, life-stylesand human health, potentially terminally. Each week brings new examples of extremeweather: floods, droughts, forest fires, melting ice caps and glaciers. In contrast, the public usually hears about biodiversity loss either when a species goes extinct or if one of thelast surviving females of a species gives birth in captivity which is unlikely to lead tospecies recovery in the wild. While there is a rapidly diminishing chance we will slow and potentially reverse climate change, extinction is forever. The evolutionary play in the ecological theater will fall apart when insufficient species actors are available to play their roles, so how do we prevent this?

Global efforts to reverse threats to biodiversity are encapsulated in two of the United Nations Sustainable Development Goals (SDG) which aim to protect, restore, and promote sustainable use of marine (Goal 14) and terrestrial ecosystems (Goal 15). Unfortunately, impossible tradeoffs and interdependencies exist among the full set of SDG, particularly tradeoffs between land for conserving nature, and land for producing food and averting global hunger (Griggs et al 2014 [nature]; Pradhan et al 2017 [earth’s future]). This has led to the recognition that integrating biodiversity into all levels of decision-making is critical to achieving international goals of protecting biodiversity. Indeed, it is explicitly recognized in the Convention on Biodiversity’s 2030 Target 14, which aims to “integrate biodiversity into decision-making at every level”. In this policy review, we highlight the multiple barriers to, and opportunities in, achieving this very practical goal. From an ecological perspective, such integration is the key to both sustainable development and conservation of biodiversity and closely aligns with Nature-Based Solutions, an approach that addresses the twin crises of climate change and biodiversity loss (Seddon et al 2020 [Phil Trans] while simultaneously supporting many of other the SDG (Maes et al 2019 [env sci policy]).

**What is biodiversity?** The United Nations defines biodiversity as the variety of life on Earth, in all its forms, from genes and bacteria to entire ecosystems such as forests or grasslands, although species numbers are often used as a shorthand. Biodiversity has a crucial instrumental value in providing ecosystem services - namely the direct and indirect contributions of ecosystems to human survival and quality of life. These range from maintaining ecosystem function to education to mental well-being (Box 1). Additionally, preservation of biodiversity is inextricably linked to climate change because forests, savannas and oceans act as carbon sinks, and without their associated ecological sculptors, such as pollinators, these biomes would neither exist, nor act as carbon sinks. Biodiversity also has an intrinsic (or final) value irrespective of people, caricatured as a ‘right to exist’. This is non-instrumental and refers to the fundamental value of species and ecosystems aside from any contribution they may have towards humans. When integrating biodiversity into decision-making, both these categorizations of value are relevant.

Biodiversity is both a complex and difficult-to measure-concept. As a first step practitioners often simply use the number of species in an area, although increasingly precise and affordable measurement and analytical technologies which can inform decision making are emerging (e.g. eDNA, satellite imagery, remote sensing, internet-of-things sensors, citizen science, open-access databases). Such technologies can generate accessible information and knowledge resources so long as biodiversity database owners adhere to the foundational data stewardship principles of Findability, Accessibility, Interoperability, and Reusability (Wilkinson, M., et al. 2016). More problematic is the challenge of communicating the value of biodiversity which often typically involves attributing a monetary value to it. Over the last three decades great strides have been made in estimating the dollar value of ecosystem services. There now exists an array of tools (e.g., Costanza et al 2017[ecosystem services]) for estimating the cash value of these services, focusing on the economic contributions of climate regulation, pollination, water supplies, food production and so on but these calculations often occur at a global scale and are typically understood as lower bounds rather than accurate central estimates. Nonetheless, they are extremely useful for communicating the need for protecting natural processes to policy makers working at a large spatial extent and to those that might otherwise disrupt ecosystem services. Unfortunately, when it comes to biodiversity, an already difficult to define concept, the problems of quantification compound. Ehrlich and Ehrlich’s (1981 [extinction]) pop rivet analogy is often used to point to the increasing risks of losing species diversity but attempts to put a monetary value on area-specific biodiversity per se, above and beyond its local ecosystem value, are far less developed.

We initially develop an informal framework which allows us to categorize constraints

on decisions that are made at each stage of any process. We then consider in more

detail the specific impediments and opportunities that characterize these decisions at

each level: individual, community, business and government and national (see Table 1).

Empirical insight is added by considering the observed patterns of land use change and

biodiversity loss in Kenya over the last Century. The conversion of grasslands to

agricultural lands supplies significant amounts of the world’s grain, but leads to the loss

of significant biodiversity, epitomizing the tensions within and between the SDG and

CDG agendas.

**Impediments and Opportunities at Every Level** Target 14 encompasses decision making at a wide range of scales with the goal of “aligning all relevant public and private

activities, and fiscal and financial flows with the goals and targets” of the biodiversity

framework. The nature of decision-making will, naturally, vary by scale. The informational component of Target14 requires that decision-makers identify a reasonable range of alternatives andunderstand, with varying degrees of formality, the effects of those alternatives onbiodiversity. The weighing component of Target 14 requires that the biodiversity beappropriately prioritized vis-à-vis other constraints and goals. Here we borrow from, but do not strictly adhere to, Ajzen’s (1991) theory of planned behaviour to categorize impediments. This theory argues that a behaviour (in this case integrating biodiversity into decision making) is predicted by an assessment of the positive and negative outcomes of doing the behaviour including economic cost and benefits which collectively inform ‘attitude’, pressure from peers to perform the behaviour from peers (‘social context’) and the ‘capacity’ of each level to undertake the behaviour based on the availability of knowledge, skills, opportunities and resources. In line with Ajzen’s advice, we also identify distal background factors that set the context within which the behaviour occurs.

*Background impediments.* Relevant to all levels of decision-making, from individual to transnational, are two background impediments: first that opportunities to incorporate biodiversity into decisions are limited simply because biodiversity is declining so rapidly (REF?) and, second, that humans, as decision makers, are poor at considering long term outcomes (Rogers 1994 [Am Ec Rev]). Dependent on level, property rights can be mismatched in a way that prevents biodiversity being considered by individuals and communities (Bradshaw et al 2020, Agrawal et al 2023 [Ann Rev Ecol]), governments may have set rules that limit or prevent green-business, community and individual decision making (REF), and the requirement of unanimity in international law limits adoption when there is no consensus (REF). Assuming such background impediments do not preclude opportunities for integrative biodiversity, more proximal categories of impediments can be identified including capacity, social and attitudinal based impediments.

*Capacity impediments* relate to ideas that biodiversity is a difficult concept to understand, there is a lack of consensus on measurement and, partly as a result, ecological literacy levels are low across most levels. The availability and quality of data, as well as syntheses of data to enable decision making also represents a capacity constraint. Relatedly, the availability of resources (staff, time and funding) to appropriately collect, analyze, synthesize and present data to decision makers can likewise inhibit integration of biodiversity into decision making. Finally, there may be competing priorities at several levels which limit individual, community, business and government capacity to incorporate new practices. For example, a government may have limited resources and feel that it needs to prioritize economic wellbeing or national security over wildlife.

*Social context impediments* include a lack of leadership and role models from to

learn and emulate, particularly at community, business and government levels. The inertia of existing practices, which exclude integrating biodiversity into decision making and are often supported by incumbent systems and processes, can act as a strong brake to the adoption of new processes. Similarly, the presence and acceptance of poor (e.g., low quality Environmental Impact Assessments [EIAs]) and potentially illegal practices (e.g. corruption, poaching) as norms can also generate inertia, or worse.

*Attitudinal impediments.* Evaluations of the positive and negative outcomes that may occur as a result of integrating biodiversity into decision-making influence individual, community, business and government attitudes toward adoption. These evaluations may consider potential trade-offs between economic productivity and biodiversity, the presence of, or need for, incentives, and the opportunity costs, as well as the social and political cost of action. Underpinning these evaluations are more general features including actors’ salient beliefs and values, identity and narratives. As illustrations, ‘country X ‘doesn’t prioritize biodiversity’ for transnational integration, ‘economic prosperity for our citizenry is our highest priority’ for national policy, or “we are the best custodians of our nature” for local activism. We now use this framework to examine impediments to incorporate biodiversity into decision making at five increasing scales, focusing particularly on communities where local action can gain most traction in the developing world where biodiversity is greatest (REF)

**Impediments to individuals** For ‘green’ decisions made by individuals, such as whether to clear or fence land, house domestic cats, purchase environmentally unfriendly goods or services, or engage in other biodiversity-relevant behaviours (see Selinski et al 2020), there are many obstructions. *Background* impediments include individuals’ tendency to discount the future over the present and rules that prevent decisions being made in the first place.  *Capacity* impediments include busy agendas, low biodiversity literacy, availability and access to relevant information about options, limited time to consider options and a lack of skills to evaluate them. *Social* impediments include a lack of role models, a history of practice both in the individual context as well as behavioural norms of the local area. Finally, *attitudinal* impediments include the values of the individual where other values trump biodiversity, belief that there is a trade-off between biodiversity and economic benefits, and where economic incentives are insufficient to warrant the integration of biodiversity.

Opportunities to reverse these baked-in hurdles include sourcing food locally, reducing meat consumption, remote meeting opportunities to reduce personal travel, economic incentives providing property rights that reduce biodiversity loss (Bradshaw et al), and experiencing nature through film and outdoor activities which enhances ecological literacy and knowledge (e.g., Ma and McLeod 2023). Optimistically, advances are being made in these directions in more affluent nations, but slowly.

**Impediments to communities** The term “communities” means different things in different parts of the world, such as members of a religious affiliation possibly spread across a large ecological area, an alliance of indigenous activist groups, or a rural village. As such, impediments to integrating biodiversity into decision-making bodies will differ wildly, depending on whether the aspect of “community” relates to shared values, shared objectives or shared natural resources. Here we try to identify some of the commonest and most trenchant barriers to addressing biodiversity concerns at the community level.

The most pertinent set of *background* conditions pertaining to communities in many lower-middle income country (LMIC) contexts regard the management of their forests, grasslands, water sources and fisheries - common pool resources that are both depletable and non-renewable. Insofar as communities often depend heavily on such resources for their livelihoods, promoting emphasis on concepts like “forest dependency” (Newton et al 2016 [Land use policy]), and time discount rates create particular challenges. The option of delaying harvests is simply inviable, and becomes quite impossible for the poorest sectors of the population most heavily dependent on natural resources (as among forest-dependent communities in Zanzibar, Andrews and Borgerhoff Mulder 2023 [World Dev]).  The insecurity of tenure that results from mismatched or otherwise unclear and unstable property rights exacerbates motivation to harvest now rather than stint for greater future gains (Ojanen et al 2017 [Env Evid]). Where there are tensions between government property rights and customary local tenure, local communities will be motivated to shift their land use patterns to maximize gains before losing their land entirely, as was seen with the conversion of savanna livestock grazing lands to bean production in Tanzania (Baird et al 2009 [Hum Ecol]). A more specific example is where community land use practices are restricted by overly centralized rules and regulations, raising the need for polycentric governance regimes (Ostrom 2010 [Am Ec Rev]). Pastoralists, for example, (see Box 2) are unable to adaptively manage their grasslands if their movements are restricted by national policies supporting protected area gazettement or agricultural expansion (Reid et al 2014 [An Rev Env Res]).

Impediments resulting from limited *capacity* depend on the nature of the community. Many anthropologists, rural sociologists, social geographers emphasize the extraordinary local or traditional ecological knowledge held by rural and/or indigenous communities (e.g. Houde 2007 [E&S]; maybe better Berkes/Folke)  Others make the more nuanced point that while communities may have sustainable land use patterns that for the most part protect biodiversity, no such specific concept is recognized (my box on Hill’s work, check). As such “ecoliteracy” as defined by conservation scientists may be limited, but not absent. Perhaps more important in LMIC contexts, there are often no data on the state of biodiversity at an appropriate scale to the community, and/or such data may be inaccessible for either political or logistical reasons. While communities may well have a very strong understanding of the dynamics of their ecosystem, with exogenous pressures from climate change, migration from outside, new markets for their products, or indeed new land use adjudications made by the state, their knowledge may need supplementing with external expertise (Caro et al 2022). Notably too, as Hartel et al (2023 [TREE]) show for communities in southern Transylvania, traditional practices that protect biodiversity are not only misaligned with current economic ambitions, but trap communities in poverty. A locally-contextualized understanding of such capacity-based impediments is critical, with further recognition that community perceptions of perceived and real tradeoffs between biodiversity and economic development are often distorted by mistrust of external actors (conservation scientists, government and nongovernment actors) who do not typically share community norms and values. Under such conditions trusted community leaders becomes key intermediaries, evidenced by the associations between charismatic leadership and conservation success in fisheries (Guitterez 2011).

Turning to the *social context*, communities often face the challenge of having limited role models from whom to learn. While socially transmitted information can cross between communities and influence institutions for managing biodiversity (Andrews et al 2024), often there are ethnic or class reasons for rejecting neighbours as models [cristina’s chapter]. Furthermore, insofar as communities are never homogenous units (Agrawal 2002), there may be strong elements of traditionalism, with individuals unwilling to update or replace long-practiced behaviors. Under such conditions it can be difficult for charismatic or visionary forward-looking individuals to emerge as charismatic leaders. Finally, with respect *to attitudes*, decisions made at the local community level are often deeply embedded in narratives surrounding identity, possibly resulting from humans’ cultural parochiality in cooperation (Handley and Mathew 2020); these strong effects of identity become particularly salient at the boundaries of different ethnic, local, religious communities (McElreath et al 2003). Against this background, decisions respecting biodiversity will most plausibly take lower precedence than, for example, securing land or water access. Such identity issues may also strongly influence the actual as opposed to perceived tradeoffs between biodiversity and development, with communities and their leaders competing for access to markets, to land and to new options for social mobility. Against this background, decisions to spare biodiversity may seem trivial (take example from Ali et al 2023 [PNAS] or Kubiszewski et al 2023 [Anthropocene Review]).

MBM STILL TO WRITE: A focus on the “bright spots” that emerge from the Anthropocene challenge to [biodiversity (Bennet et al 2017 [Frontiers]) affords plenty of opportunities for avoiding or circumventing these impediments - opportunities that benefit local communities.    MBM still to write. Poverty alleviation\*biodiversity synergies (e.g., Kubiszewski?); new community and political identities forming around biodiversity (e.g., native american initiatives); greater attention to property rights and land security (REFS).]] More generally, some major societal transitions for the better have emerged in the face of unprecedented challenges, with communities at the forefront (e.g., Ellis 2015 Ecol Monog or De Fries et al 2012 BUT CHECK);

**Impediments to business** For most business ventures, there is an inherent difficulty in discounting the future, as businesses are looking to a short-term bottom line not longer-term environmental timescales. The *background* history of business practice does not point in the right direction and there are still insufficient green-business leaders in the developing world, post-communist countries, or China to shift behaviour at the speed needed. At a grander scale, perverse subsidies support unsustainable practices, fishing fleets in Europe for instance (REF). Perhaps the most pernicious barrier is that, across the globe, economic incentives fail to internalize environmentally harmful costing (REF). Layered over that there are perceived development-conservation trade-offs which pervade decision-making by business CEOs.

For the green-minded business then, the *capacity* challenges of incorporating biodiversity into decision making can be brutal. Overarching difficulties include property rights of the country in which they are working and overly restrictive rules that hamper green-decision making. For example, in Tanzania, the Government owns all the land so hotels or tourist enterprises can only rent land for a maximum of 99 years. Green-intentioned businesses may also be impeded by insufficient capacity to trace even their own supply chains, legal structures that hobble cooperation between businesses, and government to business interactions, as well as government-mandated EIAs that simply rubber-stamp industrial infrastructure projects (Laurance & Arrea 2017). Tim and again, EIAs are insufficient because data on biodiversity are often difficult and time consuming to collect, or because poor data are collated by poorly-trained individuals, or non-independent bodies. Worse, many EIAs are toy-EIAs, inadequate by being limited in geographic scope, covering only a short time frame, being based on grossly inadequate information or are rushed through, or all of the above. Many of these restrictions are imposed on EIAs from the get-go by governments intent on completing major projects. Following an EIA , recommendations can be forgotten or ignored.

*Social* impediments include a culture of making more money than competitors rather than being greener. To save money, too often industries will use substandard equipment or materials in dealing with environmentally hazardous materials. Foreign businesses operating in the developing world, particularly Chinese businesses, are complicit in bypassing EIAs, promising eco-friendly practices that soon vanish once permits are through, being unaware of construction practices that are environmentally harmful, or simply continuing to build industry that is non-sustainable, an example being new water supply businesses that use plastic water bottles rather than household water-filtration systems on Pemba Island, Tanzania. *Attitudinal* impediments include viewing business as being at loggerheads with conservationists, something that is changing in regards to alternative energy but not reducing biodiversity loss.

Opportunities are available for businesses to improve their track records, however. Accreditation schemes improving the credibility of green-branding, prospects for biodiversity accounting, and new niches for insurance companies to certify green business practices are emerging. Consumer pressure for biodiversity positive products, at least in the western world, will drive these changes slowly although green consumer pressure in the developing world is years away.

**Impediments at the government level** *Background* impediments that bear on government decision making include tendencies to discount long-term effects because of upcoming elections in democracies, and the fact that species geographical ranges cross national boundaries allowing nations to abrogate responsibilities for conserving them. Political officials who might wish to achieve biodiversity goals may face *capacity* constraints, including problems of corruption (or shirking) at every level, governance structures that impede coordination, and difficulty in accessing relevant information. Political scientists have developed the concept of “agenda space” to model the limited bandwidth of governments. This space is limited by attention and capacity and is often devoted to immediate crises as well as perennial subjects of concern, such as employment and health care. Finite agenda space, and competing concerns, can leave little room for biodiversity considerations.  Governments also clearly face resource constraints, in terms of both financing and skilled personnel.

*Social* context that impedes the integration of biodiversity into government decision making include status quo policies and expectations, and a lack of positive role models. These two impediments act together to make it more difficult for officials to envision possibilities within their zone of influence. Finally, political incentives to account for biodiversity are an *attitudinal factor* that have a complex array of causes including government structure, economic and development conditions, and the preferences and values of relevant actors (e.g., voters and organized interest groups). In countries with democratic governance, elected officials will have incentives to respond to the preferences of voters (who may or may not be concerned with biodiversity), but the regularity of elections can make it very difficult to make short-term sacrifices to achieve long-term goals. In authoritarian or semi-authoritarian regimes, officials will face different political incentives, which may include the need to direct resources to favoured groups or maintain support within the military. These incentives frequently conflict with the interests of officials in integrating biodiversity goals into their decision making.

Opportunities for upending government impediments include education of the electorate about the biodiversity crisis in their country and hence voter pressure for governments to reconsider short term economic maximization. The recent rise in populist regimes make this an uphill battle but leaders of any stripe are able to recognize that ecotourism can drive economies, as seen in Costa Rica, Panama, Kenya and Tanzania.

**Transnational impediments** *Background* impediments to decision making at the transnational level include situations where neighboring governments have misaligned priorities, thereby creating coordination problems. Kenya and Tanzania, for example, share several large conservation landscapes but the former prohibits wildlife hunting while the latter allows it, creating discrepant priorities and tensions around conflicting biodiversity conservation goals. *Capacity* impediments include government officials shirking their responsibilities, ignoring the terms of their position, and allowing biodiversity protection measures to go unattended. *Social* and *attitudinal* impediments include transnational corruption, a persistent issue that enables cross-boundary movement and trade of illegal wildlife products.  Additionally, these latter two classes of impediments might include situations where there is a complete failure of ministries to coordinate, resulting in, for example, the transportation sector building a cross-border highway without consideration of protected areas.

A number of approaches show opportunities exist for better incorporation of biodiversity

into decision-making at the transboundary level. Misaligned priorities among

neighbouring countries can be avoided when land use planning is considered at the

landscape level. For example, the Kavango Zambizi Transfrontier Conservation Area

(KAZA TFCA) spans five southern African countries: Angola, Botswana, Namibia,

Zambia and Zimbabwe. A joint secretariat coordinates transboundary planning,

management and conservation legislation ensuring the sustainable use of natural

resources in ways that improve the livelihoods of communities and unfettered

movement of wildlife among protected areas through a network of ecological corridors.

Cross boundary collaboration to prevent trade in wildlife products also exists through

TRAFFIC’s Trade in Wildlife Information EXchange (TWIX) platform, an online tool that

connects officials across borders, allowing them to rapidly share information and

expertise to interrupt transnational wildlife trade (https://www.traffic.org/what-we-

do/thematic-issues/supporting-law-enforcement/twixs/). Other signs of hope include

URSA, the universal rangers support alliance, training (the SMART program), and recognition of rangers from any nation as environmental health workers.

**The future** These impediments working, often in concert, at multiple levels make it highly unlikely that Target 14 can beimplemented at all effectively by 2030, the date for which all other targets of the [Kunming-Montreal Global Biodiversity Framework](https://www.cbd.int/gbf/) (GBF) (https://www.nonnativespecies.org/international/convention-on-biodiversity/)

are due, along with the SDG. Given the dependency of achieving target 14 on the rest

of the GBF targets, it appears the outlook for achieving these targets, as well as

many related SDG, is not optimistic. For example, the current UK conservative government’s assault on environmental planning rules, changes to farming practice and weakening environmental laws shows how little credence is given to biodiversity even in democracies. There are a handful of exceptions to this pessimistic prognosis: improved EIAs driven by consumer demand twisting business-leaders’ arms, shame-driven U-turns forced on governments are examples. Whether these are sufficient to counteract impediments to biodiversity inclusion in decision-making by even 2050 remains to be seen.

BOX 1 List of ecosystem services potentially provided by biodiversity (from Ehrenfeld 1979; Harrison et al 2014). Note relationships between function and species number are non-linear but likely S-shaped and will depend on locality and scale.

Ecosystem services Explanation

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*Provisioning services:*

Timber production Fibre (timber and wood fuel)

Freshwater fishing Food (capture fisheries and aquaculture)

Freshwater provision (quantity) Freshwater

*Regulating services:*

Water purification (quality) Water purification/waste treatment

Water flow regulation (flood Natural hazard regulation

protection)

Mass flow regulation (erosion Erosion regulation

protection)

Atmospheric regulation (carbon Climate regulation

sequestration)

Pest regulation Biological control

Pollination Pollination

*Societal services*

Undiscovered or underdeveloped Medicine, new foods

values

Scientific research values Diversity of morphologies, physiology and genetics

Teaching values Introducing nature to students and field classes

Environmental baseline and Goals for restoration

monitoring values

Source of restoration projects Species to seed rewilding

*Cultural services:*

Recreation (species-based) Recreation and ecotourism

Landscape aesthetics Aesthetic values

Mental health Value of being outside with nature

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SFI Biodiversity Working Group : Old text that needs to be incorporated into new draft.

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First Draft

**Box 2.  A proof of principle model for Kenya’s rangelands over the last 125 years.**

Formal modeling help us investigate “different potential pasts” and study counterfactuals of how the system might have evolved as a result of varying conditions (e.g., regarding climate) and different interventions (e.g., tax-subsidy schemes). We propose two complementary approaches useful for understanding how consideration of biodiversity can ve incorporated into decision-making in the context of two areas of 20th and 21st century Kenya : Laikipia and the Mara. The first method focuses on long term changes in land-use, biodiversity and the human economy in these regions and employs dynamic optimization models similar in spirit to those used in climate policy and economic epidemiology. The second focuses on fences and follows an agent-based approach that can integrate local-scale human social learning and incentive structures with real-world land use to understand how the macroscale dynamics emerge from local land use dynamics.

We divide the total area in the region areas that have been historically dominated by wildlife, constituting mainly large predators and herbivores, and other areas mainly devoted to crop or livestock production.. Finally, some land is devoted to ecosystem services and ecotourism. Dynamic optimization begins by identifying a set of actors central to decision-making including government, livestock owners, and conservancies operating in the region. Owners of livestock try to maximize the lifetime profits from related activities. They choose the size of their livestock herds and whether or not to sell their cattle or use them as dowry to pay for additional wives.  They are also passed along as inheritance to their sons. WHAT DO GOVTs AND CONSERVANCIES DO?

Next we models historical development.  Initially the land was ‘wilderness’ containing only wild game and their predators.  Revenue during this early period (1900-1950) came primarily from hunting safaris led by professional hunters.  Both they and the government received revenue and taxes from these activities.  We then focus on the period since 1950 when human population growth began increasing rapidly in Kenya, creating demand for land for either pastoralism or crops.  The conversion of land to agriculture creates one of the biggest tensions in the SDG Goals because it explicitly offsets the need to feed people with land set aside to conserve biodiversity. Our model examines these trade-offs in the savannas that when converted to cropland provide the majority of food for humans and their domestic livestock. Lands in the both regions of Kenya have been converted to land predominantly used by pastoralists and their herds (cattle and shoats) or cropland, areas which produce high value food crops for both local consumption and export to distant cities.   Wildlife can continue to use the pastoralist areas, although at a lower intensity than when they were the sole occupants.  In contrast, cropland creates conflicts with wildlife and they are excluded from these areas, with human-wildlife conflicts occurring along the boundary.  A third stage of development considered in the framework occurs when ‘conservancies’ are set up that attract tourists whose primary interest in the biological diversity in the region, although they may also enjoy cultural tourism associated with the local pastoralist community.  Conservancies set up fences to exclude cattle, sheep and goats (shoats) from the primary tourist areas which can be broadly adopted to exclude wildlife from crop areas and for pastoralist land owners to exclude others from grazing areas.  Fencing has expanded rapidly in the Mara region and has had significantly detrimental effects on wildlife, particularly migratory species.

At each of these three stages of development, we examine the dynamics of each population using a coupled difference equation model with an annual timestep. We will incorporate economic decision making into the framework and examine the trade-offs from the perspective of a single central planner who tries to find economic solutions that maximize benefits for all populations.  Crucially, we compare solutions to this problem in ways that either ignore the value of wildlife, with those that include its value.  This will provide broad insights into who including consideration of biodiversity into decision making at government and community levels.

Livestock owners and conservancies can also choose the fraction of their land that will be fenced. Fences provide some security, for example, from predators, but also incur costs, as they act as barriers to wildlife movement, including migrations. Conservancies value biodiversity and wildlife as they contribute to their revenue from ecotourism. They use this revenue, as well as donations, to expand the land under wildlife conservancy protection and to provide payments to landowners supporting the conservancies. Finally, the government has a joint objective as it values both biodiversity and economic activity that improves the standards of living for its citizens. The government chooses various regulations, including taxes and subsidies to accomplish this goal. Clearly, the objectives among these entities are not perfectly aligned. We study the underlying dynamic game in order to characterize the path for biodiversity resulting from this interplay between various incentives. Of particular interest for us is comparing outcomes in the case in which biodiversity is valued only to the extent that it provides ecosystem services (such as ecotourism), compared with a scenario where it has intrinsic values, regardless of whether it leads to monetary benefits.

To complement the dynamic optimization formulation above, we can model local variation on smaller population, geographic, and time scales as well to understand which factors influenced observed real-world fencing patterns under historical incentive structures. It can also be used for counterfactual modeling to predict outcomes of different policies by national or local governments. In the simplest case, one might consider the decision of farmers and livestock producers whether to join a conservancy or to fence their land. In addition to the influence of national government policy and NGO incentives, there may be local policies that impact land use decisions, such as taxation on fenced versus unfenced land in certain locales. Furthermore, landowners may adopt government programs, for example to allow government inspectors to quantify wildlife diversity on their land that could lower insurance rates for crop failures. When some landowners join wildlife diversity programs, this may induce neighbors and friends to do so as well through conformity or other form of social learning (Kendal, et al., 2018). This in turn may result in less fencing, depending on the details of the distribution and size of landholdings. However, if some producers join conservancies with passable fences, this may override social learning or government incentives, since crops and grass may be consumed or destroyed by either cattle or wildlife.

Agent-based models are flexible enough to include these sorts of stochastic dynamics with specific geographic distributions of landholdings, fences, and cognitive mechanisms for social learning and adoption. To enable interpretable models and modeling results, it is essential to judiciously select a subset of important factors focused on answering a single question about a model system (Fogarty, et al., 2022). In complex social-economical systems this may feel wrong to domain specialists since there are so many subtleties. However, the sort of rigorous results that models can provide is a function of their simplicity, and a greater store of rigorous theory is built little by little, one model at a time (Smaldino, 2017).

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